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Comprehensive assessment for optimal wind energy use in cottage construction

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Abstract. The article considers the significance of an integrated assessment of the territory to ensure its sustainable development and use of its results when choosing a particular type of alternative energy source for a particular built-up area. RES (renewable energy sources) are types of energy that are continuously renewed in the Earth's biosphere (solar, wind, water, tidal energy, waves of water objects, including water bodies, rivers, seas, oceans, biogas, gas produced by waste products and consumption in landfills of such waste, gas generated from coal mining). The research presents a database of a geoinformation system for the selection and use of RES for housing construction, while multi-criteria evaluation is used in this case to determine the level of sustainable development of the territory of municipalities. The main factors in the selection and introduction of renewable energy sources in housing construction are the natural parameters, i.e. the wind region. Climate-forming factors of territory estimation are presented, as well as their dependence on climatic conditions. This system of territory assessment has been tested on the example of the Rostov Region in area of wind energy. Based on the maps built in ArcGIS ESRI, the territory of the Rostov Region is visually represented and its suitability is estimated for the introduction and development of wind energy source. The developed system is compared with the well-known works in the field of renewable energy sources; the use of GIS technologies reveals the advantages of the authors' system. Detailed conclusions were made based on the results of the study: an integrated system for choosing the location of the RES are adapted for the conditions of the Rostov region.

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1. Introduction

The goal of the energy policy at present is to provide conditions for energy supply to people while preserving the environment. This can be achieved by reducing power requirement and introducing renewable energy resources (hereinafter referred to as RES) into the economy. It is definitely worth highlighting and considering wind power engineering, which steadily holds the world leadership among new technologies of renewable energy resources. The most advantageous regions of Russia from the viewpoint of wind power generation are the territories located far from the main power generating capacities of the country. By analogy, at the level of a constituent entity of the Russian Federation these are the territories of rural settlements remote from urban districts, but having natural and resource potential for the development of this area and for the use of RES [1–3].

The object of the research is the Rostov region territory, because since 2020 the following three wind-power stations were developed and commissioned in Rostov region: Kamensk wind-power station (hereinafter referred to as WPS), Sulin WPS, and Gukovo WPS. On March 1, 2020, Sulin WPS began supplying electricity and power to the Wholesale Electricity and Power Market (WEPM). Active work at sites under the three projects of the Wind Energy Development Fund is currently being carried out in Rostov region. WPSs provide very low average annual specific electrical output (capacity), which is hundredfold or thousandfold lower than that of conventional power plants, however, the use of these capacities in cottage construction is quite reasonable from the point of view of sustainable development, preservation of natural and resource potential of the territory. In addition, one of the goals of the Strategy of Rostov region for the period until 2030 is to stimulate and develop housing construction, including low-rise housing construction, which confirms the relevance of the study undertaken.

The definition of the theoretical and methodological foundations for the development of renewable energy, the placement of RES installations in the context of the use of GIS are in the focus of attention of modern researchers. Foreign energy specialists already have successful experience in applying GIS technologies in the energy industry [4].

In the studies of Russian scientists, the features of the use of GIS in making managerial decisions on the energy development of territories are actively studied. V.L. Badenko analyzes the issues of effective search for RES sites, comparison of sites in the GIS environment in order to make the most effective management decision and meet the requirements of the investor [5].

It should be noted that in some regions of the Russian Federation there are favorable prerequisites for organizing the process of using and developing RES, including the natural and technical resources of the territory [4, 5].

RES in consumers isolated from the centralized electricity grid is a worthy alternative to traditional energy sources. At the same time, the topic of suburban low-rise housing using RES is relevant both in terms of environmental friendliness and sustainable development, as well as in terms of development of the architecture of energy-efficient houses and territorial planning.

According to the Renewable Energy Policy Network for the 21st Century (REN21) [6] tens of millions of people use renewable energy installations today. In rural areas of developing countries, 25 million people use biogas and solar plants for cooking and lighting their homes. It is interesting to note that developing countries account for only about 40% of the total capacity of all power plants based on renewable energy sources, 60% of installations are used in developed countries, which indicates their fairly high competitiveness in relation to other modern energy technologies.

The purpose of the study is to develop an integrated system for selecting a renewable energy source for cottage construction using the example of the Rostov region.

As part of the implementation of this goal, the following tasks have been identified:

– to determine the factors for the use of RES;

– to demonstrate the proposed system for selecting a territory for the use of RES for housing construction using the example of the Rostov region;

– to consider the concept of an eco-house, the pros and cons of this type;

– to demonstrate the practical application of the developed system within the framework of the construction of a low-rise cottage village on the territory of the Rostov region with the use of renewable energy sources [7].

A theoretical toolkit for combining the choice of a place for WPS construction with the choice of a place for cottage estate construction in the territory of Rostov region is presented in the study. The possibility of reducing energy consumption in the sphere of housing construction through the introduction of energy-saving technologies with the definition of their energy efficiency and economic feasibility is considered separately.

2. Methods

The preliminary stage of choosing a place for WPS necessary for low-rise housing construction is creation of a database in the geoinformation system. The scheme of creating a database is presented in Figure 1. It includes collection and analysis of legislative and normative acts, as well as different provisions of strategic documents and territorial planning, climatography and urban development zoning documents.

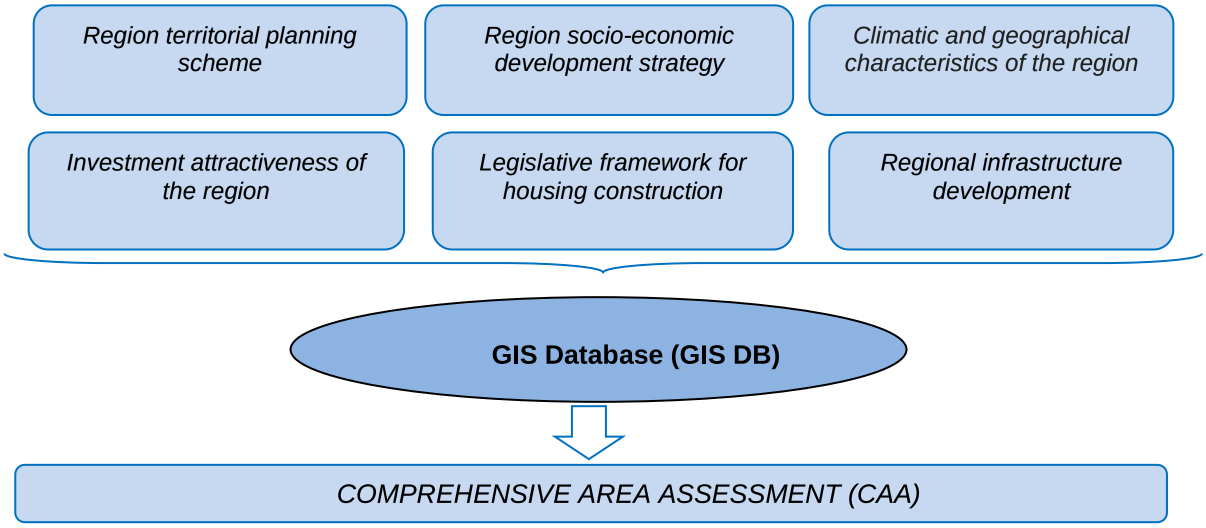

Figure 1. Scheme of creation of the database of the geoinformation system for selection and use of WPS for housing construction.

Collection and analysis of actual information on the region of construction allows creating the database of the geoinformation system of selection and use of WPS for housing construction. Complex assessment of the territory is a set of factor-based cartographic, statistical and tabular materials concerning the state of the territory of the Russian Federation constituent entity, integrated into a single shell, systematized and presented in the form of electronic maps [3,8]. According to the presented scheme, the initial data are systematized and used for creating the information system (GIS DB). The analysis of the legislative base in the sphere of housing construction and use of WPSs (in our case, for Rostov region) is carried out.

All the information collected and analyzed is the basis for making decisions and conducting a comprehensive assessment of the region. In order to select the territory for WPS construction and to construct necessary facilities for its use for energy saving, it is necessary to take into account various factors, both natural and infrastructural and spatial-economic [7]. Therefore, the system of factors is interpreted for the purposes of WPS selection and housing construction and is presented in Table 1. Cartographic, statistical and tabular materials concerning the state of the territory of the Russian Federation constituent entity are interpolated and given in the single score-based system of assessment within the limits from 0 to 1. The assessment sites are the borders of the municipal units of the Russian Federation constituent entity.

Table 1. System of factors of comprehensive assessment of the territory using renewable wind energy sources in housing construction.

Factor group	Factor	Score rating
Natural	Wind velocity	0–1
(climate-forming) factors [9]	Differences in elevation of the earth surface	0–1
Infrastructural factors	Water supply and sewerage	0–1
	Gas supply	0–1
	Transport	0–1
	Communication networks	0–1
Spatial and economic factors	Investment attractiveness of the region	0–1
	Distance to major regional centers	0–1

Electronic maps, which allow visualizing the results of complex evaluation by factors, are created in ArcGIS ESRI environment by filling in attributive tables. As an example, maps concerning climatic and infrastructural factors of the Rostov region territory as fundamental factors in the resource-based constituent of WPS association with the objects of the planned housing construction are presented. The distribution of points in determining the average monthly wind velocity is presented in Table 2.

Table 2. Territory assessment based on the average monthly wind velocity in different areas of Rostov region.

No.	Wind velocity, m/s	Score
1.	0–2.5	0
2.	2.5–3	0.50
3.	3–4.5	0.75
4.	>5	1.00

Nevertheless, it should be noted that the territory of Rostov region is assessed by all factors of complex assessment, and color classification allows visualizing the results obtained (Figure 2).

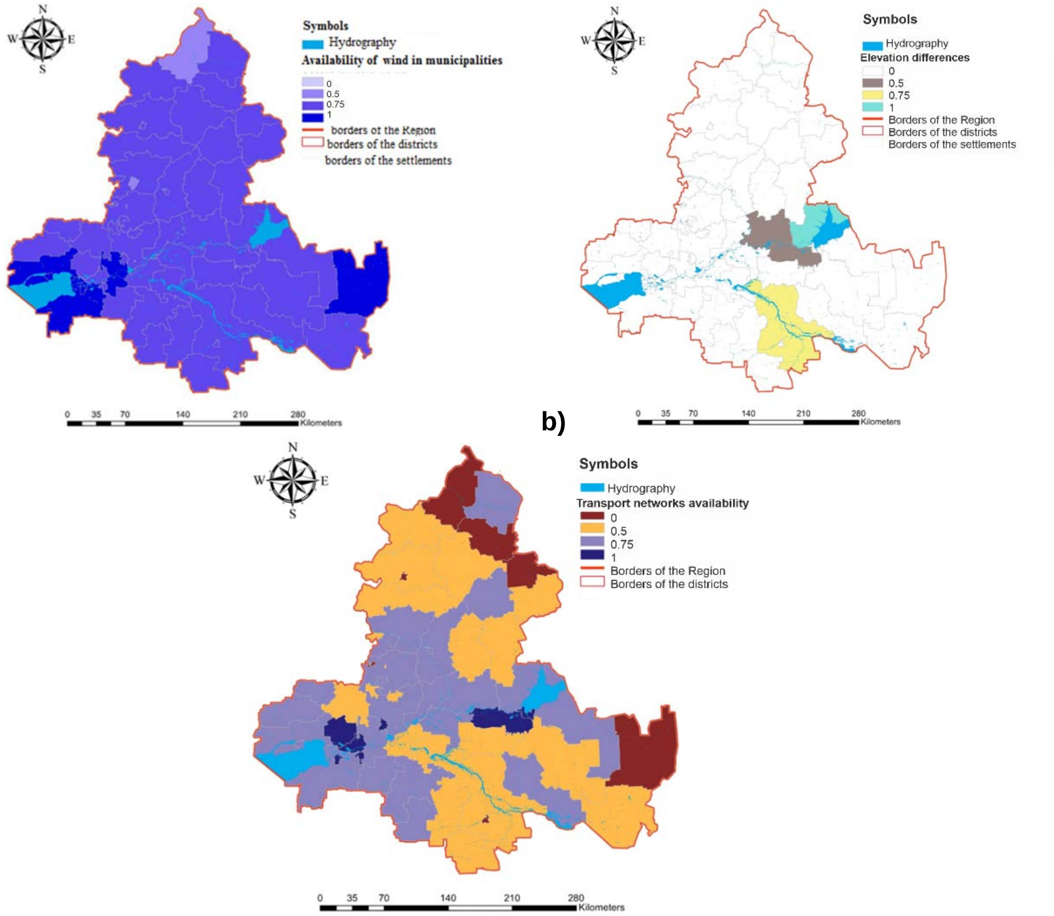

Figure 2. Comprehensive assessment of the Rostov region territory by climate formative factors: a) monthly average wind velocity, b) elevation differences, c) transport networks availability.

It is expedient to use wind-driven generators and wind turbines in districts, municipalities or urban districts, the assessment of the territory of which based on the average monthly wind velocity corresponds to 1 [5, 10]. However, after this assessment, it is required to additionally analyze the territory of the region in terms of the parameter - the average monthly wind speed, because the wind speed >5 m/s is a rather diffuse value.

According to the Territory Comprehensive Assessment Maps (Figure 2), areas having such a high natural resource-based (score – 1) and infrastructure-based (score: 0.75–1) potential are Azov, Aksay and Oktyabrsky areas. The majority of the municipal areas have medium potential for WPS placement. As an example of WPS placement, as well as for the purpose of the construction of low-rise cottage estate on the basis of the comprehensive assessment of the territory of Rostov region, Azov area was chosen.

Within the framework of the study, a system of refined territory assessment has been developed. It allows analyzing the territory of a municipal entity from the point of view of low-rise construction development and application of energy-efficient technologies [6]. In order to carry out a more accurate comprehensive assessment of a municipal entity, it is necessary to determine the assessment factors (TCOT factors). The system of factors has been created for the purpose of WPS selection and low-rise cottage construction. Cartographic, statistical and tabular materials concerning the state of rural settlements of Azov area are interpolated and given in the form of the unified system of assessment within the limits from 0 to 1. The assessed sites are the boundaries of the rural settlements of the Azov area (Table 3).

Table 3. Factors of more accurate comprehensive area assessment.

Factor group	Factor	Score rating
Natural	Wind velocity	0–1
(climate-forming) factors	5–6	0.25
	7–8	0.50
	9–10	0.75
	>10	1
Free areas	Periphery existence	0–1
Low-rise (cottage) construction	Environmental burden	0–1
	The remoteness of the construction area from industrial zones	0–1
	Existence of recreational zones in rural settlements	0–1

An example of the results of the refined comprehensive assessment of the territory of Azov area is shown in Figure 3. The color classification of the factor is the existence of periphery in rural settlements of Azov area of Rostov region and in the urban district of the town of Azov. It should be noted that electronic maps of the refined comprehensive assessment are created for all four factors [11].

To obtain data on the average monthly wind speed in the Azov area, the natural resource potential of the Azov area was analyzed, which is characterized by an average monthly wind speed of 5.5 m/s, but data on wind speed in the region vary significantly. It became known that the average monthly wind speed on the coast of the Azov sea is 7 m/s, and in winter this figure rises to 9.4 m/s (0.75 score in updated estimate). Therefore, according to the main climatic factor, it is worth choosing the coastal settlements of the Azov region [10, 29].

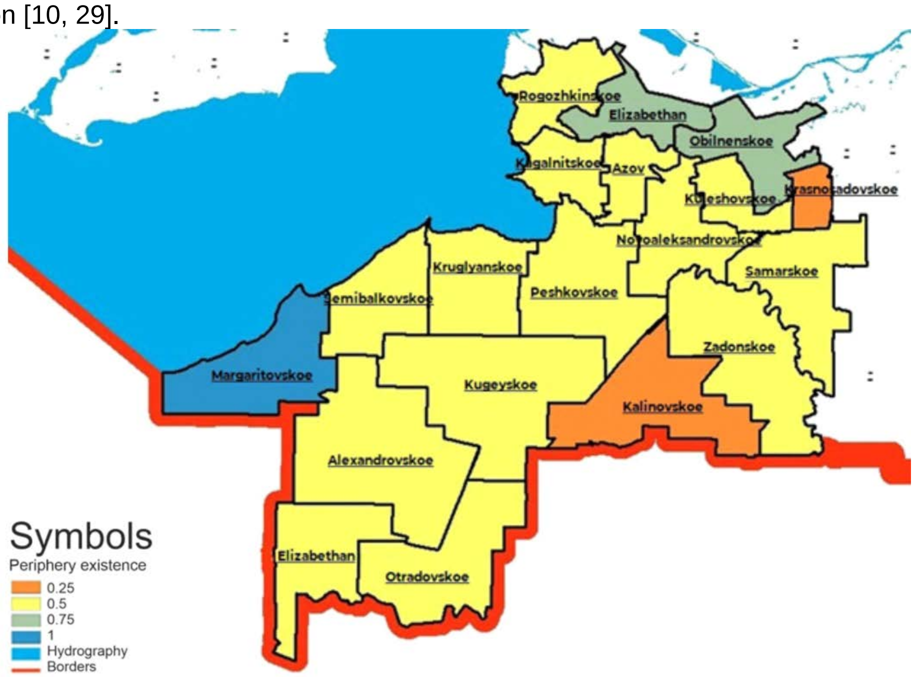

Figure 3. Periphery existence in rural settlements of Azov area of Rostov region and in the urban district of the town of Azov.

Based on the constructed maps, we can conclude that Margaritovskoe rural settlement, located on the coast of the Azov sea, is suitable for the construction of a low-rise cottage village using renewable energy. This conclusion allows choosing a place for the construction of a wind farm. For this purpose, we have analyzed the master plot plan of Margaritovskoye rural settlement, the balance of the territory, and the ecological situation. A plan of measures to improve the ecological situation in Azov area of Rostov region, as well as directly in Margaritovskoye rural settlement has also been developed. The results of implementation of a set of environmental and infrastructure measures in Margaritovskoye rural settlement are shown in Table 4.

Table 4. Results of implementing a set of environmental and infrastructure measures [12].

No.	Factor	Measures	Efficiency (result of improvement)
1	Atmospheric air condition	Creation of sanitary protection zones, purification plants, introduction of technologies with lower emissions, purification of emissions of impurities [14]	Decrease in the complex air pollution index
2	Contamination of soils with heavy metals	Development of systems for processing of production wastes converting such wastes to secondary material resources; replacement of toxic wastes with non-toxic ones; replacement of non-recyclable wastes with recyclable ones	Decrease in soil pollution, decrease in the amount of waste entering the soil
3	Drinking water quality	Development of various types of drainless technological systems and water recycling on the basis of waste water treatment methods	Reduction in the amount of waste water emissions and the concentration of pollutants in them
4	Ecological potential of territories	Withdrawal of industrial enterprises from large cities and construction of new ones in sparsely populated areas with lands hardly suitable or unsuitable for agricultural use; optimal location of industrial enterprises taking into account the topography of the area and the rose of winds [16]	Improvement of the composite environmental quality indicator in the region [15]

Then a project for the construction of a wind farm has been developed. The project is a 90 MW wind-power station (WPS) located in the southwest of Rostov region, on the border with Krasnodar territory (Figure 4).

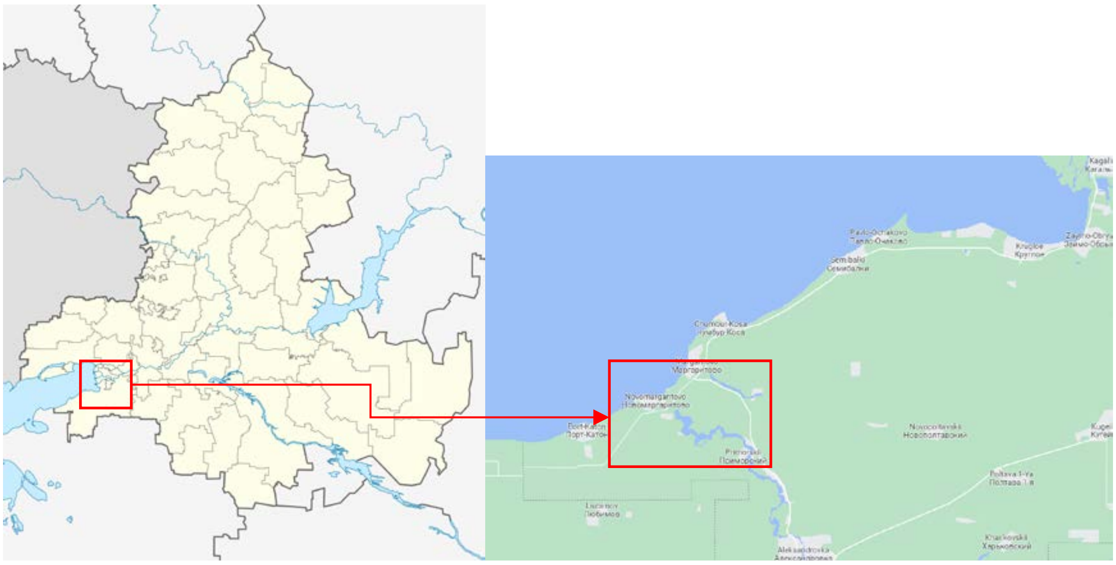

Figure 4. WPS project location.

The land plot selected for the construction of the WPS is located 2 km west of the village of Port-Katon in the territory of Margaritovskoye rural settlement of Azov area of Rostov region. The total area considered for construction of the WPS is 1093 hectares. It is the territory of the former Azov-City gambling zone.

It is assumed that 30 wind turbine generator sets (hereinafter referred to as WTGS) with capacity of 3 MW each, crane bases adjacent to each turbine, temporary construction sites for internal roads, internal power supply network, power substation including a control room and connection to the power grid will be placed. Other types of WTGS can be used to improve the efficiency of WPSs. In this case, the number of turbines can be reduced, while the unit capacity of the turbine will vary between 2.0 and 3.3 MW. In accordance with the feasibility evaluation, connection of the WPS project to the grid is envisaged by connecting it to the existing 35 kV overhead power line, which was constructed for Azov-City gambling zone and is not currently in operation. The overhead power line is led from the eastern side of the WPS project. To connect the wind farm to the electric power network, work on the modernization of the existing power line will be carried out, and new overhead power lines will be constructed.

A project of a low-rise cottage estate in the territory of Margaritovskoye rural settlement of Azov area of Rostov region has been developed. The planning design of the settlement provides for the placement of 320 cottage-type individual houses on the territory of 52 hectares. (Figure 5).

Figure 5. Settlement planning design.

The architectural and landscape design of the settlement has a single style. The cottage estate living conditions will be as comfortable as in the city: gas, water, electricity, central sewerage, individual hot water and heating boilers are provided in each house.

The project envisages the use of 15 types of cottages and 2 types of townhouses.

Each project also has from 2 to 4 variants of facade and interior layout. There are several options for the external design of the house, developed in a single style, which will give the effect of a variety of options for the houses of the settlement, maintaining a single basic set of structures of the house, which facilitates equipment recording and construction. In spite of all variety and plurality of projects, the given approach guarantees that any chosen variant will harmoniously fit in the general architectural concept of the complex. However, there is no single concept for the introduction of energy-saving technologies in the projects of the cottages [17, 18]. Thus, there is another problem at the local level: the choice of energy efficient technologies in cottage construction.

The significant cost of energy efficiency measures allows choosing only those solutions that have a relatively low cost and give maximum benefit from their use. On this basis, the expected efficiency of energy-saving technologies will be calculated by comparing the costs of their installation and purchase with the energy saving from their use, taking into account relevant information on the payback period [19, 20].

Passive energy-saving technologies have been largely successful to date in the energy-efficient low-rise construction in Russia. The main passive energy saving methods used are as follows:

- installation of energy-efficient equipment,
- use of high-tech systems (Smart Home system) [21, 22],
- application of Canadian structural insulating panel construction technology (SIP),
- improvement of the thermal efficiency of building envelopes (heat insulators ISOVER, ROCKWOOL) [23].

Let us consider the main indicators of these energy-saving solutions given in Table 5 and make a comparative analysis in terms of their economic and energy efficiency.

Table 5. Comparative analysis of energy-saving solutions applied in low-rise (cottage) construction.

Energy-efficient measure	Value (cost)	Energy output, kW·h/year	Saving of energy per year, Russian rubles (RUB)	Payback period, years
Energy-efficient equipment	1 541 658 RUB	34000	122 433.1	8–16
Smart Home system	5–7 thousand RUB/m^2	3212	12 000	15–40
Canadian SIP house	20–30 thousand RUB/m^2	15000	54 000	10–20
Multi-comfort ISOVER house	Rise in price 15–18%	11 710	42 156	15–40
Energy-efficient house Green Balance	Rise in price 14.5%	9 125	32 850	15–40

According to the data obtained, the most cost-effective application of energy-efficient measures in low-rise construction is the use of energy efficient equipment. The expediency of using such equipment is determined by the largest amount of energy produced in comparison with other options and energy-efficient measures considered in this paper, as well as by the corresponding economic component achieved by saving energy costs, which is reproduced by alternative sources [24–25].

3. Results and Discussion

The construction of WPSs in the territory of Rostov region has attracted considerable investments, which will increase the workload of logistics centers, as well as provide design, construction, electrical and other organizations and companies with additional work [26]. The technical and economic indicators of the WPS construction project are presented in Table 6.

Table 6. Technical and economic indicators of the WPS construction project.

No.	Name of indicator	Unit of measure	Design value
	Azov wind-power station (WPS)		
	power (capacity)	MW	90
	electric power output	thousand kW*h	442 072
	electric power supply	thousand kW*h	418 556
	Substation 110/35/10kW WPS	MVA	2x63
	Total length of power lines (along the route) / number of lines, including	km	
	High-voltage power lines 110 kV	km/line	121/2
	Cable lines 35 kV WPS	km	1
	Occupied area		133
	Design lands of WPSs	ha	225
	High-voltage power lines	ha	5
	Total cost of construction, according to the limit values of capital costs included in the competitive indicators for the selection of investment projects for the construction of generating projects operating on renewable energy sources for the years 2014–2024	thousand RUB	9 870 300
	Construction duration	month	20
	Number of workplaces at the stage of operation	person	20–30
	Investment payback period	year	15

Nevertheless, it should be noted that the development and implementation of the WPS project in Rostov region will allow diversification of generating capacities without harming the environment.

Comparing the results of the work, one can refer to Badenko's research; the developed GIS RES can be valuable when an investor/user chooses a solution for implementing a project in the field of renewable energy:

- based on the results of the study, an analysis of social, economic and environmental factors in choosing the location of a RES facility was carried out, as well as practical steps or a package (composition) of work within the framework of the implementation of GIS RES;

- development of a decision support system for the placement of renewable energy facilities in the form of an information and analytical geoinformation system "Renewable energy sources of St. Petersburg and the Leningrad region" will determine the limiting factors for the choice of renewable sources, create interactive maps of St. Petersburg and the Leningrad region [27, 28].

However, Badenko does not use climatic factors in the process of optimizing management decisions, which are the main ones in the placement of RES. This validates uniqueness and relevance of the system developed in our study.

4. Conclusions

1. Renewable energy sources (RES) are not developed in the territory of Russia, as the housing stock must meet specific technical requirements to implement RES programs. However, at present the housing stock of the Russian Federation is in unsatisfactory condition. As a rule, the introduction of RES is technically possible in the majority of cases, when it comes to new housing. The factors for the use of RES are determined. We can say with even greater certainty that low-rise cottage construction objects have the best conditions for RES introduction.

2. The demonstrated theoretical toolkit allows for a comprehensive assessment of the territory for the use and construction of wind-power stations (WPS) both at the level of a constituent entity of the Russian Federation and at the level of a municipality combining engineering infrastructure, environmental, planning, natural-resources and spatial and economic aspects. The proposed system for selecting a territory for the use of RES for housing construction using the example of the Rostov region are demonstrated.

3. The development of WPS projects is a promising area of the energy industry worldwide. The production of wind-powered generators is a high-tech industry, the development of which is characterized by attracting large investments. In addition, on the basis of the considered data it is possible to draw a conclusion that the most effective energy saving measure in low-rise construction is the use of unconventional kinds of energy, which replace the use of external energy sources, allowing a building to exist independently. Practically, the concept of an eco-house with the pros and cons of this type are shown in this research in detail.

4. The paper demonstrated the practical application of the developed system within the framework of the construction of a low-rise cottage village on the territory of the Rostov region with the use of renewable energy sources. The method has shown the maximum economic feasibility and has the most useful effect in comparison with other technologies considered in the study.

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