Algorithm for assessing effectiveness of renewable energy facilities placement

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Abstract. Criteria affecting the choice of an optimal option for placing renewable energy facilities with regards to the methodology for calculating the capacity and amount of generated energy have been selected. The features of calculating a spatial data matrix are shown. An algorithm for creating a spatial data matrix for renewable energy resources applicable to the Krasnodar Territory is presented. An algorithm for choosing the best option for placing renewable energy facilities is presented.

1. Introduction
Placement of renewable energy facilities is a complex and multi-level process requiring the analysis of a territory according to various criteria. Firstly, it is necessary to determine the energy parameters, which depend on the potential of a renewable energy source (RES) and technical characteristics of a power plant in order to determine if there is enough energy that can be generated by a power plant for a consumer. Secondly, it is necessary to calculate the economic parameters of the designed installation and compare costs using fossil hydrocarbon fuels and connecting to existing networks. Thirdly, it is vital to determine the legal admissibility of building a power plant in a given territory and the risks associated with the possible alienation of land. All this is difficult to achieve without the use of modern computer technology, especially if it is necessary to compare several sites, or make a choice from several available sources of energy supply.

The creation of a software product similar to the geographic information system (GIS) “Renewable Energy Sources of Russia” [1] and supplemented with a legal component and an expanded economic module to justify financial feasibility as well as having a significantly smaller minimum mapping unit, and the ability to analyze several different sources of energy will allow local governments to receive proposals on options for energy supply to small and medium-sized consumers using environmentally friendly technologies and without additional examinations to determine land plots that are advisable to make available for constructing power plants. Preliminary determination of the land plots allocated for placing renewable energy facilities will make it possible to adjust the master plans in such a way that significant infrastructure and boundaries of the treatment and health areas are guaranteed to be outside the exclusion zones of power plants, which will facilitate the implementation of agricultural activities for small and medium-sized enterprises, and simplify doing small and medium-sized businesses in resort and leisure sectors.

Studies on selecting the optimal location for renewable energy facilities are carried out around the world. Thus, in [2] the energy capacities of power plants in Spain and their optimal location using GIS...
technologies were studied. However, only solar and bioenergy resources were considered. GIS methods for calculating solar and wind farms in Colorado are also used in [3]. In [4], a decision-making model for choosing convenient locations for renewable hydrogen production systems was determined. However, the factors defying binary logic, such as the complexity of the construction work, the distance from the existing infrastructure, etc. were not taken into account. As well, only solar and wind energy sources out of renewable ones are considered. The paper [5], proposes a program determining 50 places in Iran to host a 5 MW solar power plant instead of existing energy facilities based on their electricity production, power factors, and annual greenhouse gas emissions.

In contrast to the studies discussed above, the algorithm should take into account the characteristics of installations and the potential of solar, wind, geothermal and bioenergy resources available in the Krasnodar Territory at the same time, and also consider the factors that are not amenable to binary logic, such as risks of land alienation. In contrast to [6], the algorithm must contain factors undetectable within the framework of binary logic. Compared with the algorithms proposed in [6], an option that uses a subject verification algorithm, verification of the legal admissibility of the installation of a power installation, risk assessment should be added. As well, economic calculation should be improved and adapted to the conditions of the Krasnodar Territory.

Thus, the objective of the study is to create an algorithm for constructing matrices of spatial data and an algorithm for determining an optimal option for placing renewable energy facilities.

The algorithm is targeted at filling the spatial data matrix with data on the values of the parameters that affect the assessment of the efficiency of placing renewable energy facilities. Each cell of the matrix corresponds to a site of 500 by 500 m. Thus, for the Krasnodar Territory, a square matrix of 600,000x600,000 cells has been obtained. Such a large matrix cannot be calculated manually. Consequently, a computer program is required.

2. Input data for creating spatial data matrices

The initial data for determining the efficiency of placing renewable energy facilities is a matrix of spatial data of climatic and geological data, technical characteristics of renewable energy installations, economic characteristics of lands, installations, hooking-up to the existing utilities, etc.

To determine the energy parameters of a solar photovoltaic installation, it is necessary to establish the value of the following environmental criteria: monthly average ambient temperature, monthly gross specific solar energy supply and monthly horizontal site irradiation [7].

For a solar thermal power plant, the same criteria as for a photovoltaic one are important. Thus, we will consider both types of solar power plants together.

To determine the efficiency of a wind farm location, it is necessary to take into account the speed and speed repetition for a given area, as well as the average monthly temperature, since air density directly depends on it [8].

For a geothermal power plant, the main parameters are water temperature and debit of a geothermal well [9].

For a biogas plant, only temperature is an important environmental criterion [10].

Thus, to compile the spatial data matrix, we have selected the following six criteria: average monthly air temperature, monthly solar energy supply, monthly horizontal irradiation, monthly wind speed and availability, temperature and debit of geothermal water wells.

Thus, four criteria necessary to determine an optimal position of renewable energy facilities are as follows: two climatic criteria and two geological ones. All of them are georeferenced and, accordingly, can be represented as a matrix of spatial data.

For our study, we used climatic data, the collection and systematization of which in the Krasnodar Territory is carried out by 30 meteorological stations [11].

To obtain data on the temperature and debit of geothermal waters, maps of geothermal resources of the Krasnodar Territory were used [12].

3. Optimization parameter
Thus, we have several parameters by which the optimal type of energy supply for a given site can be chosen or the optimal site for a selected type of energy supply can be selected. These parameters can be divided into three categories: energy, economic and technical ones.

The main task of optimization is to ensure that the selected energy source satisfies the following conditions:

\[
\begin{align*}
E(x) & \to \max, \\
C(x) & \to \min.
\end{align*}
\]  

(1)

where \(E(x)\) is energy yield, \(C(x)\) is economic expenditures.

In this case, the following boundary conditions exist:

\[
\begin{align*}
E_{\text{min}} \leq E(x) & \leq E_{\text{max}}, \\
0 \leq C(x) & \leq C_{\text{max}}.
\end{align*}
\]  

(2)

where \(E_{\text{min}}\) is the minimum amount of energy required by a consumer, \(E_{\text{max}}\) is the maximum amount of energy required by a consumer, \(C_{\text{max}}\) is the economic expenditures of a consumer.

Thus, we have four boundary conditions.

Variables and unknown variables which energy production and economic costs depend on are as follows:

- Type of energy source
- Type of power plant
- Average monthly air temperature
- Monthly gross specific solar energy supply
- Monthly horizontal platform irradiation
- Monthly wind speeds
- Monthly wind availability
- Temperature of geothermal water wells
- Debit of wells of geothermal waters
- Krasnodar Territory border
- Construction work complexity
- Exclusive legal factors
- Legal risks
- Land value
- Infrastructure

Accordingly, we have the following formula:

\[n > m,\]

(3)

where \(n\) is the number of variables used for optimization, \(m\) is the number of equations concerning boundary conditions.

Thus, the system of equations (2) has an infinite number of solutions. Accordingly, the search for an optimal solution is possible.

4. Algorithm for creating a spatial data matrix

The general structure of an algorithm for assessing the effectiveness of placing renewable energy facilities is presented in Figure 1.
### Figure 1. General structure of the algorithm

The algorithm consists of four blocks that are divided into two sections being the construction of matrices of spatial data and user ones.

The main stages of the first section of the algorithm are as follows (Figure 2):

1. Choosing the type of source data, which can be represented as points, contours, zones.
2. Filling in the required initial data, which include the following: initial and final coordinates of an abscissa axis, initial and final coordinates of an ordinate axis, values of corner points, coordinates of a contours and perimeters intersection, the values at the points of a contours and perimeters intersection, the points of zones and perimeters intersection, values at points zones and perimeter intersection.
3. Filling in the source data, which include the following: coordinates and values of points, coordinates and values at the points of a scale grid and contours intersection, coordinates and values at points of a scale grid and zones intersection.
4. Translating the input data from degrees into cell numbers of the spatial data matrix of for making calculations.
5. Calculating the values of unfilled perimeter points interpolating between the known points.
6. Calculating the values of unfilled points in the array, for this we enter the value of the search radius of the filled points, determine the data points included in the search radius, calculate and fill in the variables for the values in the point.
7. Checking the cells completeness and, if necessary, repeating the filling of spatial data matrix with regards to the already calculated points.
8. Repeating from the 1st point while the user enters data.
9. Combining matrices and exclusive parameters.
10. Creating spatial data matrices.
11. Saving matrices by assigning indices to them.

| Source data | values and coordinates of points | values and coordinates of contours | values and coordinates of zones | spatial matrix scale | power plant specifications | economic characteristics of power plants | economic characteristics of energy resources |
|-------------|---------------------------------|----------------------------------|--------------------------------|----------------------|---------------------------|------------------------------------------|------------------------------------------|
| Matrices of spatial data | energy resources potential | exclusive parameters | construction site suitability | legal risks | economic characteristics of the site | specificity from infrastructure |
| User query | plot coordinates | types of energy resources | technical characteristics | economic characteristics | Экономические характеристики |
| Recommendations | RER installation | traditional installation | legal risks | economic indicators |
Creating spatial data matrices

Filling the coordinates and values

Translating from geographical coordinates to cell numbers

Calculating the values in cells

Transition to a new matrix

Creating spatial data matrices

Creating matrices of exclusion parameters

End

Figure 2. Algorithm for creating spatial data matrices

The first paragraph of the algorithm determines how the initial values will be set, if the initial data are presented in the form of data from meteorological stations, then the initial view will be points, if the resource is maps, then the original data will be isolines, and for the maps of excluding parameters the initial data will be zones.

The second and third paragraphs specify known values for some points of the matrix. Corner points are necessary to fill and if they are not known, the values at these points are calculated manually.

In the fourth paragraph, the matrix is referenced to geographical coordinates, which in the future will benefit calculating the recommendations for a specific part of the Krasnodar Territory.

Then the perimeter points are calculated, for this we use a cycle until the unknown points end. We find the two nearest known points and determine the value at the desired point by linear interpolation.

In the sixth paragraph, we determine the values at all points of the array, with a similar procedure, using not the two nearest points, but all the points in the search radius, which will increase the calculation accuracy. It should be taken into account that there are at least two opposite points between
which it is possible to build a segment and locate the desired point. Otherwise there is a high probability to get an unreliable result.

Then, the filling of all cells is checked and, if necessary, the 6th step is repeated for the remaining unfilled points.

After all the matrices of the source data are created, the calculation parameters are determined, the matrices of the calculated parameters are created, and the matrices of the excluding parameters are combined as follows: if at least one of the matrices for a given cell has a value “0”, which means that for some reason the calculation is not performed at this point or the construction of a renewable energy installation is impossible, then this cell will get the value “0” in the combined matrix.

5. Algorithm for choosing the best option for placing renewable energy facilities

After filling in all x matrices, it is necessary to analyze them. For this an algorithm was compiled (Figure 3):
1. Introduction of user data
   1.1. Selection of the applied energy sources
      1.1.1 Centralized/Decentralized
      1.1.1.1 Traditional (coal / gas / diesel / firewood / peat / electricity / heat)
      1.1.1.2 Renewable (sun / wind / geothermics / biofuel)
      1.2. Choice with / without regard to legal restrictions on land categories
      1.3. Selection with / without regard to legal risks.
      1.4. Choice with / without regard to land value
      1.5. Setting coordinates and plot size
      1.5.1 Validation of the site
      1.5.1.1 If a site is outside the boundaries of the Krasnodar Territory, the message “The site you selected is outside the Krasnodar Territory” should be displayed
   2. Making recommendations
      2.1. Verification of the construction project possibility
      2.1.1. Checking the entered coordinates of the plot on the matrix of exclusive parameters.
      2.1.1.1 If “1” is displayed, then the message “Construction on this site is permissible” must be demonstrated and calculation must continue
      2.1.1.2 If “0” is displayed, then the message “Construction on this site is unacceptable” must be demonstrated and the reasons for the construction inadmissibility must be determine
      2.1.1.2.1 For each matrix of exclusive parameters, carry out a construction validation test
      2.1.1.2.1.1 If “1” is displayed, then move to the next matrix
      2.1.1.2.1.2 If “0” is displayed, then the message “Construction on this site is unacceptable because of ...
      2.1.1.2.1.3 ... matrix name ...” must be demonstrated
      2.2. Risk inferencing
      Check the value of the risk matrix and display the line “The site you have chosen has a high / medium / low disposal risks”
      2.3. Conclusion on the renewable energy potential
      Depending on the selected renewable energy sources, check the value of the corresponding potential matrix and display the line “The site you have chosen has a high / medium / low potential name of the energy source”.
      2.4 Calculate the cost of connection and annual operation of a traditional power plant
      2.5 Calculate the cost of creation and annual operation of a renewable energy installation
      2.6. Calculate the payback period of a renewable energy installation. If traditional installations are chosen for calculation, then it must be calculated relative to the cheapest option of a traditional energy installation, if not, then relative to an average installation.
   3. Derive recommendations: the cheapest traditional installation, the cheapest RES installation, the RES installation with the shortest payback period.

Based on this algorithm, a software product allowing a user to determine the optimal parameters of energy supply, which can significantly reduce the cost of designing an energy supply system, and will also enable to choose the optimal combination of traditional and renewable energy sources is created.
User Algorithm

User data entry

Construction feasibility study

Displaying "Construction on this site is permissible"

Identification of disposal risks

Displaying "The site you have chosen has a …disposal risks"

Calculating the cost of connection to a traditional power plant

Calculating the cost of creation and operation of a renewable energy installation

Calculating the payback period of a renewable energy installation

Comparing different options of energy supply

Displaying "The most beneficial options are …"

Determination of the reasons for the prohibition of construction

Displaying "Construction on this site is unacceptable"

End

Figure 3. User Algorithm
6. Conclusion
Creating spatial data matrices on the energy potential of renewable energy will greatly facilitate the process of calculating the parameters of renewable energy facilities, which will make the use of renewable energy accessible to an average person. To calculate the energy characteristics, it is enough to obtain information about the air temperature, incoming solar radiation, wind speed and frequency, temperature and geothermal wells rate. To obtain data in each cell of the matrix, it is advisable to use computer simulation.

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