Algorithm for assessing the efficiency of siting solar power plants at the enterprises of the agro-industrial complex of Krasnodar region

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Abstract. The features of agricultural energy in the Krasnodar Territory are considered and two main problems are identified: the shortage of generating capacities and the remoteness of low-power consumers from centralized networks, for the solution of which renewable energy sources, including solar energy, can be used. The use of solar power plants at the enterprises of the agro-industrial complex of the region has been substantiated. The importance of automating the process of assessing the territory suitable for the placement of solar power facilities and the features of its implementation are substantiated. Criteria have been obtained that influence the choice of the optimal option for placing solar power facilities, based on the methodology for calculating the power and the amount of generated energy. The features of calculating the matrix of spatial characteristics for renewable energy facilities in the Krasnodar Territory are shown. An algorithm for creating a matrix of spatial data and an algorithm for choosing the optimal option for placing solar power plants are presented. The use of a high-level programming language Python is proposed to implement the created algorithm. The conclusion is made about the possibility of automating the process of assessing the efficiency of the placement of solar power plants in the Krasnodar Territory using modern computing technology in the format of a geoformation application developed in the Python programming language.

1. Introduction
The Krasnodar Territory is an advanced region in Russia for the production of agricultural products, which imposes certain restrictions on the choice of a source of energy supply and the preference for using environmentally friendly energy sources over traditional energy resources.

The use of solar power plants at the enterprises of the agro-industrial complex can solve two main problems of rural energy in the Krasnodar Territory: a shortage of generating capacities, so the generation of electricity in the operating area of the Kuban Regional Dispatch Administration in 2019 amounted to 10,365.6 million kW·h, electricity consumption - 27,628 million kW·h [1], and remoteness of low-power consumers from centralized networks. However, the assessment of the efficiency of the placement of solar power plants is a complex and multi-level process, in which many different criteria are assessed, which is difficult to implement without the use of modern computing technology. It requires the involvement of highly qualified engineers, which significantly increases the cost of creating solar power plants, especially for small and medium-sized consumers.

To reduce the cost of analysing the suitability of a territory for locating renewable energy facilities and conducting a preliminary assessment of their economic efficiency, it is necessary to create an
algorithm for finding optimal solutions, which is based on the matrix of spatial characteristics of the potential of solar energy, climatic and other parameters of the area, as well as the technical and economic characteristics of solar power plants.

Thus, the purpose of the study is to develop an algorithm for creating a matrix of spatial data and an algorithm for choosing the optimal option for placing solar power plants.

2. Literature review

The selection of sites for solar electrical installations is a complex process due to the uneven intake of solar radiation, the level of technical excellence of the used technologies, various safety requirements, economic, environmental and social requirements that must be taken into account in the problems associated with the choice of seats. Various multicriteria methods are used to solve the problems associated with the choice of the location of the power plant.

Multicriteria methods for assessing the efficiency of the placement of energy facilities differ in terms of a set of significant criteria, an approach to determining the optimal solution, selection algorithms, etc.

In a study R.Z. Farahani [2] carried out a comprehensive analysis of the literature, more than 700 sources, 26 of which are dedicated to the placement of energy facilities to solve the problem of choosing a location for various types of objects, while identifying three groups of approaches to solving this problem:

1. The classical approach - a group of methods is to reduce the task of placing an energy object to a single criterion with a universal criterion of efficiency.

2. Pareto-optimal approach - a method in which each selected solution is Pareto-optimal, that is, such that any change in the distribution worsens at least one considered parameter of the system.

3. Approach using evolutionary algorithms - a group of methods in which the search for an optimal solution uses and simulates the processes of natural selection.

Eleni Strantzali [3] carried out a more detailed analysis of the problem of the location of renewable energy facilities in the article in order to study trends in the assessment of investments in RES. The study is based on a representative sample of a literature review of energy planning documents from 1983 to 2014. The paper states that the most commonly used approaches to modeling a power system were Life Cycle Assessment (LCA), Cost Benefit Analysis (CBA), and Multi-Criteria Decision-Making Assessment (MCDA).

In a study by Kirichenko A and Kirichenko E [4], an analysis of the criteria was carried out, which was proposed to be divided into four groups:

- technical criteria;
- economic criteria;
- social criteria;
- environmental criteria.

Some of the given criteria are independent, for example, the cost of the installation, the amount of CO2 emissions, etc., while others are complex, such as the payback period, impact on ecosystems, etc. Thus, the latter can be considered as criteria used to simplify multivariate analysis to one-way analysis.

It should also be noted that there are separate works devoted to the selection of the optimal site for the location of renewable energy facilities. In Russia, the geoinformation system "Renewable Energy Sources of Russia" [5] has been developed, which lists the potentials of wind, solar, geothermal and hydroelectric power in Russia, and also shows the location of RES power plants and their capacity. In the work of Bink J. et al. [6], a study of the energy capacities of power plants in Spain and their optimal location using GIS technologies was carried out; however, only solar and bioenergy resources were considered. Jenck J. [7] also uses GIS methods to calculate solar and wind farms in Colorado. In the work of Dagdugi H. et al. [8], a decision-making model was defined for choosing convenient locations for renewable hydrogen production systems, but factors that do not lend themselves to binary logic, such as the complexity of the construction of works, remoteness from the existing infrastructure,
etc., are not taken into account, as well as, from renewable energy sources, only solar and wind are considered. In the work Besarati S.M. et al. [9] proposed a program to identify 50 locations in Iran to place a 5 MW solar power plant instead of existing energy facilities based on their electricity production, power factors and annual greenhouse gas emissions.

3. Criteria for evaluating the efficiency of the placement of solar power plants

To determine the main criteria affecting the choice of the location site, let us consider what factors determine the energy production of a solar power plant and its economic indicators. 

Electricity generation of a solar photovoltaic plant in the i-th month:

\[ W_i = W_G \cdot F_S \cdot m \cdot \eta_k \cdot \left(1 - \left[\frac{\eta}{120} \cdot (T - T_0)\right]\right) \cdot \eta_{AP} \cdot \eta_{AE} \]

(1)

where \( W_G \) is the gross specific arrival of solar radiation at the site under consideration, kWh/m²; \( m \) is the number of modules in the solar battery; \( \eta_k \) – efficiency silicon solar cell; \( T \) - ambient temperature for a given month, °C; \( T_0 \) - standard and calculated temperatures of the solar cell; \( \eta \) – efficiency solar cell for design conditions; \( \eta_{AP}, \eta_{AE} \) - respectively, the power losses determined by the series connection of the elements and the transfer of energy to the consumer.

The power of a solar photovoltaic power plant for the i-th month is calculated by the formula:

\[ N_{Ei} = E_{AI} \cdot n \cdot F_A \cdot \eta_S \]

(2)

where \( E_{AI} \) is the average monthly solar cell irradiance for the i-th month, W/m²; \( n \) - number of solar cells, \( F_A \) - solar cell area, m².

Thus, in order to determine the energy parameters of a solar photovoltaic installation, it is necessary to set the values of the following environmental criteria: the average ambient temperature by months, the gross specific input of solar energy by months and the average daily irradiance of the horizontal site by months.

Climatic reference books [10], computer databases [11] and geographic information systems (GIS) [12], climate maps and atlases [13], as well as calculations [14] can be used to obtain the indicated climatic data. To compile the matrices of the spatial characteristics of the energy parameters of the renewable energy sources of the Krasnodar Territory, long-term observations of the climate can be used. The collection and systematization of which in the Krasnodar Territory is carried out by 30 meteorological stations [15], as well as the results obtained in the dissertation research of V.V. Butuzov [16]. Climate reference books and paper maps of RES resources are still the main source of climate data, but most of them have not been adjusted for decades. Computer databases and electronic maps of energy resources of renewable energy sources (RES), for example, the Russian GIS RES [17] or the American NASA SSE [18] have too large scale of 1°x1°. This is 1.23 million hectares, thus, over the entire area there will be only 9 complete squares in the Krasnodar Territory, which will not allow an adequate analysis of the efficiency of the placement of renewable energy facilities. Therefore, in those cases where it is possible, the data of meteorological stations and data obtained for the territory of Krasnodar Territory by local scientists should be used to construct the matrix of spatial characteristics [15, 16].

In addition to climatic data, when assessing the efficiency of the placement of power plants, economic factors should be taken into account, such as the cost of the solar power plant itself, the cost of additional equipment and installation, the cost of the land plot required to locate the power plant, the cost of traditional methods of energy supply, etc., as well as legal and technical factors affecting the placement of the power plant.

To obtain information on the cost of power plants, it is necessary to monitor the market, collecting information from the main Russian manufacturers and suppliers of power equipment.

To estimate the value of a land plot, you can use online cadastral maps.

To obtain information on the legal and technical feasibility of construction, it is necessary to collect data on exclusion factors such as land use, geological data, etc.
4. Algorithm
For the simultaneous consideration of all the above factors, it is necessary to create a specialized software product, the algorithm of which consists of two sections. The first section is aimed at structuring the initial data and presenting them in a form convenient for further analysis. The second section is devoted to the direct assessment of the efficiency of the placement of solar energy facilities in the Krasnodar Territory.

Climate and exclusion data are processed using the algorithm shown in figure 1 to generate spatial matrices.

In the first block, the known values of the parameter for specific points are set, for example, the average ambient temperature by months, the gross specific arrival of solar energy by months and the average daily irradiance of the horizontal site by months, etc., obtained from meteorological stations of the Krasnodar Territory and from the works of regional scientists. In the second block, the matrix is linked to geographic coordinates, which in the future will make it possible to calculate recommendations for a specific section of the Krasnodar Territory. In the third block, the values are determined at all points of the initial data matrix.

After all the matrices of the initial 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. To collect information on the value of a land plot, a program for polling the online cadastral map of the Krasnodar Territory is being created, and to obtain information on the cost of power plants, an aggregator program collects information from the main Russian manufacturers and suppliers of power equipment. After filling in all the matrices and obtaining economic data, the second algorithm is performed (fig. 2), aimed at processing the initial data and making recommendations on the use of solar energy in the area of interest.

**Figure 2.** In this case simply justify the caption so that it is as the same width as the graphic.

Based on this algorithm, a software product is created that will allow the user to determine the optimal parameters of power supply, which can significantly reduce the cost of designing a power
supply system, and also allow choosing the optimal combination of traditional and renewable energy sources.

To create a software product, a high-level programming language Python was chosen, since it, due to plug-in libraries, allows not only creating and analysing large data sets, but also visualizing in the form of geographic information maps and applications.

5. Conclusion

Thus, the creation of a software product for assessing the location of solar power plants in the Krasnodar Territory will greatly facilitate the process of calculating the parameters of renewable energy facilities, which will make the use of solar energy available to consumers of any scale. The proposed algorithm solves the problem of choosing the economically optimal type of power supply, and the use of the Python programming language allows the indicated software product to be implemented.

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