Analysis of multivariate assessment methods for effective location of renewable energy facilities

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Abstract. The article emphasizes the importance of a method for assessing the efficiency of power plants based on renewable energy sources. The key criteria of the main multivariate models were analyzed and prioritized. The main current methods including those using fuzzy logic were studied. The technical, economic and legal characteristics that maximize the choice of the optimal methodology for assessing the effectiveness were identified. The method was selected on the example of Krasnodar Territory.

1. Introduction
The development of the agricultural industry is associated with an improved technology of growing and processing products and increased power supply of agricultural enterprises. The use of power plants using renewable energy sources can provide agro-industrial enterprises of Krasnodar Territory with cheap energy. Power plants based on renewable energy sources can be used provided that there is a method for assessing their efficiency which must take into account many criteria whose influence cannot be expressed in physical terms, which complicates the process of choosing the location of power plants using renewable sources energy.

Single-criterion methods are often based on one of the parameters, such as the value of the gross potential of the energy resource, the cost of equipment, construction and operation of the power plant, etc. This approach was popular before active implementation of computer calculations for the design and calculation of energy facilities. It can be used to approximate the feasibility of location of the designed power plant or economic benefits of already existing plants.

Multivariate models have become widespread due to the increased power of modern computers, since manual processing would take too much time.

2. Literature review
The selection of location for renewable energy plants is a complex process due to the uneven distribution of renewable energy resources, the level of technologies used, various safety requirements, economic, environmental and social requirements that must be taken into account.

Multivariate methods for assessing the efficiency of energy facilities location differ by a set of criteria, an approach to determining the optimal solution, selection algorithms, etc.

In the work “Multiple criteria facility location problem” [1] R.Z. Farahani analyzed literature on the problem of location choices. More than 700 sources were analyzed and divided into three groups:

1. The classical approach is a group of methods reducing the problem of energy facility location to a single criterion, with a universal criterion of effectiveness.
2. The Pareto-optimal approach is a method in which each decision is Pareto-optimal, that is, any change in distribution worsens one parameter of the system.

3. The approach using evolutionary algorithms is a group of methods searching for the optimal solution and modeling the processes of natural selection.

However, the author proposes to separate the “multi-objective” and “multi-attribute” location problems, while in the “multi-objective” problems, it was proposed to distinguish “bi-objective” location problems which are different from location problems having three or more selection criteria. However, it only 26 literature sources deal with energy issues. A more detailed analysis of the renewable energy facilities location problem was carried out by Eleni Strantzali in the article “Decision making in renewable energy investments” [2]. The article aims to study trends in the assessment of investment in renewable energy sources. The study is based on a representative sample of the literature review of energy planning documents adopted in 1983-2014. The author says 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).

The use of fuzzy logic to solve the problems of multivariate analysis of energy systems is given in L. Suganthi’s “Applications of fuzzy logic in renewable energy systems”, the review presents the main works published in the period from 1995 to 2015 [3]. However, in the Russian-language literature, there are no reviews on the classification and use of multivariate analysis methods for the energy sector.

3. Criteria
The classification of methods for determining the effectiveness of renewable energy facilities location should begin with an analysis of the criteria.

Figure 1. Criteria Application frequency distribution.
All the criteria can be divided into four groups:

- Technical criteria;
- Economic criteria;
- Social criteria;
- Environmental criteria.

The distribution of criteria is presented in Figure 1 [2]. Some of the criteria are independent (cost of installation, the amount of emissions of CO2, NOx, etc.), while others are complex (payback period, impact on ecosystems, etc.). Thus, the latter can be considered as criteria used to reduce the multivariate analysis to the univariate one.

4. Methods of multivariate analysis of territories to assess the effectiveness of energy facilities location

There are different methods of a multivariate analysis. The ratio of frequency of their use is shown in Figure 2.

The classic approach distinguishes between a LCA life cycle analysis [4] and a cost-benefit analysis of CBA [6].

The LCA method is based on the analysis of the impact of the life cycle of a power plant on the environment.

The CBA method is based on the translation of all relevant criteria into the monetary equivalent of costs and benefits. The advantage of this approach is understandable and easily interpreted results.

The Pareto-optimal method is one of the central concepts of modern economic science [7]. According to this method, a compromise solution is chosen between mutually affecting criteria.

The methods of a multivariate analysis are a group of methods including the analytical hierarchy process (AHP) [8], ranking methods: ELECTRE [9] and PROMETHEE [10], the method of order preference similar to ideal TOPSIS solutions [11], the multifunctional theory of utilities MAUT [12], the method of pairwise ranking of all possible alternatives PAPRIKA [13], etc.

![Figure 2. Frequency distribution for multivariate analysis criteria.](image)

The AHP is a widely used MCDA method in which pairwise comparisons of criteria are carried out using numerical values on an AHP scale from 1 to 9.

The ANP is generalization of the analytic hierarchy process based on the pairwise comparison using networks.

The method of Transformation and Elimination of Choices (ELECTRE) is an analysis of the dominance relationship between alternatives. The main concept is to build a hierarchy of solutions using pairwise comparisons of alternatives for each criterion.

The method of organizing preference assessment (PROMETHEE) uses the principle of leading evaluation to rank alternatives. Like the ELECTRE method, it also performs a pairwise comparison of alternatives to rank them according to a number of criteria.
The method of a preference order by the similarity with ideal solutions (TOPSIS). This method has been developed as an alternative to ELECTRE. The alternative should have the shortest distance from the negative ideal solution. The method assumes that each attribute has a monotonously increasing or decreasing utility. This makes it easy to find ideal and negative ideal solutions. Thus, the order of preference for alternatives is determined by comparing Euclidean distances. An ideal alternative has the best level for all criteria, while a negative ideal is one that has all the worst criteria.

The theory of utilities with several attributes (MAUT) chooses alternatives in the form of a utility function determined for a set of attributes. The utility value can be determined by defining utility functions with one attribute, followed by checking conditions that depend on the utility, and deriving utility functions with several attributes.

Ranking of All Potentially Possible Alternatives (PAPRIKA) is a multi-criteria decision-making or a collaborative analysis method based on the relative importance of the criteria or attributes that are of interest to the decision or choice made by the pairwise comparison (ranking) of alternatives.

Models based on fuzzy logic can be used to assess the effectiveness of renewable energy facilities location. Fuzzy logic deals with reality, parameters whose value is approximate and has language rather than clear values. Fuzzy logic processes the concept of truth, which fluctuates between completely true and completely false (0–1). The theory of fuzzy sets uses the concept of belonging to fuzzy sets, while the theory of probability uses the concept of subjective probability.

Models based on fuzzy logic can vary from the simplest to the most complex. The distribution by application frequency is shown in Figure 3.

![Figure 3. Frequency distribution of multivariate analysis criteria using fuzzy logic](image)

Among the variety of methods of fuzzy logic, there are: Fuzzy models, including the fuzzy Delphi method, fuzzy regression, fuzzy gray prediction, fuzzy AHP / ANP, fuzzy clustering; Hybrid models: neuro-fuzzy, adaptive neuro-fuzzy logical inference systems (ANFIS), fuzzy genetic algorithms (GA), neuro-fuzzy GA, fuzzy expert systems, neuro-fuzzy expert systems, fuzzy DSS, fuzzy DEA, neuro-fuzzy DEA; multivariate decision-making models based on fuzzy logic.

It is possible to single out methods that use geoinformation systems (GIS) which is especially important when solving the problem of renewable energy facilities location.

5. Results and discussion
Given the need for applying the multivariate analysis of the effectiveness of renewable energy facilities location on the territory of Krasnodar, it seems important to identify several key characteristics that have the greatest impact on decision making.

Among the technical characteristics, it is necessary to highlight the resource potential of the site chosen for location, since the amount of generated energy and the estimated income will depend on this value. The resource potential of Krasnodar Territory is described in [14]. Other technical characteristics are the suitability of the site and its infrastructure.
Basic economic characteristics are as follows: the purpose of a land plot, the cost of a land plot, the cost of construction, the service life, the cost of operation. The derivative characteristics are as follows: the cost of production, the energy payback period.

In Krasnodar, the location of power plants by the environmental criterion should take into account specially protected natural areas.

Considering the efficiency of renewable energy facilities location and taking into account the selected criteria, it seems optimal to use an adaptive neuro-fuzzy logic inference system of fuzzy logic and GIS modeling.

6. Conclusion
Attention to renewable energy sources caused the need to adapt decision-making methods to a new field of application. The LCA, CBA and MCDA methods are suitable for this purpose.

Fuzzy logic allows you to adapt to the impossibility of the numerical description of some parameters for assessing the effectiveness of the placement of renewable energy facilities. The GIS modeling allows you to visually interpret the results.

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