energies

MDPI

Article

Location Study of Solar Thermal Power Plant in the State of Pernambuco Using Geoprocessing Technologies and Multiple-Criteria Analysis

Verônica Wilma B. Azevêdo [1], Ana Lúcia B. Candeias [2] and Chigueru Tiba [1,*]

1 Departamento de Energia Nuclear, Centro de Tecnologias e Geociências, Universidade Federal de Pernambuco, Av. Prof. Luiz Freire, 1000, Cidade Universitária, Recife PE 50.740-540, Brazil; veronica_wilma@hotmail.com

2 Departamento de Engenharia Cartográfica, Centro de Tecnologias e Geociências, Universidade Federal de Pernambuco, Av. Acadêmico Hélio Ramos, s/n, 2nd Floor, Cidade Universitária, Recife PE 50.740-530, Brazil; analucia@ufpe.br

* Correspondence: tiba@ufpe.br; Tel.: +55-81-2126-7976

Academic Editor: Francesco Calise
Received: 23 May 2017; Accepted: 13 July 2017; Published: 20 July 2017

Abstract: Solar Thermal Technology for the generation of electricity in large scale has been a reality in the world since the 1980s, when the first large-sized solar plants in the United States were introduced. Brazil presents great potential for the development of large-scale projects, although it is noted that the main barriers for the insertion of this technology in Brazilian market are the lack of incentives and goals and associated costs. In a way to contribute to the insertion of solar thermal technology in Brazil, this paper presents a macro-spatial approach, based on the use of Multiple-Criteria Decision Analysis and Geoprocessing, for the location of solar thermal power plants. The applied methodology for Pernambuco, located in the Northeast Region of Brazil, considered the implantation of parabolic trough solar power plant of 80 MW, operating only in solar mode, without heat storage. Based on performed analysis, it was confirmed that Pernambuco presents great potential for the installation of solar power plants, especially in the backlands of Pernambuco. Performed validations in the model demonstrate that the methodology attended the objective once the consistence between the assigned weights to the thematic layers, individually, and the final Map of site suitability were evidenced.

Keywords: Solar Energy; Solar Thermal Power Plant; Geoprocessing Technologies

1. Introduction

Notably, in the past few years, electricity generation through renewable sources has presented continuous increase, which mostly relates to the concerns of climate changes, the dependency of fossil fuels and the need to supply power generation with resources that cause less impact to the environment. According to data in the Global Status Report on Renewable Energy [1], the installed capacity of renewable energy in the world, which was of 800 GW in early 2004, reached 1712 GW in the year of 2014 and its participation in the energy matrix also increased, reaching the percentage of 22.8% in 2014.

Brazil has a mainly renewable energy matrix. According to data in the National Energetic Statement, about 74.6% of electric energy generated in 2014 came from renewable energy sources, with greater participation of water (65.2%), biomass (7.4%) and wind (2.0%) resources. The remaining percentage (25.4%) came from fossil fuels and nuclear sources, as shown in Figure 1.

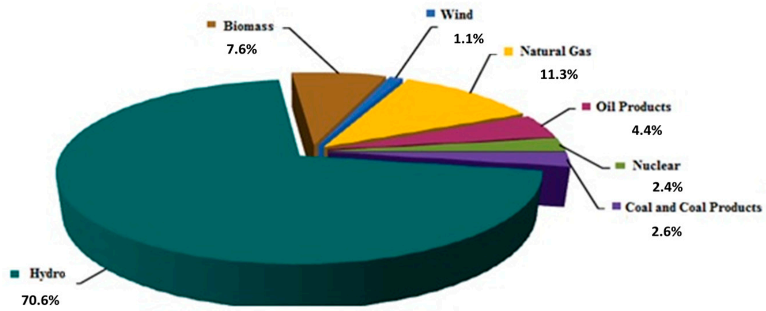


Figure 1. Internal offer of electric energy by generation source.

However, while the country has a typically renewable energy matrix, the main generation system is the hydraulic utilization, which is very vulnerable to the climate variations and may present the reduction of its installed capacity in the long term. Another problem for the electricity generation by water resources in the country is the fact that its remaining potential is located in the Amazon biome, making the energetic use process more thorough and costly in time, due to the environmental restrictions [2].

To contribute in the diversification of the Brazilian energy matrix, this paper presents a methodology based on the use of Geographic Information System (GIS) and Multiple-Criteria Decision Analysis (MCDA) to assist in identifying potential areas for the insertion of solar thermal power plants. The methodology applied for Pernambuco, Northeast region of Brazil, considered the implantation of parabolic through solar power plants of 80 MW, Solar Energy Generating Systems (SEGs) type, operating only in solar mode, without heat storage. The solar power plant with nominal power of 80 MW was chosen because great majority of commercial power plants with parabolic cylinder technology currently installed in the world present this power. The LCOE (Levelized Cost of Energy) of a thermal power plant is calculated for a given spatial coordinate (pixel) and depends, for example, on the local meteorological parameters, the Euclidean distance from this pixel to main road, water conduit and transmission line or on the topography, i.e., terrain slope (greater or lesser need for land movement). The generated electricity will depend on the local meteorological conditions and the technical specifications of the power plant.

1.1. Solar Technology

According to [3], a parabolic trough solar power plant is formed by the following components: (a) the solar collector that, by reflection and diffraction of light, performs its collection and concentration; (b) the absorber tube that absorbs the light and transfers the heat to a thermal fluid; (c) a steam generating system; and (d) a conventional system of thermal energy conversion to electricity, as shown in Figure 2.

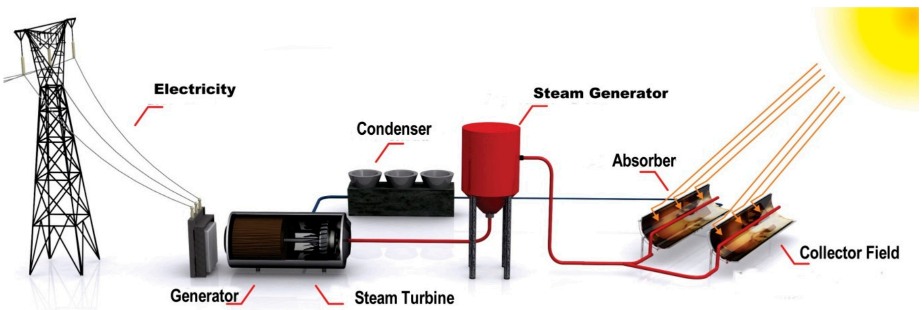


Figure 2. Scheme of solar thermal power plant.

Among all the concentrated solar power technologies (parabolic cylindrical collector, linear Fresnel, solar towers, and parabolic dish), parabolic collectors (Figure 3a,b) are, without a doubt, the most mature technology and with greater installed capacity in operation. According to [1], the percentage of installed capacity of this technology in late 2014 was 95%, meanwhile, solar towers and linear Fresnel account for 5% participation. Parabolic dishes did not have representation.

(a) (b)

Figure 3. Concentrated Solar Power Technologies: (**a**) parabolic cylindrical collector; and (**b**) parabolic trough solar power plant—ANDALUSIA AND SOL I—ANDASOL I (50 MW, Granada, Spain).

The estimative is that Concentrated Solar Power (CSP) technologies present even stronger growth in the next few years. According to International Energy Agency [4], this technology may provide 11% of worldwide demand for electricity in 2050, in a hi-Ren scenario (High Renewable Scenario), when renewable energy, solar and wind, would represent the main agents to reduce carbon dioxide emissions in the environment.

1.2. Optimal Location of Thermal or Phovoltaic Solar Power Stations

The use of GIS in renewable energy, which began in the 1990s, went through considerable progress and, as a result, various decision support tools were developed [5]. The pioneering study regarding GIS usage for Concentrated Solar Power (CSP) is due to [6] who analyzed Northern Africa providing a rank of sites concerning the potentiality and cost of solar thermal electricity for a particular power plant configuration. Recently, this type of study is widespread: Ref. [7] for Southwest USA, Ref. [8] for South Africa, Ref. [9] for Oman, Ref. [10] for Burkina Faso, Ref. [11] for Australia and [12] for India. Generally, these studies search for an optimal location based on the lowest levelized cost of energy (LCOE) of a solar power station hypothetically localized on a given pixel. The LCOE will depend on the generated energy (climatic factors), the need for infrastructure (distance from water conduits, roads and transmission lines), the implantation costs (topography) and finally on the environmental factors.

Another methodology used to the location of solar power plants is the one that gathers the concepts of GIS and the Analytic Hierarchy Process (AHP) method for the identification of suitable sites [13–19]. Basically, the methods are elaborated for the creation of an environmental decision support system for the installation of large solar photovoltaic power plants. Such systems also take into account climatic, topographic, environmental and localization criteria to determine the classification and suitability of the sites studied.

In short, most of the optimal location for solar power station studies performed with association of GIS and AHP methods were applied for PV technology. There are very few studies on large-sized solar thermal power stations.

Because of the above, the current paper proposes to extend the methodology already widely used on PV technology for solar thermal technology. In addition, the criteria and sub-criteria will be treated with much more detail to represent the real complexity of the system.

2. Geoprocessing Technologies in the Support of Location Studies for Solar Thermal Power Plants

2.1. Geographic Information Systems (GIS)

GIS are computerized systems developed with the purpose of digital processing of geographic information and, for [20], GIS can be represented as a network that relates people to spatial data, through the use of hardware, software and proceedings, as shown in Figure 4.

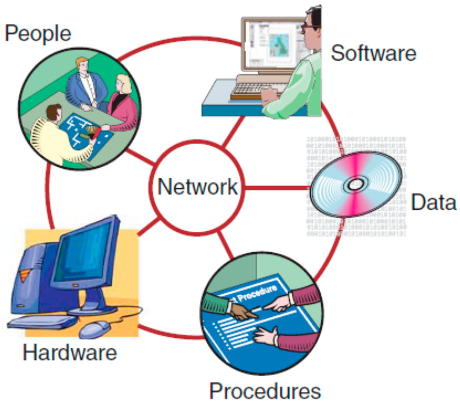


Figure 4. Geographic Information Systems (GIS) components.

The software corresponds to computer programs. The data correspond to the geographic information that forms the Spatial Database (SDB) of the system. The proceedings correspond to the methodology and existing practical actions so that the system operates properly to the organization. The hardware corresponds to the used computing platform. The people represent the professionals responsible for the project, as well as the system users.

2.2. Map Algebra

Map Algebra, introduced by Dana Tomlin and Berry in the 1970s, comprehend a set of conventions, capabilities and analytical techniques for the performance of operations with geo-fields in the matrix model in the GIS environment [21]. Its operators treat geo-fields as individual variables, layers, associating each geographic position to a particular study area, a qualitative or quantitative value, from the use of expressions with well-defined syntax.

Map Algebra operators group into four classes, punctual, zonal, neighborhood and global, according to the relationship mode between the variable used in these operations (origin geo-field) and the variable resulting from these operations (destiny geo-field). For more details, see [21].

2.3. Fuzzy Logic

In location studies of power plants, a very important stage is the standardization of spatial data, the main objective of which is to represent the spatial data values, originally not comparable, in continuous scale. A technique widely used in this process is standardization by Fuzzy logic.

Fuzzy logic is based on the fuzzy sets theory, which represents classes of elements that do not have well-defined borders. There are two extremes in the traditional logic (completely true (1) or completely false (0)), but the fuzzy logic has a premise that varies in degree of truth from 0 to 1, making the question partially true or partially false.

The use of fussy sets is based in rules of inference and is indicated for situations that deal with ambiguity, abstraction and ambivalence in mathematical or conceptual models of empirical phenomena [22]. Among the best-known fuzzy functions are linear, triangular, trapezoidal, Gaussian and sigmoidal functions. For more details, see [23].

3. Multiple Criteria Decision Analysis—The AHP Method

Multiple Criteria Decision Analysis (MCDA) consists of a set of systematic procedures to analyze complex decision problems where doubt situations or information conflicts predominate. One of its main methods is the Analytic Hierarchy Process (AHP), developed by Thomas Saaty, in the 1980s [24].

Generally, the AHP method structures the problem in hierarchical levels, subdividing them in criteria, sub criteria, and in as many levels necessary for the search of the best solution. Once the problem hierarchy is built, the criteria pairs are compared using a measurement scale (Table 1).

Table 1. Saaty's Fundamental Scale [1].

Importance	Definition
1	Equal Preference or Importance
3	Weak Preference or Importance
5	Moderate Preference or Importance
7	Strong Preference of Importance
9	Absolute Preference or Importance

[1] In this scale, the even numeric values from 2 to 8 are intermediate values between the elements of the main scale.

From the pairwise comparison of the criteria, the pairwise comparison matrix is generated (Figure 5). The number of judgments needed for a particular matrix of order n, the number of elements being compared, is $n\ (n-1)/2$ because it is reciprocal and the diagonal elements are equal to unity.

$$
A = \begin{array}{c|cccc} & C_1 & C_2 & \cdots & C_n \\ \hline C_1 & 1 & a_{12} & \cdots & a_{1n} \\ C_2 & a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ C_n & a_{n1} & a_{n2} & \cdots & 1 \end{array}
$$

Figure 5. Pairwise Comparison Matrix.

After the definition of Pairwise Comparison Matrix, the standardization of its elements for the estimation of weights (w_j) is performed. One of the most used methods for estimation is the Mean of Normalized Columns. In it, first, the sum of the elements of each column in the A matrix ($S_1, S_2, \ldots, S_n$) is made and, after that, a new matrix is generated, where each element is the result of dividing each a_{ij} element in A matrix by the sum of the corresponding column. The last stage of this procedure is calculating the average of the normalized values of the lines that correspond to the estimated weights. According to [25], the sum of obtained weights for each criteria of the study must always be equal to 1.

After the definition of the weights for the criteria (global priorities), an evaluation of the consistence of the model must be performed to analyze the transitivity of the judged values. It is performed from the Consistency Ratio (CR), which is given by Equation (1):

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{1}$$

where CI is the consistency index of the judgments and RI is the random consistency index.

The consistency index of the pairwise comparison matrix (CI) is calculated from the relation between the order in this matrix (n) and its higher eigenvalue (λ_{max}):

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

The random consistency index (RI) was empirically determined considering a sample of 500 positive reciprocal matrices, generated randomly [25]. The values attributed to RI by Saaty, according with the order of the matrix (n), are shown in Table 2.

Table 2. Empirical Values of the Random Consistency Index.

n	RI
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

If the value found for the Consistency Ratio (CR) is equal or greater than 0.1, the values of the judgments in the pairwise comparison matrix must be reviewed because they are not sufficiently constant to estimate the weights (w_j). On the other hand, if such value is smaller than 0.1, the judged values are considered satisfactory [24].

Once defined as constant the judged values of the criteria, the entire process for obtaining the priorities should be repeated for the other hierarchical levels. In addition, for these, analyses of the consistency of the judged values have to be made [13].

4. Materials and Methods

4.1. Material Used

Computer Programs used were ArcGIS 10.1 (ESRI) and Spring 5.2.6 (INPE). The Spatial Database were Shapefiles related to the Information Plans, Mission data SRTM3 and Satellite images LANDSAT 8.

The following stages for the construction of the SDB included actions such as Survey, Analysis and Systematization of Existing Information, Analysis of Spatial Data Quality, Base Edition and Database preparation. In the Base Edition stage, the spatial data were also standardized. In it, SIRGAS2000 was used as Geodetic Reference System, Geodetic Coordinate System, Equidistant Conic Cartographic Projection, vector and matrix Data Model and Scale of 1:4,000,000.

4.2. Study Area

According to IBGE (Brazilian Institute of Geography and Statistics), Pernambuco is located in the East center of Northeast Region of Brazil, between the coordinates 7°15′ and 9°27′ South latitude and 34°00′ and 48°19′ West longitude. With a territorial area of 98,149.119 km^2, Pernambuco borders the Atlantic Ocean and the States of Paraíba, Ceará, Piauí, Bahia and Alagoas. Fernando de Noronha Archipelago, located 545 km from Recife (capital of Pernambuco).

Considering the regional division of Brazil in Geographic Mesoregions, Pernambuco has five well-defined environments: Metropolitan Recife Region, Forest Zone, Agreste, Backlands and São Francisco Region. These environments are presented in Figure 6.

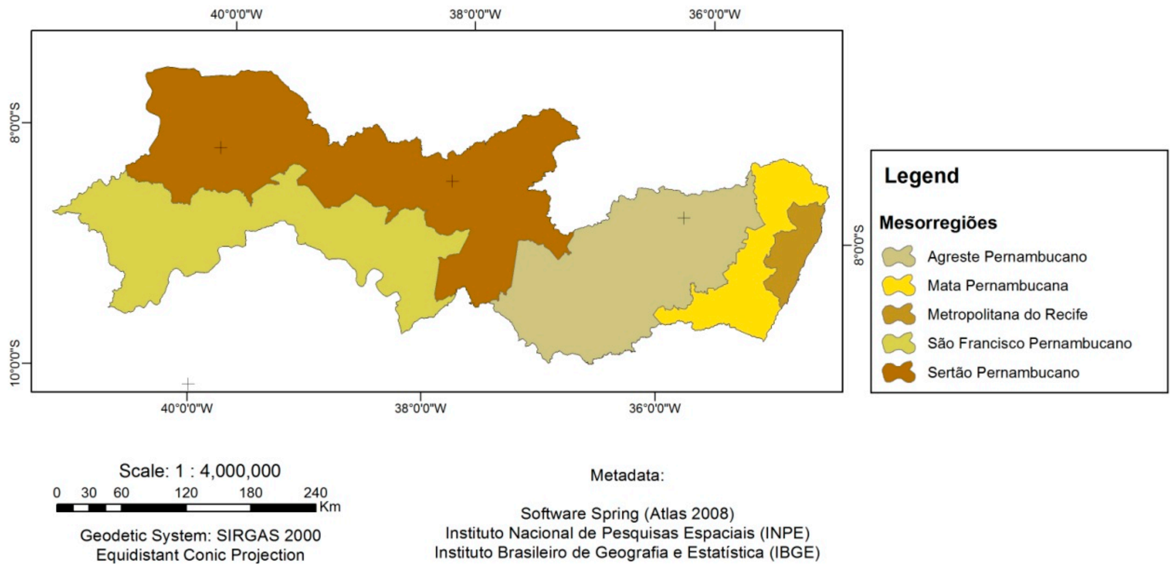


Figure 6. Map of Geographic Mesoregions of the State of Pernambuco.

4.3. Methodological Procedures

The application of AHP method for the location of solar power plants in Pernambuco began with the explicit definition of the objective to be achieved, as illustrated in Figure 7. The sequence shows the defined criteria and sub-criteria of the study. As subsequent stages, the decision rules were defined and the consistency calculations were performed for the different scenarios generated. At last, the potential degree of Pernambuco's territory was determined for the implantation of the projects, and the validation of the model was performed.

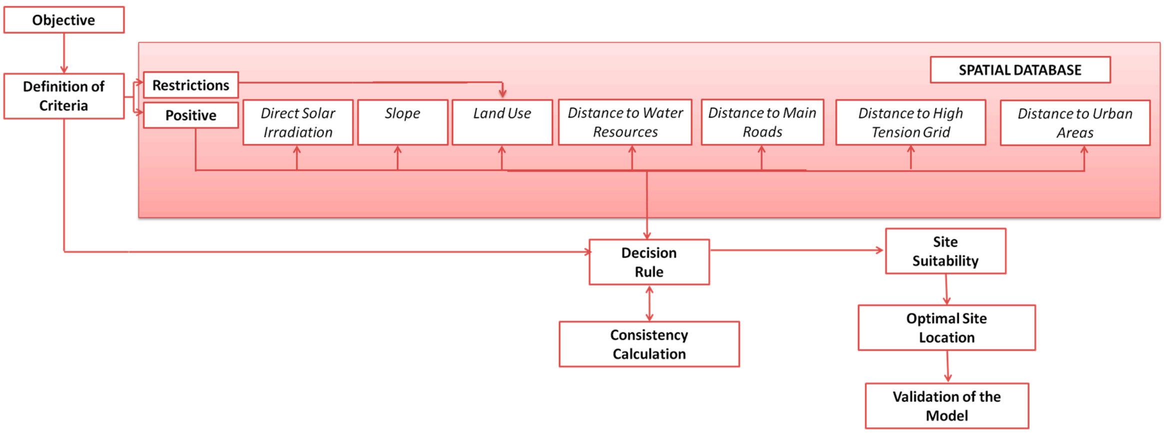


Figure 7. Methodological Procedures Performed for the Location.

4.3.1. Objective of the Method

The objective of the method is to find locations with potential for the installation of solar thermal power plants of parabolic trough collectors in Pernambuco, according to the requirements defined by the decision rules in each scenario of the study.

4.3.2. Criteria and Sub-Criteria Definition

To assess the problem of the location of solar power plants in Pernambuco, four criteria were defined: Climatic, Topographic, Location and Environmental. In turn, they were divided into sub-criteria, featuring the positive indicators (Table 3) and the restrictions of the study (Table 4).

Table 3. Positive Indicators.

Criteria	Sub-Criteria	Positive Indicator
Climatic	Direct Normal Irradiation	3.8–4.2 kWh/m^2·day 4.2–4.6 kWh/m^2·day 4.6–5.0 kWh/m^2·day 5.0–5.4 kWh/m^2·day 5.4–5.8 kWh/m^2·day
Topographic	Slope	0–2% 2–4% 4–5% >5%
Environmental	Use of Soil	Regular Agricultural Potential Regular to Restrict Agricultural Potential Restrict Agricultural Potential Restrict to Unfavorable Agricultural Potential Unfavorable Agricultural Potential
Location	Distance to the Power Lines	0–6.8 km 6.8–15.7 km 15.7–26.6 km 26.6–40.9 km 40.9–64.7 km
	Distance to the Water Resources	0–7.8 km 7.8–17.6 km 17.6–27.7 km 27.7–39.9 km 39.9–69.2 km
	Distance to the Main Roads	0–2.5 km 2.5–5.7 km 5.7–9.6 km 9.6–15.0 km 15.0–29.2 km
	Distance to Urban Areas	0–11.4 km 11.4–23.1 km 23.1–37.4 km 37.4–57.2 km 57.2–93.5 km

Table 4. Negative Indicators or Restrictions.

Criteria	Sub-Criteria	Restriction
Environmental	Use of Soil	Conservation Units Remnant of the Atlantic Forest Indigenous Territories Quilombo Territories High Agricultural Potential Areas Urban and Urban Expansion Areas Water Bodies

- Positive Indicators

The positive indicators are those that enhance the suitability of an alternative. They relate to the direct normal irradiation, the terrain slopes, the use of the soil, distance to the power lines, distance to the water resources, distance to the main roads and the distance to the urban areas and urban expansion.

The direct normal irradiation is the most important parameter for the indication of potential areas for the installation of solar thermal power plant. According to [3], the location where the power plant will be installed must present the minimum direct normal irradiation value of 2100 kWh/m^2·year, that is, 5.75 kWh/m^2·day (annual average daily value), to secure the efficacy or the CSP projects. This value is based on projects installed around the world. In Pernambuco, the maximum DNI value is 5.8 kWh/m^2·day (annual average daily value) and represents the current information available and published by the competent governmental agency.

The terrain slope where the power plant will be installed determines the acceptability of the site according to its impact in the related cost for the preparation and flatwork of the ground. This location should be as flat as possible, but with enough inclination to allow natural drainage of the terrain. Regarding the visual horizon of the field of solar collectors, only obstruction (hills, trees, towers, etc.) with visual angles lower than 10° are allowed [3].

The positive aspects related to the use of the soil include those areas which activity or occupation is permissible. In the present research, the areas not used for production purposes, with potential classified as regular, regular to restrict, restrict, restrict to unfavorable and unfavorable were considered as most indicated for the installation of the solar power plants.

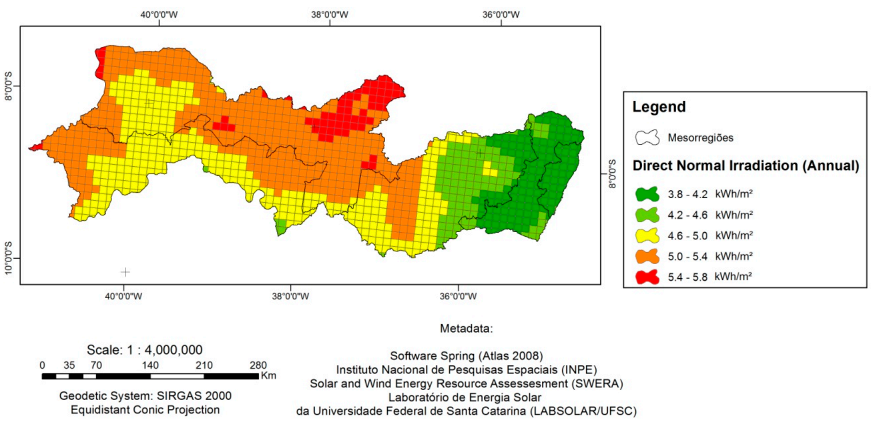
The requirement for the solar power plant interconnection with the electrical system are similar to the others thermoelectric plants. Lines with load capacity or substations are necessary, as close as possible from the solar power plant, once the construction cost for new power lines are generally high.

A parabolic trough solar power plant, SEGS type, of 80 MW, operating 350 days in a year and 12 h a day, uses around 2,000,000 m^3 of water. From this total, 90% are destined for the refrigeration towers and the rest for steam generation (8%) and cleaning of the mirrors (2%) [26].

The access to the site of the power plant is relevant, mainly because of the need to transport large-sized and fragile equipment, such as mirrors. Therefore, the proximity of this factor to the implantation site of the power plant is an important requirement and may reflect in the general cost of the plant if, for example, it demands the expansion of the road network.

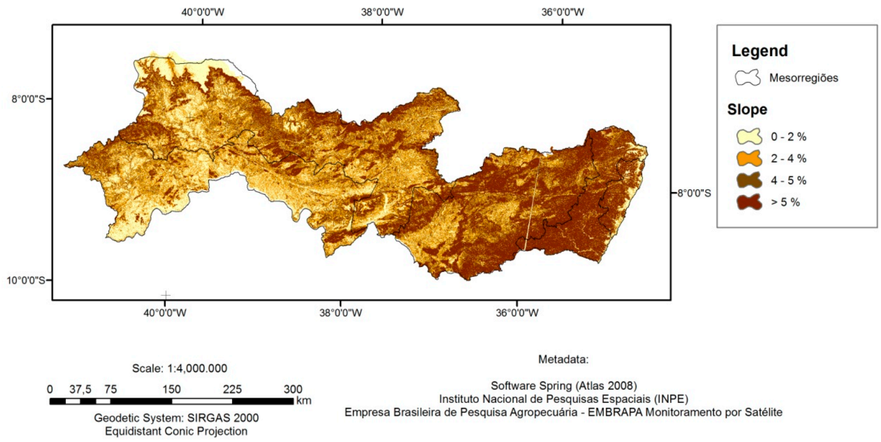
Urban areas and urban expansion areas must be preserved in order to meet its social function. That is why these regions should be considered as unsuitable for solar power plant installation (excluded from the model) and, besides that, be evaluated as its proximity to the power plant. For this study, only the municipalities with more than 25,000 inhabitants were considered.

Figure 8a–g Maps of: a: Direct Solar Irradiation; b: Terrain Slopes; c: Agricultural Potential of the Soils; d: Distances to Power Lines; e: Distances to Water Resources; f: Distances to Main Roadways; g: Distances to Urban Areas illustrates the spatial distribution of the positive indicators in the State of Pernambuco. The set of thematic maps was produced from the use of a Spatial Database (SDB) built specifically for this study, with the aid of ArcGIS 10.1 software. This map set is presented in [27].

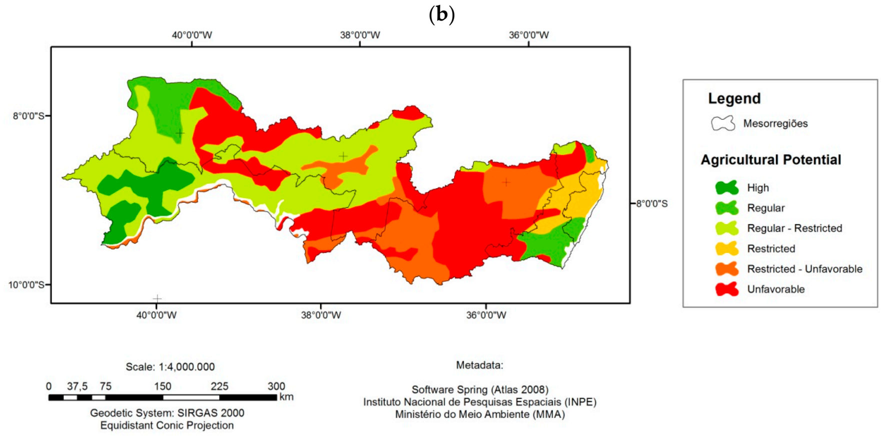


(a)

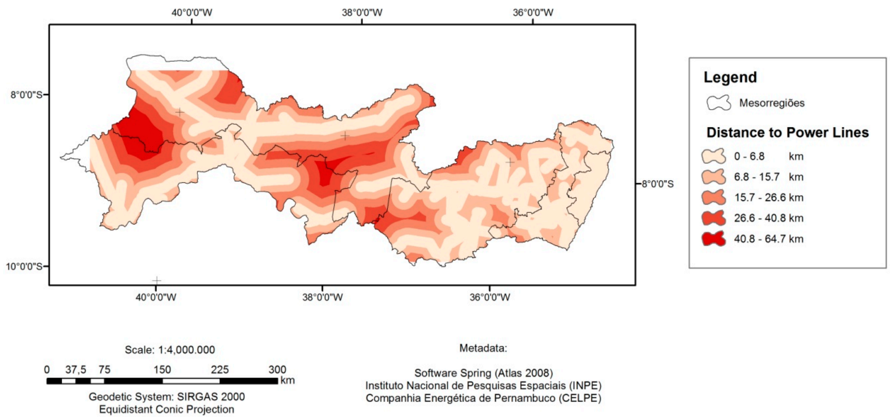
Figure 8. *Cont.*



(**b**)

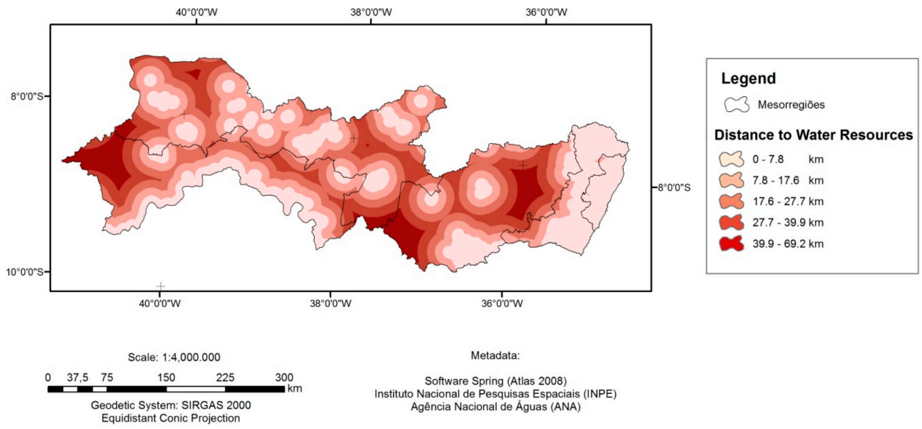


(**c**)

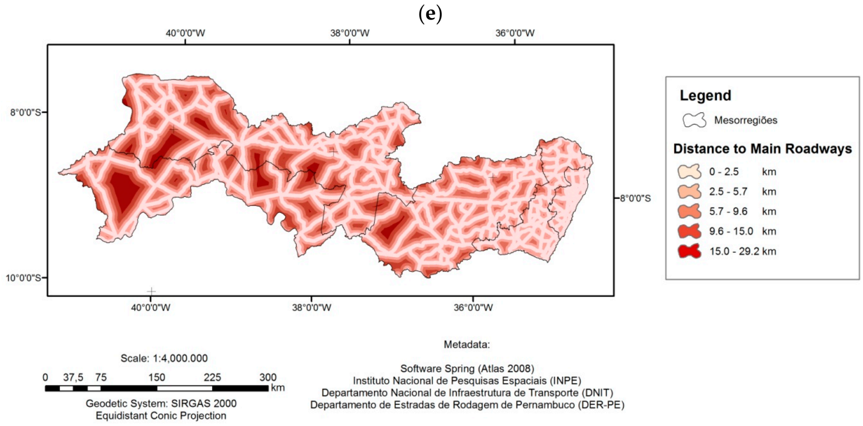


(**d**)

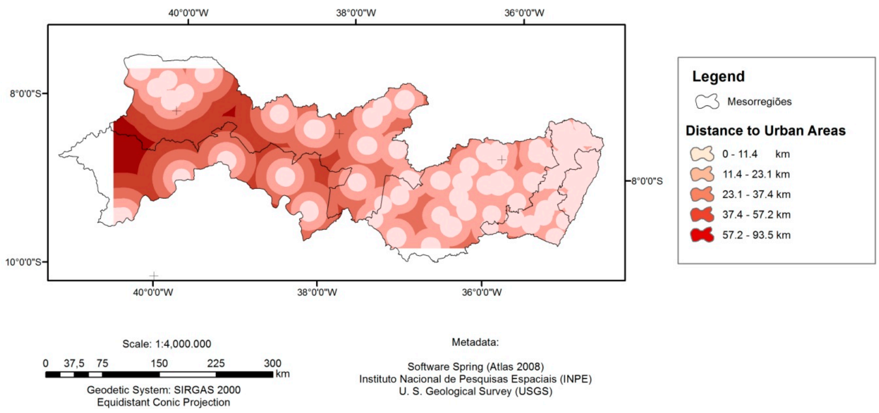
Figure 8. *Cont.*



(**e**)



(**f**)



(**g**)

Figure 8. (**a**) Map of the Direct Solar Irradiation; (**b**) Map of Terrain Slopes; (**c**) Map of Agricultural Potential of the Soils; (**d**) Map of the Distances to Power Lines; (**e**) Map of the Distances to Water Resources; (**f**) Map of the Distances to Main Roadways; (**g**) Map of the Distances to Urban Areas.

Generally, the State of Pernambuco presents high levels of direct normal irradiation, ranging from 3.8 to 5.8 kWh/m^2·day, with highest levels (5.4–5.8 kWh/m^2·day) located in the mesoregion of the Backlands and in isolated areas of the São Francisco Mesoregion. The gentler slopes (0–2%, and 2–4%) are also found in these mesoregions, mostly in the areas located on the banks of São Francisco River.

Regarding the agricultural potential area, the state has multiple areas of unfavorable potential, especially in the mesoregions of Agreste, Backlands and São Francisco. Regions with agricultural potential of regular and regular to restrict classes are found in the mesoregions of Backlands, São Francisco and, in smaller portions, in the Agreste, Forest Zone and Metropolitan Recife Region. The restrict and restrict to unfavorable potential areas are mostly found in the Agreste of Pernambuco.

Maximum distances of 7 km to the power lines are noticeable in the State in all its mesoregions. However, larger distances to the power lines (above 40.8 km) are in those sites where there is the absence of such lines, especially in the extreme west of the state, and in its central region, in the border region between the Backlands and São Francisco.

Greater distances to water resources (above 39.0 km) are found mainly in the Agreste and São Francisco region (extreme west of the State). In contrast, smaller distances (0–7.8 km) are seen in all mesoregions of the State, especially in the São Francisco Region, where the São Francisco River is, and the Forest Zone and Metropolitan Recife mesoregions, which offer several water sources.

In general, maximum distances of 10 km to the main roads are predominant in the State and reach all the mesoregions. The greater distances for this layer (above 15.0 km) are observed in the Backlands, Agreste and São Francisco mesoregions.

Regarding to the distances to urban areas, the greater distances (above 57 km) are mostly located in the extreme West of the State, borderline between the Backlands and the São Francisco mesoregions. However, smaller distances (0–11.4 km) are found in all mesoregions of the State, especially in the Metropolitan Recife mesoregion.

- Restrictions

The restrictions or negative indicators restrict alternatives depending on the activity evaluated. In this study, the restrictions relate to those areas which activities or occupation must be preserved and controlled, such as, Conservation Units of Sustainable Use and Full Protection, in state and federal scope; Remnants of the Atlantic Forest; Indigenous Territories; Quilombo Territories; High Agricultural Potential Areas; Urban and Urban Expansion Areas of the municipalities with population greater than 25,000 inhabitants; and Water Bodies (Figure 9).

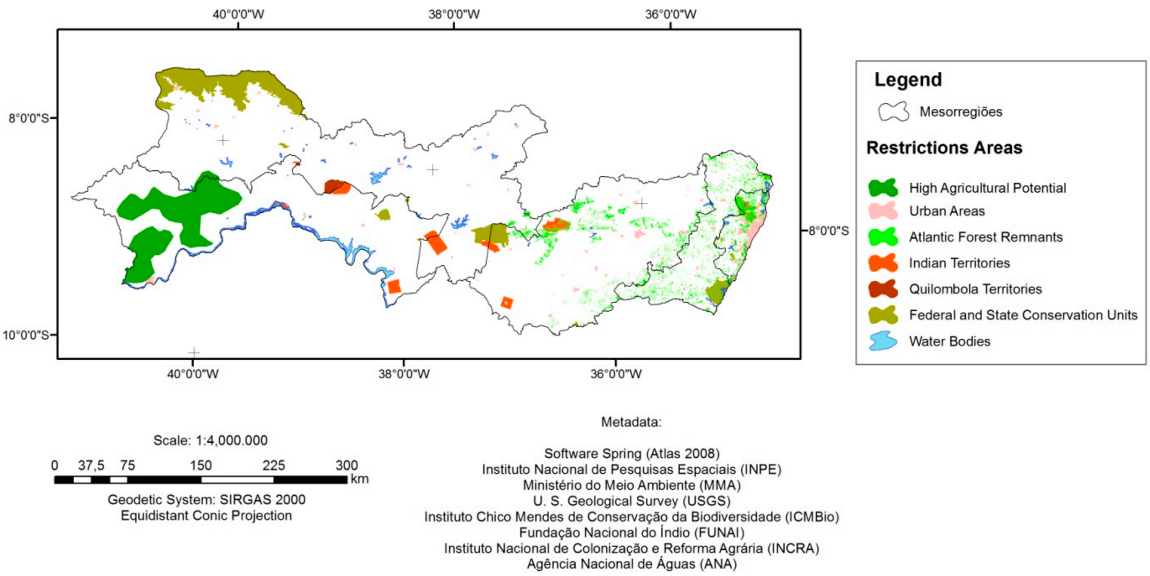


Figure 9. Map of the Restriction Areas of the State of Pernambuco.

The restriction areas considered in this study totalize 26,554.78 km^2 of the State territory and are located in all mesoregions of the State.

4.3.3. Definition of the Decision Rule and Model Consistency Calculation

To achieve the study objective, a decision rule was establishment for each study scenario (Table 5). In Scenario 1, for example, the Climatic criteria were considered as the most important decision rule, followed by the Topographic, Environmental and Location criteria were defined, sequentially.

Table 5. Presentation of Decision Rules for each Study Scenario.

Scenario			Decision Rule
Scenario 1	Order of Importance	↑	Climatic Topographic Environmental Location
Scenario 2	Order of Importance	↑	Climatic Location Topographic Environmental
Scenario 3	Order of Importance	↑	Environmental Climatic Topographic Location

Once established the decision rule for each scenario, the pairwise comparison between the criteria was performed in each scenario, using the Saaty's Fundamental Scale. After the definition of the pairwise comparison matrix, the standardization of its elements was performed, starting from the Mean of Normalized Columns, to estimate the priority vectors (w_j). The estimated weight values for the criteria in each scenario are presented in Table 6.

Table 6. Estimated Weighs for the Criteria of the Study.

Scenario	Estimated Weights (%)
Scenario 1	Climatic (46%) Topographic (29%) Environmental (16%) Located (9%)
Scenario 2	Climatic (46%) Located (31%) Topographic (16%) Environmental (7%)
Scenario 3	Environmental (46%) Climatic (27%) Topographic (18%) Located (9%)

With the achievement of the priority for the criteria, an evaluation of the model consistency was performed to verify the transitivity of the judged values. The Consistency Ration (CR) calculum was performed, as well as the Random Consistency Index value equivalent to $n = 4$ (order of the matrix). The values found for the higher eigenvalue (λ_{max}), the consistency index of the judgments (CI) and the consistency ratio (CR) for each scenario of the study are shown in Table 7.

Table 7. Higher Eigenvalue (λ_{max}), Consistency Index (CI) and Random Consistency Index (CR) values for the Criteria of the Study.

Scenario	λ_{max}	CI	CR
Scenario 1	4.045870784	0.015290261	0.016989179
Scenario 2	4.108684635	0.036228212	0.040253569
Scenario 3	4.088439432	0.029479811	0.032755345

As the CR value was smaller than 0.10 (model request) in all scenarios of the study, the estimated values for the criteria were confirmed as consistent.

With all of the criteria hierarchically organized, the entire process of obtaining the vectors of the priority and evaluation of the consistency was performed for the sub-criteria, in each scenario. The final weights of those as well as the values for do λ_{max}, CI and CR are presented in Table 8.

Table 8. Sub-criteria Weighs and Higher Eigenvalue (λ_{max}), Consistency Index (CI) and Random Consistency Index (CR) values.

Scenario	Sub-Criteria Weights (%)	λ_{max}	CI	CR
Scenario 1	Solar Radiation (42%) Slope (26%) Use of Soil (18%) Dist. to Power Lines (5%) Dist. to Water Resources (4%) Dist. to Main Roads (3%) Dist. to Urban Area (2%)	7.12523894	0.020873158	0.015812998
Scenario 2	Solar Radiation (47%) Dist. to Power Lines (14%) Dist. to Water Resources (13%) Dist. to Main Roads (10%) Dist. to Urban Area (9%) Slope (4%) Use of Soil (3%)	7.21056631	0.035009438	0.026586656
Scenario 3	Use of Soil (40%) Solar Radiation (22%) Slope (20%) Dist. to Power Lines (7%) Dist. to Water Resources (5%) Dist. to Main Roads (4%) Dist. to Urban Area (2%)	7.05681448	0.009469081	0.007173547

With the CR value less than 0.10 (model requirement) in all the scenarios in the study, the estimated values for the sub-criteria are also confirmed as consistent.

4.3.4. Sites Suitability for the Insertion of Solar Thermal Power Plants

The first stage of the process to determine the suitability of the sites was the standardization of the spatial data related to the positive indicators. The process was performed using the fuzzy sigmoidal membership function, because according to [23], the use of this function associated to a set of control points, allows properly representing the period in which the effect of the standardized value in the final result is more effective. An illustration of the fuzzy sigmoidal membership function is presented in Figure 10.

For the normal direct solar radiation layer, the value 5.0 kWh/m^2·day (annual average daily value) was fixed as a control point for the normalization. The appropriated fuzzy sigmoidal function for its representation was the increasing sigmoidal, since the higher the solar radiation indexes, the greater the site suitability will be for the implantation of the projects.

Control points for the terrain slope were fixed in 0% and 5% as several studies indicate the use of 5% of slope as the maximum threshold for the insertion of the projects. The most appropriate sigmoid function to represent the importance of this layer is decreasing sigmoid, once the greater the terrain slope, the smaller is the site suitability for the insertion of projects.

Regarding the distribution lines, the acceptability of the site will be given in function of the smaller distance from these lines to the site of implantation of the power plant. That way, the most appropriated fuzzy function to represent this layer is the decreasing sigmoidal. The control point defined was 15 km (value arbitrated for the application of the methodology) because construction costs of new lines greatly increase with larger distances.

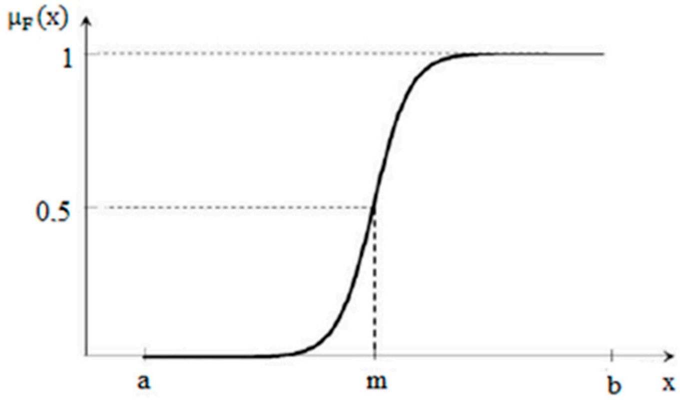


Figure 10. Fuzzy sigmoidal membership function. *U* is a given set Universe. A fuzzy subset *F* from *U* is characterized by a membership function, represented by μF: $U \rightarrow [0,1]$, which associates to each $x \in U$, a real number $\mu F(x)$ defined in the interval [0,1]. This representation allows a gradual transition between the membership ($\mu F(x) = 1$) and the non-membership ($\mu F(x) = 0$) [28].

To avoid large costs with construction of new conduits, it is important that the solar power plant is located as close as possible to water resources. That way, the greater the distances from the solar power plants to water resources are, the smaller the site suitability will be for installation. The fuzzy membership function used for the normalization was also a decreasing sigmoidal, with control point defined at 20 km (also an arbitrated value).

For the roads, the decreasing fuzzy sigmoidal function was also used, since the greater the distance from this parameter to the solar power plant is, the smaller the site suitability will be for projects insertion. The control point for the normalization of the roads was also fixed at 20 km.

For the urban and urban expansion areas, the relation with proximity to the solar power plant is different from other indicators. For these regions, the greatest suitability is given in function of larger distances from this parameter, since it is intended to preserve this environment. Therefore, the fuzzy membership function used for normalization of this indicator was an increasing sigmoidal, with a control point defined at 10 km (arbitrated value), since the greater the distances between urban areas and the solar power plants are, the greater suitability the site will present.

Finally, regarding the use and occupation of soil, it is verified that sites that are not used for agricultural production purposes are the most indicated for solar power plant installation. Thus, the greater the agricultural potential of the site, the smaller is the suitability for solar power plant installation. The fuzzy function used here was the decreasing sigmoidal.

In contrast to the positive indicators that determine continuous surfaces for the site suitability, restrictions present well-defined boundaries, segmenting the classification of the areas as suitable and not suitable for the final purpose. That way, the restrictions present a Boolean format with suitability analysis given by: value 1 when the area is suitable; otherwise, the value 0.

After positive indicator standardization and Boolean representation of restrictions in Boolean format, a Weighted Linear Combination (WLC) was performed among all the sub-criteria of the study. In this technique, the criteria are combined with their respective weights to generate final maps of suitability.

According to [29,30], when there are positive indicators and restrictions to be considered to determine the suitability of the sites, such as the in case of solar thermal power localization, WLC technique is given by Equation (3):

$$I = \sum_{i=1}^{n} w_i x_i \times \prod_{j=1}^{k} c_j \quad (3)$$

where I is the final value of the score; n is the number of positive indicators; w_i is the weight of i positive indicator; x_i is the standardized value of i positive indicator; k is the number of exclusion criteria and c_j is the score (0 or 1) of the exclusion criteria.

4.3.5. Solar Power Plant Location

The identification of suitable areas for the implantation of Solar Thermal Power Plants in Pernambuco was made from the evaluation of the site suitability degrees in the generated scenarios.

4.3.6. Model Validation

As final stage of the model construction, to verify if the developed system corresponded to a pertinent representation of the real world, a validation was performed. According to [13,31], there are several techniques for system validation in GIS, such as pixel-to-pixel validation, visual comparison and analysis, and in loco visits.

In pixel-to-pixel validation, the pixels of a given thematic layer are selected in the resulting map of the model as well as in an existing cartographic model to confirm if their information coincide. In the visual comparison and analysis, the relation between the individually weighted layers and the final suitability of the sites are analyzed to verify the consistency of the weights attributed in the model. Finally, in the in loco visits technique, visits to the defined location in the model are performed to verify its suitability characteristics. In this paper, the techniques used were the pixel-to-pixel validation and visual comparison and analysis.

5. Results and Discussion

To assist the identification of the suitable areas for installation of solar thermal power plants in Pernambuco, first a Scenario Starting Point was generated, where all the indicators (positive and restrictions) were linked disregarding the weights. This scenario is shown in Figure 11. In Figure 11 it is observed that the sites most suitable in the Scenario Starting Point (classes 7–8) were found mainly in the Backlands region (in the center portion, were the cities of Parnamirim, Salgueiro and Verdejante are located). In addition, in Agreste (west and center south portions) and in São Francisco region, sites with those suitability characteristics were found. However, the lower class (class 3) was found in the east portion of Agreste, in the Forest Zone and in the Metropolitan Recife mesoregion.

The region that covers the cities of Parnamirim Salgueiro and Verdejante has, in general, a direct solar radiation index of de 5.0 kWh/m^2·day (annual average), terrain with gentle slopes and unfavorable and regular to restrict agricultural potential sites. The region also has connection possibilities to water resources (Bela Vista dam, Abóboras dam), to 69 kV to 138 kV power lines, to federal and state roads (BR-232, BR-316, PE-460, among others) and distances to urban centers higher than 10 km. However, for the restriction sites, the availability for project installation is verified.

In the lower class of suitability sites in this Scenario (class 3), the direct solar radiation index are around 3.8 a 4.3 kWh/m^2·day (annual average), the terrains has steep slopes (above 5%) and the electric and hydric interconnections for several sites are not present.

Once the Scenario Starting Point analyses were completed, Scenario 1 was generated, and its results are shown in Figure 12.

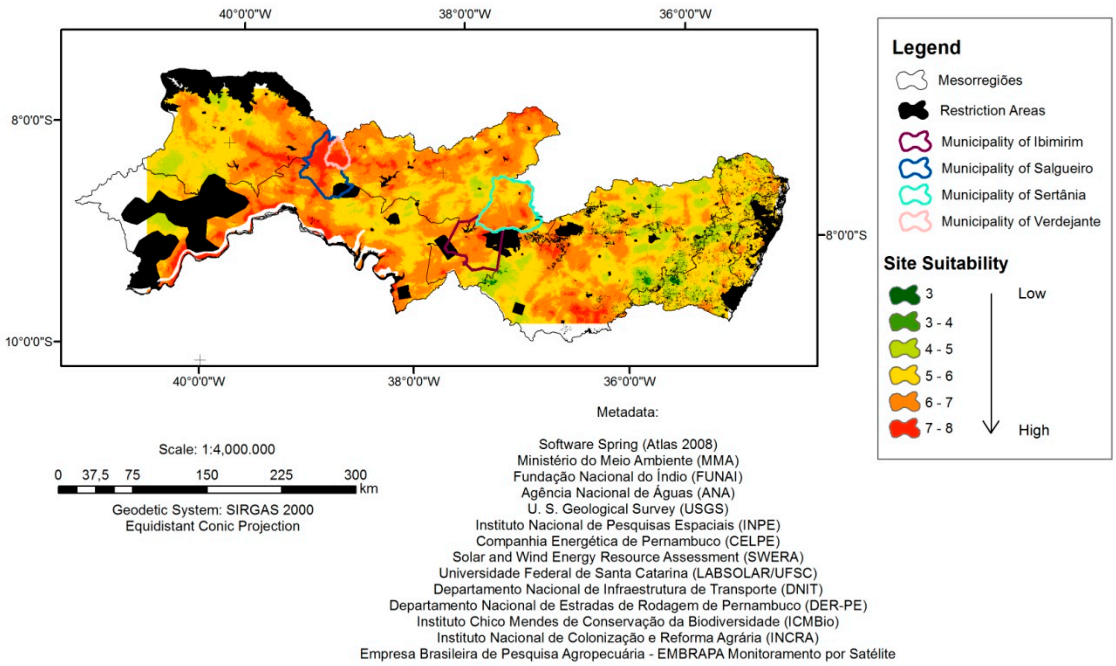


Figure 11. Site Suitability Map for the Installation—Scenario Starting Point.

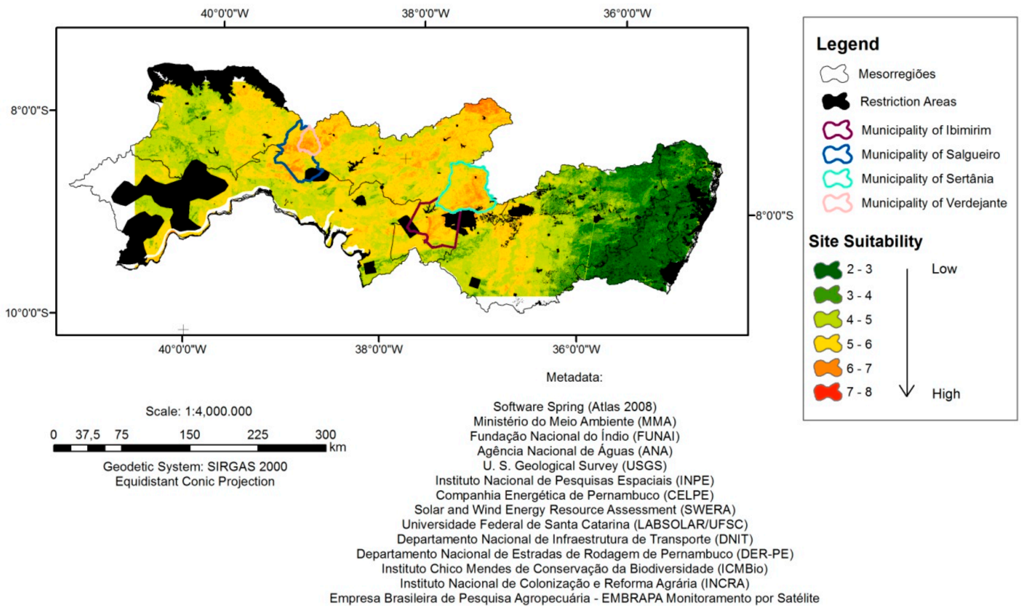


Figure 12. Site Suitability Map for the Installation—Scenario 1.

In Figure 12, the effect of the weightings on the thematic layers for the presentation of the final map in Scenario 1 can be verified. In it, six classes of suitability were also generated.

The region with highest suitability for power plants installation (classes 7 and 8) was found in the Backlands, especially in the cities of Brejinho and Santa Teresinha, were the direct solar radiation indices are superior to 5.2 kWh/m^2·day, annual average, the slope values of the terrain are lower than 4%, the agricultural potential of the soils is unfavorable, and there is proximity to power lines, water resources, and main roads. Distances greater than 10 km of urban centers and area availability for the insertion of the projects are also verified.

The lowest suitability class in Scenario 1 was found in Metropolitan Recife, Forest Zone and Agreste (east portion) mesoregions, where the solar radiation indices are 3.8 kWh/m^2·day to 4.7 kWh/m^2·day (annual average) and the terrain slope is higher than 5%. In these regions, the closest proximities to urban areas are also found.

In Scenario 2, six suitability classes were also generated. The highest class was defined as 7 to 8, whereas the lowest class value is 3, as shown in Figure 13.

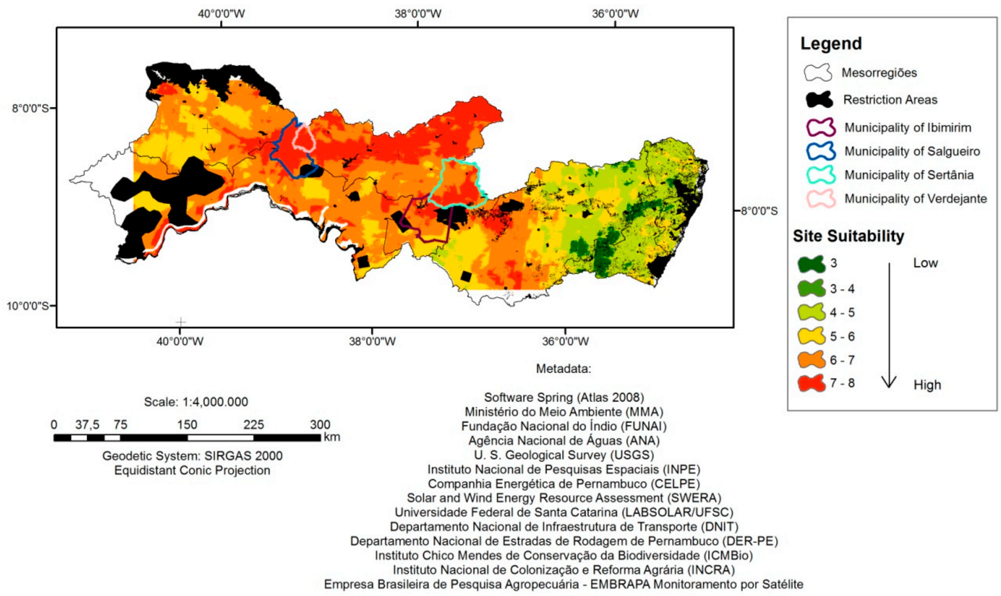


Figure 13. Site Suitability Map for the Installation—Scenario 2.

Referring to Figure 13, the regions with highest suitability were found in the central portion of the Backlands, where the direct solar radiation indices are greater than 5.0 kWh/m^2·day, there is possibility for electric (69 kV to 138 kV transmission lines), road (BR-232, PE-320, among others) and water (Serrinha dam, Boa Vista dam, and other dams without toponymy in the spatial data). The slope is not steep and the agricultural suitability of the soils is usually classified as regular to restrict. In this region, distances greater than 10 km from urban centers and area availability for the implantation of projects are also found.

However, the least suitable sites found are mostly found in Metropolitan Recife, Forest Zone and Agreste mesoregions, where the solar radiation indices are defined between 3.8 kWh/m^2·day and 4.7 kWh/m^2·day (annual average), the declivity values are higher and there is greater proximity to the urban areas considered in the model.

In Scenario 3, six suitability classes were also generated. The highest suitability class (classes 6 and 7) was found in Agreste, in the Backlands and in São Francisco region, whereas the lowest suitability (class 2) was found in the Forest Zone, as shown in Figure 14. As shown in Figure 14, the highest suitability areas in Scenario 3 are characterized for showing direct solar radiation indices greater than 5.0 kWh/m^2·day (annual average), agricultural potential classified as unfavorable and regular to restrict, terrain slope value not as steep and the possibility for connection to electric network (69 kV power lines), hydric system available (Poço da Cruz dam, located in Ibimirim, Serrinha dam in Serra Talhada, among other water bodies) and main roads (BR-232, BR-116, entre outras). Distances greater than 10 km from urban centers are observed. About restriction sites, there is availability for projects installation.

In the Forest Zone mesoregion, where the lowest suitability was found in Scenario 3, the regions present regular agricultural potential, direct solar radiation indices around 3.8 to 4.3 kWh/m^2·day (annual average) and very steep slopes. Regarding the infrastructure elements (hydric, electric and road), the possibility for connection was verified. The region also has settings for the installation of projects, considering the distances to urban areas, but when it comes to soil use, use restrictions due to the presence of Forest Remnants of the Atlantic Forest are observed.

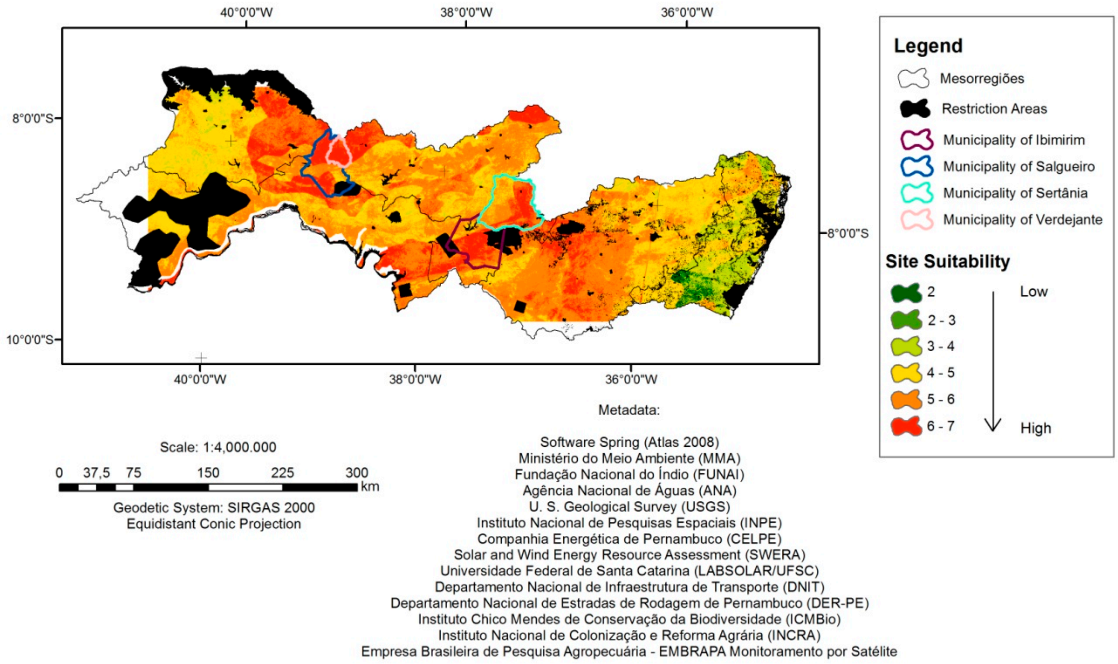


Figure 14. Site Suitability Map for the Installation—Scenario 3.

5.1. Identification of Suitable Sites

Considering all the performed analyses, the following sites in Pernambuco that were suitable for the installation of Solar Thermal Power Plants are established.

1. Municipality of Salgueiro: Salgueiro is inserted in the Backlands mesoregion and has a population of 59,409 inhabitants, according to IBGE. The city had, in all scenarios of the study, high potential for the installation of solar power plants once it remained in the highest suitability class in each scenario presented (suitability class from 7 to 8 in the Scenarios Starting Point, 1 and 2; suitability class from 6 to 5 in the Scenario 3).
2. Municipality of Verdejante: Verdejante has a population of 9430 inhabitants, according to IBGE and is located in the Backlands mesoregion. Verdejante also presented high potential for the installation of solar power plants in all scenarios of the study, remaining in the higher class of suitability in all scenarios—suitability class from 7 to 8 in Scenario Starting Point and Scenario 1 to 2; and suitability class from 6 to 7 in Scenario 3.
3. Municipality of Sertânia: Sertânia is also located in the Backlands of Pernambuco and has a population of 35,207 inhabitants, according to IBGE. Sertânia has high potential for the installation of solar power plants, remaining in the highest suitability class in two scenarios of the study (Scenario Starting Point—classes 7 to 8; Scenario 3—classes 6 to 7) and in the class immediately bellow to the class of highest suitability in Scenarios 1 and 2 (Sertânia presented classes 6 to 7).
4. Municipality of Ibimirim: Ibimirim is located in the Backlands of Pernambuco and has a population of 28,403 inhabitants, according to IBGE. The city remained in the highest suitability class in Scenario Starting Point (classes 7 to 8) and in Scenario 3 (classes 6 to 7); and in the class immediately bellow the class with highest suitability in Scenarios 1 and 2 (classes 6 to 7).

5.2. Model Validation

The process of Model Validation was performed from the validation techniques pixel-to-pixel and visual comparison and analysis. An example of the applied process can be seen in Figures 15 and 16, which show the application to the city of Salgueiro, in Scenario Starting Point.

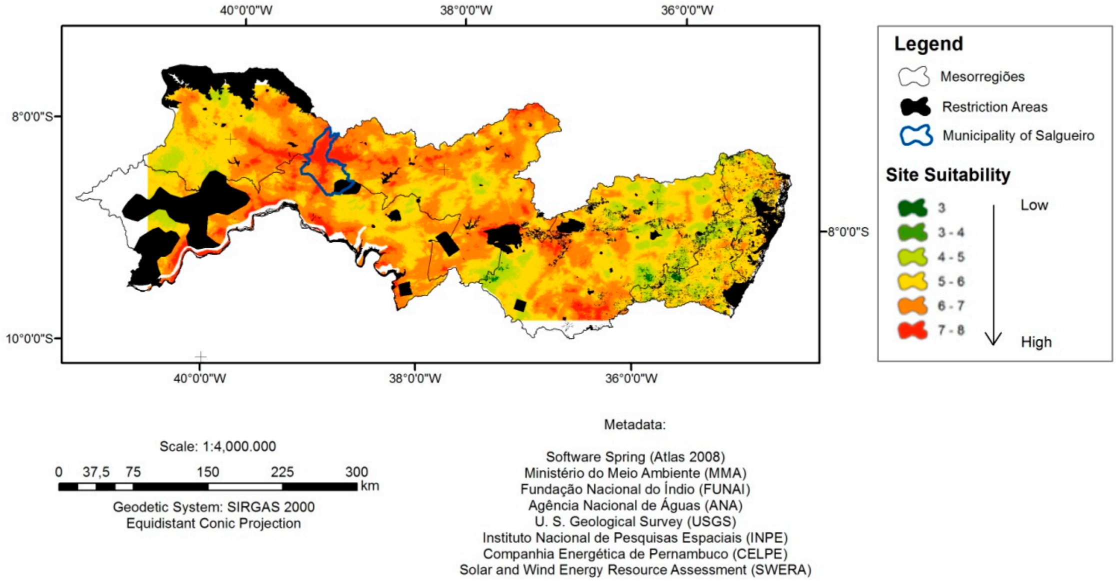


Figure 15. Municipality of Salgueiro in Scenario Starting Point.

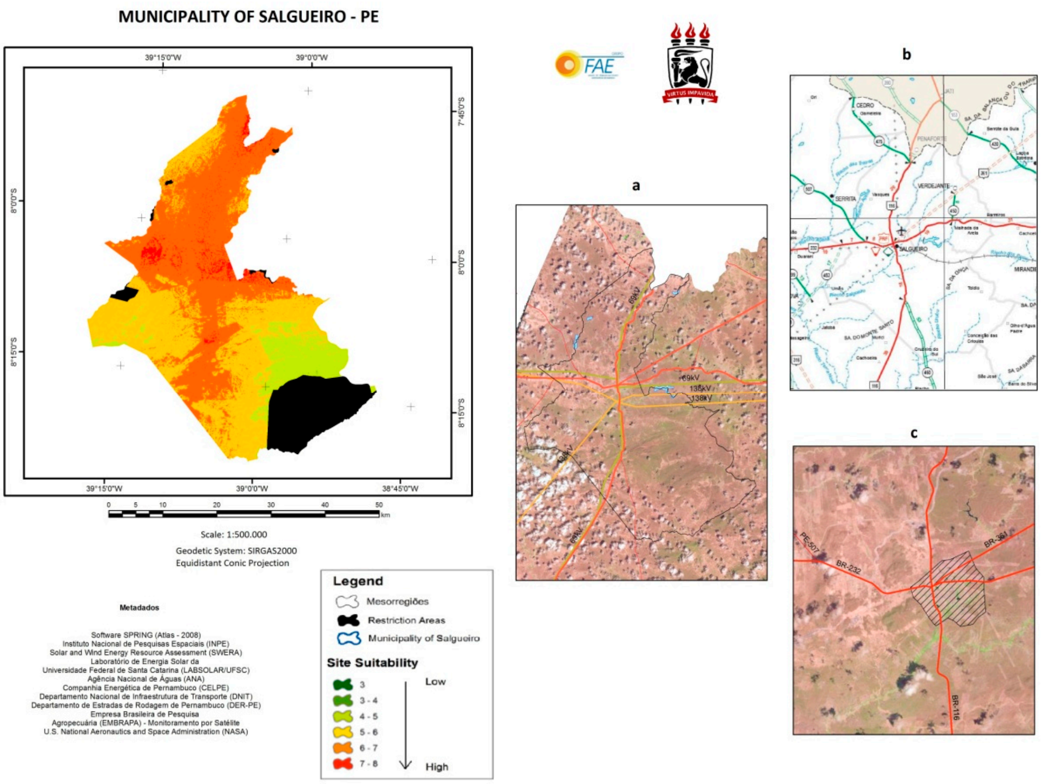


Figure 16. Municipality of Salgueiro in LANDSAT8 images: (**a**) the spatial position of the municipality of Salgueiro; (**b**) multimodal map of the State of the Pernambuco; and (**c**) the spatial position of the urban area of Salgueiro.

The spatial position of the urban area of the municipality was confirmed from the analysis performed. By means of Multimodal Map of the State of Pernambuco, made in the year of 2009 by the Departamento Nacional de Infraestrutura de Transporte (DNIT) (National Department of Transportation Infrastructure), the positional coincidence of the layer of the roads was possible to verify. The toponymy and elements of the neighborhood around this layer was also observed, such as localities, water resources, etc. Because of the spatial resolution of the image, it was possible to check the coincidence of the layer in the power lines.

To evaluate the influence of the weights of the thematic layers in the definition of the final suitability map in Salgueiro, a comparison of the obtained result in Scenario 1 was performed, with the individual characteristics of Salgueiro. In this Scenario, the solar radiation thematic layer, for example, showed values above 5.0 $kWh/m^2 \cdot day$ (annual average) in all its territory. In the central and south portions, the radiation value is set in the range of 5.2 to 5.7 $kWh/m^2 \cdot day$ (annual average), which also favors the installation of solar power plants. In Scenario 1, the solar radiation showed a weight of 42%.

The terrain slope layer shows that the municipality has lands with lower than 5% of steep in the central and north portions. The slope layer was the second in order of importance, presenting the weight of 26%.

Regarding the use of soil, most of the territory of Salgueiro is composed of land with unfavorable potential, which is the class of agricultural suitability that most favors the installation of power plants. This parameter has weight value of 18%, third in order of importance. Finally, regarding the infrastructural aspects for the interconnection of the solar power plant, the municipality has all the elements of infrastructure, disposed on the territorial extension, which allows that the proximity to this means is considered favorable for the installation of the solar power plant.

As the thematic layers presented individually, the most favorable conditions for the location of solar power plant, especially in the central portion of the municipality of Salgueiro, its aggregation, along with their respective weights (final map resultant pixel), returned the generation of high suitability values for the desired purpose.

6. Conclusions

The AHP Method application in the location of solar thermal power plants has shown to be a precise and adequate tool to identify potential sites to locate thermoelectric plants. Based in the performed analyses, Pernambuco showed great potential for the development of these technologies, especially in the Backlands mesoregion, where the most suitable sites for installation were found.

The evaluation of the Scenario Starting Point (reference scenario of the study, where weights were not considered), for example, showed that several Backlands, Agreste and São Francisco environments present high potential for the installation of the solar thermal technology. However, when the weights were considered, especially in Scenarios 1 and 2 where the solar radiation presented more weight (in general, higher than 40%) compared to the other criteria of the study, the most suitable sites were dislocated to the Backlands, mainly to its central, northeast and southeast portion.

In Scenario 3, where the environmental criteria showed the highest percentage compared to other criteria in the study, the highest suitability environments for solar power plant installation were found in a vast area of Pernambuco, characterized by presenting the lowest class of agricultural suitability for the soils (class unfavorable). This vast area of the state covers the Backlands, Agreste and São Francisco mesoregions. Comparing the Scenario Starting Point, the sites with higher potential in Scenario 3 showed greater quantity of available area for installation, reaching regions that obtained lower insertion potential in Scenario Starting Point (lower suitability class).

Validations performed for the municipality of Salgueiro showed that the used models attended to the proposed objective once the spatial position of the thematic layers were confirmed, based on the Cartographic Documents available, as well as the consistency present in the weights assigned individually to the thematic layers and the final Map of site suitability, in which the thematic layers were added along with their respective weights.

It is important to mention that the methodology developed in this study is easily applied to small regions. Obviously, for small regions, the meteorological parameters are approximately constant. Thus, the most sensitive parameters to LCOE are those originating from infrastructural aspects to the interconnection of the power plant (water conduits, transmission lines and main roads distances), from terrain costs and finally from terrain topography (greater or lesser need for land movement). However, it is important to remember that the result of a GIS based analysis depends intrinsically on the thematic layers used. Therefore, for the correct representation of the phenomena of the real world in a small region, high quality spatial data are required.

Acknowledgments: Our thanks to the CAPES Agency for its financial support granted through scholarship.

Author Contributions: Verônica Wilma B. Azevêdo: Literature review, elaboration and standardization of the maps, standardization and analysis of cartographic data, development of the methodology employed and analysis of results. Chigueru Tiba: Driving force, both intellectually and financially, behind the research; elaboration and standardization of the maps; standardization and analysis of cartographic data; literature review; development of the methodology employed; and analysis of results. Ana Lúcia B. Candeias: Literature review, assistance in the analysis of the cartographic data and obtained results.

Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

References

1. REN21. *Renewables 2015—Global Status Report*; Renewable Energy Policy Network for the 21st Century: Paris, France, 2015.
2. Burgi, A.S. Avaliação do Potencial Técnico de Geração Elétrica Termossolar no Brasil a partir de Modelagem em SIG e Simulação de Plantas Virtuais. Ph.D. Thesis, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil, 2013.
3. Tiba, C.; Reis, R.J.R.; Costa, J.C.E.; Azevêdo, V.W.B.; Abreu, J.F.; Alves, M.A.S.; Guimarães, D.P.; Porto, M.A.D. Siting Study of Solar Thermoelectric Plants in the State of Minas Gerais. *JGIS* **2014**, *6*, 423–493. [CrossRef]
4. IEA. *Technology Roadmap—Solar Thermal Electricity*; International Energy Agency: Paris, France, 2014.
5. Bravo, J.D. *Los Sistemas de Información Geográfica en la Planificación e Integración de Energías Renovables*; CIEMAT, Ed.; Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas: Madrid, Spain, 2002.
6. Broesamle, H.; Mannstein, H.; Schillings, C.; Tieb, F. Assessment of Solar Electricity Potentials in North Africa Based on Satellite Data and a Geographic Information System. *Sol. Energy* **2001**, *70*, 1–12. [CrossRef]
7. Mehos, M.; Owens, B. An Analysis of Sitting Opportunities for Concentrating Solar Power Plants in the Southwestern United States. In Proceedings of the World Renewable Energy Conference VIII, Denver, CO, USA, 28 August–3 September 2004.
8. Fluri, T.P. The Potential of Concentrating Solar Power in South Africa. *Energy Policy* **2009**, *37*, 5075–5080. [CrossRef]
9. Charabi, Y.; Gastli, A. GIS Assessment of Large CSP Plant in Duqum, Oman. *Renew. Sustain. Energy Rev.* **2010**, *14*, 835–841. [CrossRef]
10. Azoumah, Y.; Ramde, E.W.; Tapsoba, G.; Thiam, S. Siting Guidelines for Concentrating Solar Power Plants in the Sahel: Case Study of Burkina Faso. *Sol. Energy* **2010**, *84*, 1545–1553. [CrossRef]
11. Clifton, J.; Boruff, B. Assessing the Potential for Concentrated Solar Power Development in Rural Australia. *Energy Policy* **2010**, *38*, 5272–5280. [CrossRef]
12. Purohit, I.; Purohit, H. Techno-Economic Evaluation of Concentrating Solar Power Generation in India. *Energy Policy* **2010**, *38*, 3015–3029. [CrossRef]
13. Arán Carrión, J.; Espín Estrella, A.F.; Aznar Dols, F.; Zamorano Toro, M.; Rodríguez, M.; Ramos Ridao, A. Environmental Decision-Support Systems for Evaluating the Carrying Capacity of Land Areas: Optimal Sites Selection for Grid-Connected Photovoltaic Power Plants. *Renew. Sustain. Energy Rev.* **2008**, *12*, 2358–2380. [CrossRef]
14. Charabi, Y.; Gastli, A. PV Site Suitability Analysis Using GIS-based Spatial Fuzzy Multi-Criteria Evaluation. *Renew. Energy* **2011**, *36*, 2554–2561. [CrossRef]

15. Sánchez-Lozano, J.M.; García-Cascales, M.S.; Lamata, M.T. Decision Criteria for Optimal Location of Solar Plants: Photovoltaic and Thermoelectric. In *Assessment and Simulation Tools for Sustainable Energy Systems*; Springer: London, UK, 2013; pp. 79–91.
16. Sánchez-Lozano, J.M.; Teruel-Solano, J.; Soto-Elvira, P.L.; García-Cascales, M.S. Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) Methods for the Evaluation of Solar Farms Locations: Case Study in South-eastern Spain. *Renew. Sustain. Energy Rev.* **2013**, *24*, 544–556. [CrossRef]
17. Noorollahi, E.; Fadai, D.; Shirazi, M.A.; Ghodsipour, S.H. Land Suitability Analysis for Solar Farms Exploitation Using GIS and Fuzzy Analytic Hierarchy Process (FAHP)—A Case Study of Iran. *Energies* **2016**, *9*, 643. [CrossRef]
18. Sánchez-Lozano, J.M.; García-Cascales, M.S.; Lamata, M.T. GIS-based onshore wind farm site selection using Fuzzy Multi-Criteria Decision Making methods. Evaluating the case of Southeastern Spain. *Appl. Energy* **2016**, *171*, 86–102. [CrossRef]
19. Sanchez-Lozano, J.M.; Henggeler Antunes, C.; Garcia-Cascales, M.S.; Dias, L.C. GIS-based photovoltaic solar farms site selection using ELECTRE-TRI: Evaluating the case for Torre Pacheco, Murcia, Southeast of Spain. *Renew. Energy* **2014**, *66*, 478–494. [CrossRef]
20. Longley, P.A.; Goodchild, M.F.; Maguire, D.J.; Rhind, D.W. *Geographic Information Systems and Science*, 2nd ed.; John Wiley & Sons: Hoboken, NJ, USA, 2005.
21. Mennis, J.; Viger, R.; Tomlin, C.D. Cubic Map Algebra Functions for Spatio-Temporal Analysis. *Cartogr. Geogr. Inf. Sci.* **2005**, *32*, 17–32. [CrossRef]
22. Burrough, P.A.; Mcdonnel, R.A. *Principles of Geographical Information Systems*; Oxford Clarendon Press: Oxford, UK, 1998.
23. Eastman, J.R.; Jiang, H. Fuzzy Measures in Multi-Criteria Evaluation. In Proceedings of the Second International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Studies, Fort Collins, CO, USA, 21–23 May 1996; pp. 527–534.
24. Saaty, T.L. *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*; McGraw-Hill: New York, NY, USA, 1980.
25. Saaty, T.L. *Método de Análise Hierárquica*; Makron Books: São Paulo, Brazil, 1991; 367p.
26. Kelly, B. *Nexant Parabolic Trough Solar Power Plant Systems Analysis, Task 2: Comparison of Wet and Dry Rankine Cycle Heat Rejection*; National Renewable Energy Laboratory: Golden, CO, USA, 2006.
27. Azevêdo, V.W.B. Estudo de Localização de Usina Solar Termoelétrica no Estado de Pernambuco. Ph.D. Thesis, Federal University of Pernambuco, Recife, Brazil, 2016.
28. Zadeh, A. Fuzzy Sets. Information and Controls. *Inf. Control* **1965**, *8*, 338–353. [CrossRef]
29. Mussone, L.; Sala, G. A Method to Evaluate Vehicular Accident Probability by Using Self Organizing Maps. In Proceedings of the CUPUM—7th International Computers in Urban Planning and Urban Management Conference, University of Hawaii, Honolulu, Hawaii, USA, 18–20 July 2001.
30. Zambon, K.L.; Carneiro, A.A.F.M.; Negri, J.C. Análise de Decisão Multicritério na Localização de Usinas Termoelétricas Utilizando SIG. *Rev. Pesqui. Oper.* **2005**, *25*, 183–199. [CrossRef]
31. Pozzobon, E. Utilización de un Sistema de Información Geográfica para la Selección y Priorización de Áreas a Reforestar en los Alrededores de la Ciudad de Mérida, Venezuela. *Rev. For. Venez.* **2003**, *47*, 61–72.