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FEASIBILITY STUDY FOR INSTALLATION OF PHOTOVOLTAIC PLANTS USING AHP METHOD IN THE STATE OF MARANHÃO

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Abstract. *The number of photovoltaic plants in the state of Maranhão is still low when compared to other states. However, the photovoltaic power generation model has a great prospect of growth to next years. Studies to identify the regions of the state that are more favorable to installation of solar energy contribute for the managers of the power generation industry to make more rational decisions about the viability of their investments. This work deals with a feasibility study for the installation of solar photovoltaic plants covering the entire territory of the state of Maranhão using the multicriteria method (AHP) to weight the parameters or variables that can impact significantly the investment decision-making process. The parameters chosen for this study were: global solar radiation, normal separation and maximum temperature, power grid, road network, conservation units and indigenous territories. The data were normalized and standardized using the Quantum Gis software (QGis), which allows working with the Geographic Information System (GIS). Then the weighting matrix between pairs of criteria (judgment matrix) and the consistency ratio were calculated to ensure that the weights adopted in the peer relationships are consistent. The weights were used to weight as their only criterion layers and added up as information from the layers, multiplying by the restriction layer. A new layer of information was obtained, values varying from 0 to 0.795, which identify throughout the territory of the state of Maranhão, which regions are most suitable for the installation of solar plants. This new layer of information allows to order the most recommended places for investment in this business model, considering the criteria adopted.*

Keywords: *AHP Method, Solar Power Plants, GIS, Decision-making, QGis.*

1. INTRODUCTION

The demand for increased energy supply has intensified over the past few years in Brazil. Despite the fluctuations between periods of economic growth and periods of crisis that the country has been experiencing, the energy generation sector remains with promising prospects for investment.

In Brazil, the most used energy matrix is hydroelectric. However, despite the relative abundance of hydrographic basins that allow the installation of plants with a hydroelectric matrix, the expansion of this model has been questioned by environmentalists due to the great environmental impact during the installation of hydroelectric plants, requiring immense flooded areas to compose their lakes, resulting in the destruction of local fauna and flora (PAQUETE, 2021). In addition to the environmental impacts, the areas available for the installation of this type of plant have become increasingly rare, as a large part of this unexplored potential is contained either in environmental reserves, or in indigenous territories; where the installation of this type of enterprise is prohibited by law.

In this context, since the last decade, Brazil has been making efforts to diversify its energy sources by adopting models based on wind and solar matrices, which cause less environmental impact when compared to other matrices. According to the NATIONAL ELECTRIC SYSTEM OPERATOR (2020), it is estimated that by 2025, solar energy will account for 2.9% of the country's energy production; a considerable increase when compared to 2.2% of production in 2021, as shown in Table 1. The hydroelectric matrix will reduce to 60.3% of total production in 2025, compared to 63.9% installed in 2021. In particular, plants based on solar energy photovoltaics became popular after regulations approved by the National Electric Energy Agency (ANEEL) and due to government incentives that subsidize this business model(DE OLIVEIRA et al., 2019).

Table 1. Perspectives for Brazil's energy matrix

Energy matrix	**2021**		**2025**	
	Power (MW)	**Percentage (%)**	**Power (MW)**	**Percentage (%)**
hydroelectric	108641	63.9	109299	60.3
wind	18459	10.9	22836	12.6
thermal coal	3017	1.8	3017	1.7
biomass	14102	8.3	15096	8.3
Solar	3794	2.2	5270	2.9

The installation of solar power plants has grown significantly in the last two years. Several groups of investors, including foreign ones, have been looking to Brazil in search of information for the installation of generating plants from the solar array. However, as these are relatively complex investments due to the high implementation costs and long duration, it is not always easy for project managers and investors to take a decision on the best location for such projects.

(SANTOS et al.,2019). It so happens that the need for studies that support decision making on the choice of suitable locations for the installation of photovoltaic plants has increased as the demand for this type of investment increases. These studies must consider the weights of the main variables that decision makers use to make their choices.

The objectives of this work are divided into general and specific. The general objective of this work is to identify the areas or municipalities in Maranhão that offer the best conditions for the installation of photovoltaic plants through the application of the hierarchical analysis multicriteria decision method (AHP), using data extracted from remote sensing and processed. through Geographic Information Systems (GIS) tools, such as climatic variables (temperature, solar irradiation), geoenvironmental (conservation units and indigenous lands) and infrastructure (location of roads and energy distribution networks), which influence costs installation, operation, and generation of solar power plants.

2. THEORETICAL FRAMEWORK

2.1 AHP - Analytic Hierarchy Process

According to Santos et al (2019), the AHP multicriteria method developed by mathematician Thomas L. Saaty was developed to help people in everyday decision making, as the method emphasizes the importance of the weights of the criteria involved that affect decision making. The most challenging and creative task in decision making is choosing the factors or criteria that most impact the decision. People often make decisions intuitively without being aware of the weights that the variables or criteria have in the result (SAATY, 1990).

AHP is the most adopted multi-criteria method to support the resolution of negotiation conflicts in problems that involve several criteria. For Marins, Souza and Barros (2009), “AHP is a Cartesian way of thinking” that simplifies complex problems by dividing them into factors by hierarchical levels that are then synthesized. Once selected the most impactful factors for decision making, they must be organized in a hierarchical structure that descends from a general objective, to criteria and sub-criteria; and alternatives at successive levels (SAATY, 1990).

Once selected and ranked, the criteria must be compared in pairs, at each level, to determine the degree of importance that one criterion has in relation to the other, as shown in Table 2, adapted from (SAATY, 1990).

Table 2 - Fundamental peer comparison scale

Importance	**Definition**
1	The two criteria are of equal importance.
3	One of the criteria is slightly more important than the other.
5	One of the criteria has a strong importance in relation to the other.
7	One of the criteria has a much stronger importance in relation to the other.
9	One of the criteria is absolutely important than the other.
2,4,6,8	Intermediate values to be used in case of doubts.

The choice of criteria that impact the business to be analyzed, as well as the weights between these criteria, can be obtained based on consultations with stakeholders, on the experience of specialist managers or through published literature of previous works related to the same business area (GIAMALAKI; TSOUTSOS, 2019).

According to the method, a matrix called judgment matrix, or paired, A (n x n) is created, composed of weight relations defined in pairs, according to Equation 1.

$$A_{n\,x\,n} = \begin{bmatrix} 1 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ 1/a_{n1} & \cdots & 1 \end{bmatrix} \quad , \tag{1}$$

Where $a_{ij} > 0\,, a_{ij} = \frac{1}{a_{ji}}\ e\ a_{ij} = 1\ for\ all\ i = j$.

In sequence, the normalization of the matrix A_(n x n) is performed, from the division of each element a_ij by the sum in each column of the judgment matrix. Then, the Autovector (W) is calculated, consisting of the weights of each criterion through the average of the weighted values of each line of the normalized matrix. The values of the Autovector correspond to the respective weights of each criterion adopted for decision making, that is; what is the intensity with which one criterion overlaps in relation to the others (MARINS; SOUZA; BARROS, 2009). However, there is a certain degree of uncertainty when creating the judgment matrix (SAATY, 1990). To find out if there is consistency in the weights adopted in the relationships between the criteria, (SAATY, 1990) proposed that a consistency relationship of judgments given by Equation 2 should be calculated.

$$RC = \frac{IC}{IR} \quad , \tag{2}$$

Where RC is the consistency ratio to be found, IC is the calculated consistency index and IR is a random consistency index given from Table 3, whose value depends on the matrix dimension.

Table 3 - Random consistency index for an n-dimensional array.

Matrix Dimension	**3**	**4**	**5**	**6**	**7**	**8**	**9**
IR	0.52	0.89	1.11	1.25	1.32	1.40	1.45

As for the consistency index (CI), it can be calculated from Equation 3:

$$IC = \frac{(\lambda_{máx} - n)}{n-1} \quad , \tag{3}$$

Where $\lambda_{máx}$ is the maximum eigenvalue of the judgment matrix. For RC ≤ 0.10 it means that the consistency of the weights assumed in the judgment matrix is satisfactory. Otherwise, you must adopt other weights among the criteria (SAATY, 1990).

2.2 Studies of solar power plants using AHP and GIS.

There is a vast literature applying the AHP method in studies aiming to identify the best locations for the installation of solar power plants. Among them, the following studies can be mentioned:

•Sánchez-Lozano et al (2013) prepared a study to evaluate sites for the installation of solar farms in Cartagena, southwestern Spain, using the AHP and GIS method;

•Uyan (2013) presents a study for solar farms based on AHP and GIS, in the region called Karapinar, Turkey;

•The work by Al Garni and Awasthi (2017) used AHP and GIS to analyze the most suitable locations for the installation of photovoltaic plants in Saudi Arabia;

Each of these studies differs in the quantity and detail of the criteria adopted, which vary according to the level of detail of the information sources and the importance that managers decide for each criterion.

In Brazil, we have the study by Santos et al (2019) that uses the AHP method to support the decision in the location of photovoltaic solar energy generating facilities for the state of Sergipe. However, instead of using GIS software, it was decided to treat the variables and process the method through algorithms for digital processing of the acquired images.

A geographic information system (GIS) facilitates the application of the AHP method because in a GIS software each variable works in different layers or layers in which, in addition to the variable information, there is information on the location coordinates in each value. thus facilitating arithmetic operations of the variables. Processing can be carried out within the GIS software, ensuring with great fidelity that the variables processed in the different layers of information belong to the same locations.

3. METHODOLOGY

This research will be applied in nature, as it generates knowledge of practical application to solve the problem of choosing the best location for the installation of a photovoltaic plant.

As for technical procedures, this work consists of a case study covering the entire territory of the state of Maranhão.

The first step of the work consisted of a bibliographic survey that serves as a reference for the study that will be developed.

The chosen criteria that impact the business model were the same ones adopted by Santos et al (2019), as well as the weight ratio between them, considering that the criteria are the minimum found in the entire researched literature. With the same criteria, the values adopted for the comparison between pairs were similar, as it is the same business model. There was not enough time to research experts.

There are five criteria adopted for this work are:

Solar radiation (data in Wh/m2.day): Solar radiation is the “raw material” for generating electricity through solar cells. The number of hours and intensity of incident solar radiation vary according to location and throughout the year. The sunny hours of the day decrease according to the period of the year, although these variations are barely noticeable in Maranhão due to its proximity to the equator. A map of average annual solar radiation was used in shapefile format with a resolution of approximately 10 x 10 km throughout Brazil (LABORATORY OF MODELING AND STUDIES OF RENEWABLE ENERGY RESOURCES, 2017).

Annual Maximum Temperature (data in ºC): Solar panel generation conditions consider tests at an ambient temperature of 25º C. The more the temperature increases, the more the generator loses efficiency, impacting on power loss in the panels. Maximum temperature data from the Climatological Normals (1981 – 2010) of INMET from 12 meteorological stations spread throughout Maranhão were used. Normals consist of the annual average of 30-year data. They were acquired in the “csv” format (INSTITUTO NACIONAL DE METEOROLOGIA, 2020).

Precipitation (data in millimeters): The occurrence of rain is often associated with cloudiness that negatively interferes with the generation of photovoltaic energy, as the amount of solar radiation that falls on the panels significantly decreases when there is cloudiness. This criterion is important for the analysis because the state of Maranhão has distinct regions of precipitation. It rains more on the coast and west of the Legal Amazon than in the eastern region of the state, bordering Piauí. Climatological Norms (1981-2010) from 12 INMET stations were used for precipitation and acquired in the “csv” format (INMET, 2020).

Power grid: The proximity of power grids reduces infrastructure costs (poles, cables, protection systems, environmental impact studies, etc.) to connect solar farms to the closest transmission/distribution networks. We used ANEEL maps of transmission lines in shapefile format throughout Brazil (GEOREFERENCED INFORMATION SYSTEM OF THE ELECTRIC SECTOR, 2017).

Road Network: The proximity of highways to the installation site is important because it reduces investment in road infrastructure. The state road map covering federal, state, and local roads in shapefile format for 2017 comes from (INSTITUTO MARANHENSE DE ESTUDOS SOCIOECONÔMICOS E CARTOGRÁFICOS, 2020).

In addition to the criteria, maps of federal, state, and municipal protected areas (UC) plus indigenous territories throughout Brazil were used (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, 2014). For these areas, legislation prohibits the installation of industrial projects. These criteria were unified into a single layer of information called restriction areas.

3.1 Problem Structuring

The hierarchical structure containing the objective to be achieved and the adopted criteria to be weighted are shown in Figure 1.

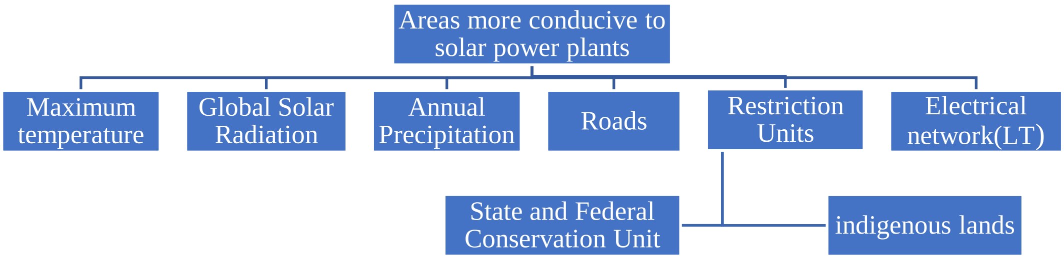

Figure 1. Hierarchical Construction.

It can be seen in the scheme presented above that the weighting relationships related to each area as alternatives were not presented. This is due to the ease that a GIS software provides us. Instead of a second and laborious step of creating weighting matrices for the alternatives, the software already does this because the result is a resulting georeferenced map in which it is possible to verify the weighted values for each region.

3.2 Data treatment (Normalization of Criterion Maps).

Before applying any analysis, it was necessary to homogenize the information based on the treatment of the source data. All processes described below were performed using an open-source software for geoprocessing called QGIS in version 3.10 LTR. All information files in shapefiles format have been reprojected to the same coordinate system. In this work, the SIRGAS 2000 UTM 23S was adopted.

The normal data of annual precipitation and maximum annual temperature measured by 12 automatic meteorological stations of INMET were used to generate the maps by the method of interpolation IDW (inverse squared distance). From the results obtained, it is necessary to normalize the map values. Normalization consists of transforming the scale of values by assigning the maximum value of the criterion in the studied region to 1 and to the minimum value, assigning the value 0. However, as the two criteria discussed contribute negatively to the generation of solar power plants, or be; the higher the precipitation or maximum temperature value, the more it will harm the generation, the normalization must be reversed, applying Equation 4:

$$V\ norm = 1 - \frac{V_{atual} - V_{mín}}{V_{máx} - V_{min}} \tag{4}$$

The values of $V_{mín}$ and $V_{máx}$ correspond respectively to the minimum and maximum value of the criterion under analysis. The V_{atual} refers to the point value you want to normalize, which varies according to the location on the map. V norm refers to the normalized value, ranging between "0" and "1".

Global solar radiation for all of Brazil was cut for the state of Maranhão and then normalized according to Equation 5. This is direct normalization, considering that solar radiation is a criterion that, the higher the value, the better it will be for the business model:

$$V\ norm = \frac{V_{atual} - V_{mín}}{V_{máx} - V_{min}} \tag{5}$$

As for the electrical networks (LTs) and the road network, as they are vector files in which there is only information on the presence or absence of the line, a procedure of discretization of the information was used before normalizing it. The discretization process transforms a binary information (absence or presence of information) into a gradient that assigns a maximum value (where the information is present) to the minimum value (the most distant location possible from the presence of the information).

The vector map of the highways was discretized through an implementing algorithm that discretizes the information. In Figure 2 you can see the resulting map. It starts with a value of "1" for places with darker blue tones (indicating greater proximity to the road network) to a value of "0" for places with lighter blue tones (indicating the most distant areas of the map in relation to to the road network).

Figure 2. Gradient Map of the Normalized Road Grid

The same treatment given to the road map is applied to that of energy networks (transmission lines): discretization and inverse normalization.

Figure 3 shows, in blue, the 12 specific locations where the INMET meteorological stations are located, where the maximum temperature values were obtained. The same figure shows the result of the interpolation performed by weighting the inverse of the distance (IDW), followed by the inverse normalization.

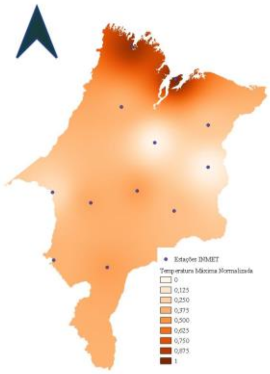

Figure 3. Normalized Maximum Temperature (Inverted) and location of INMET Stations.

The resultant map of the normalization of average global solar radiation is shown in Figure 4.

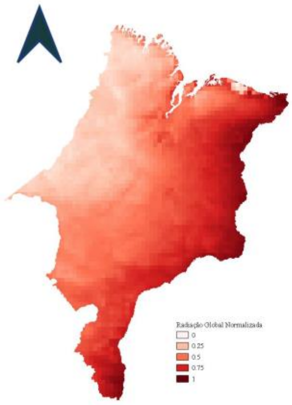

Figure 4. Normalized Global Solar Radiation.

Finally, the vector files of federal, state and indigenous land conservation units were unified into a single file. As this information is prohibitive, or excluding, a value of '0' is assigned for the presence of these restricted areas and for the other regions of the state of Maranhão, a value of '1' is assigned. This layer will be multiplied to the others in the resulting map, thus excluding information that overlaps these restriction areas. The resulting map is shown in Figure 5.

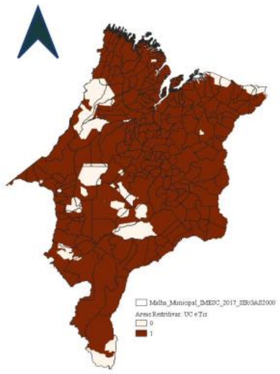

Figure 5. Areas with UC and TI's Restrictions (Normalized Map).

With the normalized maps, it is enough to prepare the judgment matrix comparing the criteria in pairs, calculate the weights (eigenvector) for each criterion, validate them through the consistency ratio (RC) and apply them by multiplying the criteria by the weights, obtaining a resulting map, as per Equation 6.

$$Cr = \left(\sum_{i=1}^{n} C_i x P_i\right) x\, C_e \tag{6}$$

Where C_i is the normalized value contained in the map, P_i is the value of the eigenvector referring to the respective criterion and C_e is the value contained in the map of restrictions (conservation unit and indigenous lands). Cr is the layer resulting from this calculation.

4. RESULTS AND DISCUSSIONS

Once the decision criteria have been adopted and all the criteria maps have been elaborated and standardized, the calculation of the weights between criteria is started, building the judgment matrix. The matrix is shown in Table 4.

Table 4 - Weighted Criteria Matrix.

D	**Radiation**	**Temperature**	**Precipitation**	**Electrical network**	**Roads**
Radiation	1.00	3.00	5.00	5.00	9.00
Temperature	0.33	1.00	3.00	3.00	5.00
Precipitation	0.20	0.33	1.00	1.00	3.00
Electrical network	0.20	0.33	1.00	1.00	3.00
Roads	0.11	0.20	0.33	0.33	1.00

Table 4 shows that the criterion “radiation” is “absolutely more important than” the criterion “road network”. In other words, the “weight” of the first criterion is much higher than the second criterion. On the other hand, when radiation is compared to temperature, the value ‘3’ indicates, as described in Table 2, that the first criterion is “slightly more important than” the second criterion.

Due to the similarity between the criteria adopted in this study and the criteria adopted in Santos et al (2019), Table 4 has adopted the same weights between such criteria adopted by those authors, and it is not necessary to consult specialists for the definition of weights to be adopted.

The eigenvector is then calculated from the weighted matrix, which are the weights of each of the criteria and the consistency ratio (RC), shown in Table 5. The Table presents the values found for the $\lambda_{máx}$.

Table 5 - Criteria Priority Autovector and consistency validation.

Critério	**Priority Values**	**Consistency Validation**
Radiation	0.5110	$\lambda_{máx}$ = 5.133
Temperature	0.2410	IR = 1.11
Precipitation	0.1027	IC = 0.033
Electrical network	0.1027	RC= 0.030 ≤ 0.10
Roads	0.0427	

The value for consistency ratio of 0.030 and below 0.10 confirms that the peer weights assigned to the criteria are consistent.

The next step would be to repeat the process carrying out the weights for each supposed alternative, that is; a judgment matrix of installation alternatives (municipalities, for example) for each of the criteria. This step, as already informed, is unnecessary, since the criteria for each possible alternative have already been normalized using the QGIS software in each of the information layers, as described in item 3.2.

The result was obtained by multiplying each criterion layer by the value of the corresponding eigenvector and then performing the summation as shown in Equation 6.

The resulting map (Figure 6) indicates that the regions in blue are the most prone to the installation of farms or solar plants, considering the adopted criteria. The map varies from "0", attributed to the places that have restrictions for installation (white regions), to the places more prone to the installation of plants, reaching values of up to "0.795" (value found in some localities in the regions in blue).

For ease of understanding, the numerical values were reclassified according to Table 6, assigning recommendations ranging from "Very Highly Recommended" regions (places most conducive to installation) to "Not Recommended" areas that coincide with conservation units and indigenous lands.

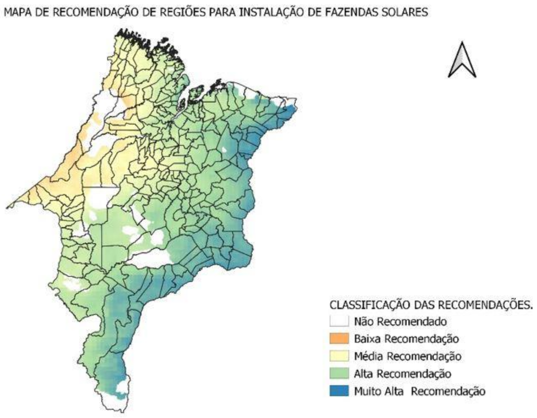

Figure 6. Map with the most suitable areas for the installation of UFV.

Table 6 associates the numerical values to the qualitative legend. This label is merely didactic and can assume any description of recommendation.

Table 6 - Legend Description

Numerical Ranges	Color	Label
$\boldsymbol{x = 0}$	White	Não Recomendado
$\boldsymbol{0 < x \leq 0.199}$	Orange	Baixa Recomendação
$\boldsymbol{0.199 < x \leq 0.397}$	Yellow	Média Recomendação
$\boldsymbol{0.397 < x \leq 0.596}$	Green	Alta Recomendação
$\boldsymbol{0.596 < x \leq 0.795}$	Blue	Muito Alta Recomendação

It is observed that the westernmost regions of the state of Maranhão are less favorable to this business model. These results demonstrate to be very coherent, considering that the westernmost region of the state belongs to the Amazon Biome, a region whose cloudiness and rainfall attenuate the incident solar radiation on solar generators. These regions vary between orange and yellow colors on the map. The green region represents an intermediate region that mainly covers the central region of the state. The regions in blue, on the other hand, are closer to the drier regions, with greater solar radiation, more scarce precipitation, and cloud cover, being considered the "Muito Alta Recomendação" regions. It can be seen on the map that the "Muito Alta Recomendação" region comprises a narrow strip of territory, from the green region to the eastern limit of the state of Maranhão.

The 10 municipalities most favorable to solar farm installations are shown in Table 7. This result can be easily obtained through arithmetic operations of the values contained in each municipality, from the map shown in Figure 6. Calculating the simple average for the values for each municipality, using a vector file with the outline of all municipalities as the operation mask. The QGis software provides functions to perform this calculation without major difficulties.

Table 7 shows the municipality of Magalhães de Almeida as the one with the best conditions for installing solar power plants, as this municipality has an average value of "0.7415". In tenth place is the city Benedito Leite, with a value of "0.7042". It is observed that all 10 municipalities are labeled as "Muito Alta Recomendação".

Tabela 7 - The 10 most favorable municipalities for the installation of Solar Power Plants.

Order	City	Average
1	Magalhães de almeida	0.7415
2	Brejo	0.7380
3	Duque bacelar	0.7321
4	Buriti	0.7231
5	Milagres do maranhão	0.7211
6	São bernardo	0.7139
7	Nova iorque	0.7122
8	Barão de grajaú	0.7088
9	Coelho neto	0.7087
10	Benedito leite	0.7042

It is known, however, that a detailed map of the statewide distribution network, covering the utility grid more accurately, would be the ideal situation. As already mentioned, the detailed distribution network in shapefile format was not made available by the concessionaire.

5. CONCLUSION

As a result of this work, a georeferenced map was obtained on a scale ranging from 0 to 0.795 ; indicating the most favorable locations for the installation of solar generators (0.795), up to the prohibitive locations for this type of installation (0).

The RC value obtained considering the criterion power network containing only the transmission lines, compared to the RC without using this criterion were approximated: 0.030 and 0.032, respectively. These values are less than 0.10; indicating that there is consistency in the two simulations.

The Municipality of Magalhães de Almeida, for the study with the energy network, presents the best conditions for the installation of solar plants, considering the average of the values indicated on the map for each municipality.

Finally, it is possible to conclude that the inclusion of more criteria in the analysis (soil slope, soil type, etc.) would reduce the weight of the radiation criterion, which proved to be preponderant to the other criteria, in the two simulations addressed (with and without the network of energy).

6. REFERENCES

AL Garni, H. Z.; AWASTHI, A. Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia., 206, 2017. 1225-1240.

BESER DE DEUS, A. L.; SANTOS, C. S.; FREITAS, M. A. A utilização de sistema de informação geográfica como Suporte ao gerenciamento de bacias hidrográficas Transfronteiriças-sig geoamazona. Revista Geográfica de América Central, 2011.

CCCE. Tipos de Leilões. CCCE, 2019. Disponivel em: <https://www.ccee.org.br/portal/faces/ pages_publico/o-que-fazemos/como_ccee_atua/tipos_leiloes_n_logado? afrLoop= 3958- 285 5654571&adf.ctrl-state=apopfulof_47#!%40%40%3F_afrLoop%3D39582855654571%2 6 _adf.ctrl-state%3Dapopfulof_51>. Acesso em: 21 jan. 2021.

DE OLIVEIRA, ALZIRA; DOS SANTOS, DANIEL ;PACHECO,MARCOS; MÁRIO,MAURICIO. Uma Avaliação das Projeções da ANEEL para Avanço da Energia Solar Fotovoltaica no Brasil em Área Rural. Anais do Encontro Nacional de Pós-Graduação – VIII ENPG, 3, 2019. 68-72.

GIAMALAKI, M.; TSOUTSOS, T. Sustainable siting of solar power installations in Mediterranean using a GIS/AHP approach. Renewable Energy, p. 64-75, 2019.

IBGE. Instituto Brasileiro de Geografia e Estatística. IBGE, 2014. Disponivel em: <ttp://www.ibge.gov.br/>. Acesso em: 21 nov. 2020.

IMESC. Instituto Maranhense de Estudos Socioeconômicos e Cartográficos- IMESC. IMESC, 2020. Disponivel em: <http://www.imesc.ma.gov.br/>. Acesso em: 21 NOV 2020.

INMET. Instituto Nacional de Meteorologia - Normais Climatológicas do Brasil - Temperatura e Precipitação. INMET, 10 NOV 2020. Disponivel em: <https://portal.inmet.gov.br/ normais>.

KARLA A.V. BORGES, CLODOVEU A. DAVIS JR. E ALBERTO H.F. LAENDER. Modelagem de Dados Geográficos. In: ______ Banco de Dados Geográficos. São José dos Campos: [s.n.], 2005.

LABREN. Laboratório de Modelagem e Estudos de Recursos Renováveis de Energia. QGS (Projeto QGis), 2017. Disponivel em: <http://labren.ccst.inpe.br/ atlas_ 2017.html>. Acesso em: 10 nov 2020.

LAGO, D. Modelagem de banco de dados geográfico para subsídio a gestão integrada de recursos hídricos. Revista de Ciências Exatas e Tecnologia, p. p. 79-90, 2006.

MARINS, C. S.; SOUZA, D. D. O.; BARROS, M. D. S. O uso do método de análise hierárquica (AHP) na tomada de decisões gerenciais–um estudo de caso. XLI SBPO, 1, 2009. 49.

NUGEO. Núcleo Geoambiental - Malha Rodoviária. UEMA, 2017. Disponivel em: <https://www.nugeo.uema.br/>. Acesso em: 12 jan. 2021.

NUGEO. Núcleo Geoambiental - Unidades de Conservação. UEMA, 2020. Disponivel em: <https://www.nugeo.uema.br/>. Acesso em: 12 jan. 2021.

ONS. Operador Nacional do Sistema Elétrico - ONS. Sumário Executivo PAR/PEL 2020: Plano de Operação Elétrica de Médio Prazo do SIN., 2020. Disponivel em: <http://www.ons.org.br/AcervoDigitalDocumentosEPublicacoes/Sum%C3%A1rio_executivo_ONS_PAR-PEL-2021-5.pdf#search=Sum%C3%A1rio%20PAR %2FPEL% 202021%2D%202025>. Acesso em: 10 dez 2020.

OSGEO. QGIS - O Líder em GIS para Desktop de Código Aberto. QGIS.ORG, 2020. Disponivel em: <https://qgis.org/en/site/about/index.html>. Acesso em: 15 fev. 2020.

PAQUETE, S. Qual o impacto ambiental da instalação de uma hidrelétrica? SUPERINTERESSANTE, 18 Abril 2021. Disponivel em: <super.abril.com.br/mundo-estranho/qual-o-impacto-ambiental-da-instalacao-de-uma-hidreletrica/>. Acesso em: 05 jan 2021.

SAATY, T. L. How to make a decision: the analytic hierarchy process. European journal of operational research, 48, 1990. 9-26.

SAATY, T. L. A ratio scale metric and the compatibility of ratio scales: The possibility of arrow's impossibility theorem. Applied Mathematics Letters, 7, 1994. 51-57.

SÁNCHEZ-LOZANO, J. M. Solanob, J.T., Elvirab, P.L.S., Cascales, M.S.G. Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: Case study in south-eastern Spain. Renewable and sustainable energy reviews, 24, 2013. 544-556.

SANTOS, A. L. B. Ferreira, D.V. , Barbosa da Silva. L. G. , Macedo, M. S., Ferreira, T. Método de análise hierárquica para suporte à decisão na localização de instalações geradoras de energia solar fotovoltaica no estado de Sergipe. Brazilian Journal of Business, 1, 2019. 924-943.

SCG. Superintendência de Concessões e Autorizações de Geração-SCG. ANEEL, 23 nov. 2015. Disponivel em: <https://www.aneel.gov.br/scg>. Acesso em: 10 fev 2021.

SIGEL. Sistema de Informações Geográficas do Setor Elétrico – SIGEL. SIGEL, 2017. Disponivel em: < https://sigel.aneel.gov.br/portal/home/index.html>. Acesso em: 29 nov 2020.

SRD. Geração Distribuída. ANEEL. Geração Distribuída. ANEEL - SRD, 2016. Disponivel em: <https:// www.aneel.gov.br/ informacoes-tecnicas/-/asset_publisher/CegkWaVJWF5E/content/geracao-distribuida-ntroduc -1/656827?inheritRedirect=false>. Acesso em: 10 jan 2021.

UYAN, M. GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya/Turkey. Renewable and Sustainable Energy Reviews, 28, 2013. 11-17.