This paper considers the task of ensuring the energy and environmental security of regions under the conditions of shortage of traditional energy resources. The method of expert assessments has been applied to justify the choice of types of acceptable energy resources that provide an increase in the relative energy supply of the territories of the regions.

A list of factors from 6 groups has been devised and compiled that includes 27 indicators characterizing the technological, environmental, and other consumer characteristics of energy resources available for use.

The maximum and minimum values of the indicator scores, the permissible intervals for their change, and the weighting coefficients that assess the importance of the indicator in the list have been determined.

The method of expert assessments is supplemented by a random number generator for the formation of an information field on the values of the characteristics of energy resources and statistical processing of data on acceptable energy resources under the conditions of the considered regions.

A quantitative comparative analysis of available energy resources and technologies based on them was carried out. It is proposed to use the acceptability index and the environmental conservation index as a criterion for the preference of a resource. Index values equal to or greater than 1 indicate resource preference. It is shown that for the base region under consideration, such resources are nuclear, solar, wind, and hydropower.

The method of expert assessments makes it possible to get an objective idea of the acceptability of using a certain energy resource to ensure energy security, taking into consideration its environmental impact in a particular region of the country.

A quantitative comparative analysis of the state of the existing structure of energy resources in the region and their availability has been carried out.

To conduct a comparative analysis of acceptability by indicators and types of resources, a graphical and analytical methodology was used. The reliability of the results obtained was assessed using a concordance coefficient.

The results could be useful for devising projects for the development and ensuring the energy security of the regions in the context of reforms

Keywords: expert assessments, applicability, energy resources, energy security, environmental friendliness, acceptability, environmental conservation index

ASSESSING THE REGION'S ENERGY PROVISION

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1. Introduction

Europe's energy potential, which is far from being fully exploited, lies in the wide variety of landscapes and cultures that have shaped it. The development of mutual assistance and cooperation in various regions of the continent determines the relevance of ensuring the energy and environmental security of the regions.

The availability of reliable sources of energy (thermal and electrical) is a prerequisite for the normal functioning and development of the region.

The work of industry, transport, utilities, and the social area depends on the reliability of energy supply. Energy security is at the top of the list of strategic priorities for planning the economic development of the regions. This requires reliable tools for forecasting the use of promising energy resources. To test the tool, it should be applied to the base territory, where the energy security and environmental safety is of some interest.

The schematic map, shown in Fig. 1, demonstrates a significantly uneven distribution of installed capacities throughout the region [1, 2]. There is a site of dense place-

ment of stations of different capacities in the eastern region and two belts in the direction from the south-east to the north-west of nuclear power plants and hydroelectric power plants along the river.

The remaining regions are practically deprived of energy supply sources, which makes the industrial, transport, municipal and social facilities located on their territory vulnerable.

An important indicator characterizing the energy security of the region is its relative energy supply, depending on the level of industrialization and the size of the territory of the countries. In the European Union (Germany, Italy, France), the security ranges from 0.65 to 0.25 MW/km^2; in the USA, it does not exceed 0.18 MW/km^2; and in Ukraine, Belarus, and Rossi, it does not exceed 0.07 MW/km^2.

Fig. 1 shows that at least 40 % of the territory is not provided by the presence of installed capacities. The green energy facilities created in the last decade somewhat improve the situation. However, some regions are practically not provided with capacities and, therefore, they are characterized by insufficient energy security. The current situation is due to the presence or absence of energy resources in the territories under consideration.

The steps taken to improve the current situation, due to the lack of regional development plans and scientifically based methods for choosing energy resources in accordance with the capabilities of the territories, are, often, opportunistic in nature.

In this regard, the issue of justifying the choice of the type of energy resource to increase the relative energy supply of these territories and, consequently, their energy and environmental safety becomes relevant.

2. Literature review and problem statement

The most common resources fall into two main categories: fossil and non-fossil. An analysis of the current state of fossil fuel resources, their characteristics, and extraction techniques is given in work [3]. This group includes coal, peat, oil, and gas.

About half of all electricity is generated by thermal power [4]. The main sources of primary energy for thermal energy generation are fossil fuels – coal, natural gas and oil. Given the relative cheapness of production, sufficient, to date, reserves, and availability of these resources, they are characterized as non-ecological, generating large amounts of waste, harmful emissions, and damage to nature and ecology during fuel extraction. In addition, large fuel losses in energy generation and the need to transport fuel reduce their benefits [5]. The annual emission of CO_2 by all TPPs of the world is approaching 10 billion tons of carbon dioxide, accounting for about 30 % of all anthropogenic greenhouse gas emissions into the atmosphere of the planet. Combustion products and anthropogenic emission of carbon dioxide accumulating in the atmosphere contribute to the development of the greenhouse effect.

Paper [6] analyzes the possibilities of using non-fossil resources, represented by subgroups of renewable and manufactured resources. Solar, wind, and hydropower form a subgroup of renewable resources. And biogas, household waste, hydrogen and nuclear energy make up a subgroup of manufactured resources.

Work [7] shows that renewable sources have a sufficient resource, and their use favorably affects the environmental situation. In comparison with traditional energy production techniques, they are advantageously distinguished by the absence of obvious negative indicators of an environmental nature, but, in terms of energy safety, their advantages are limited by daily cyclicity and random factors.
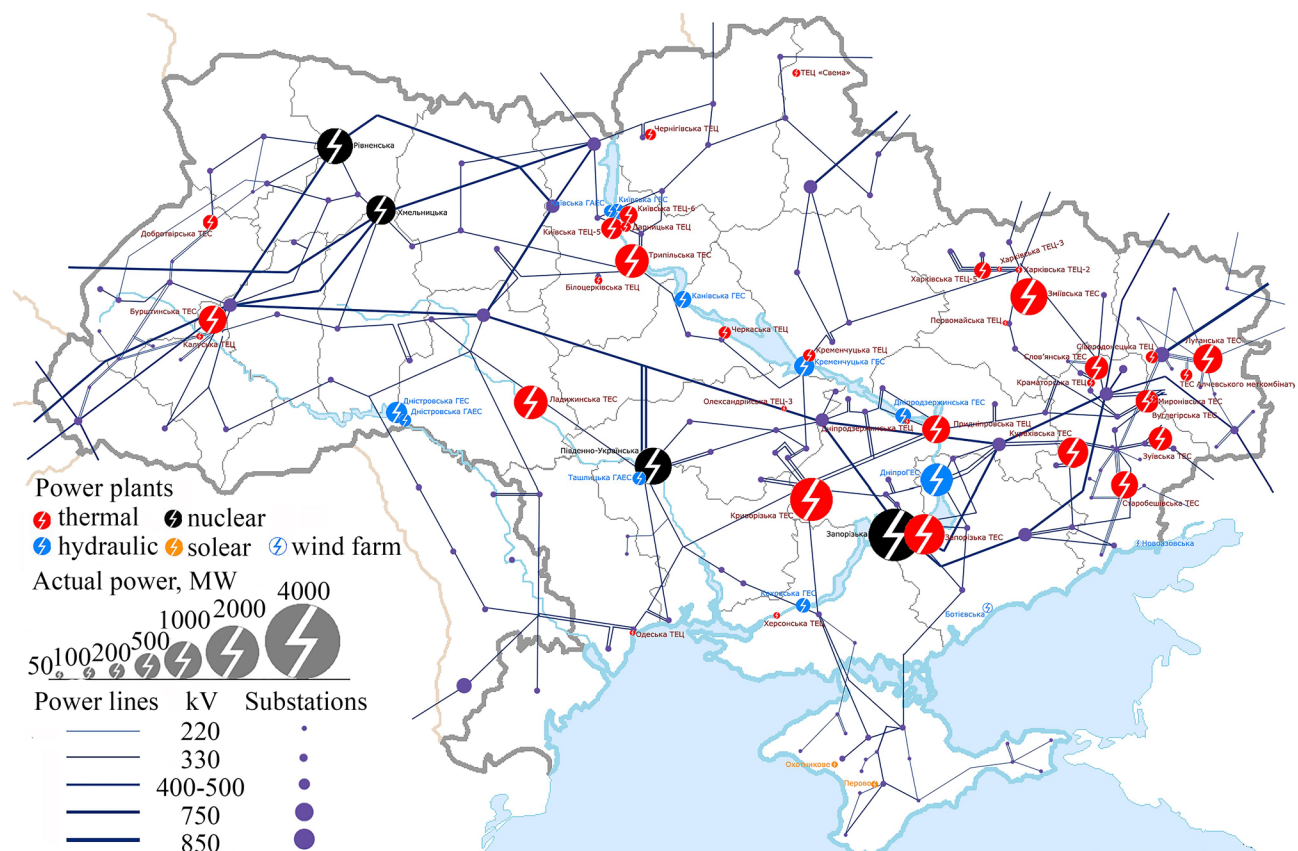

Fig. 1. Distribution of power plant capacity throughout the region

Traditional generation techniques include hydropower engineering, based on the water resources of rivers and the tidal cycles of the oceans. Their relative performance is comparable to TPP but inferior to nuclear power plants. They are characterized by high construction costs, ambiguous environmental safety, and disruption of existing ecosystems.

The current global trend suggests the predominant development of the use of non-fossil resources. The main disadvantages include relatively low, relative to traditional methods, specific capacity. The trend in the development of energy generation with the use of mainly renewable resources is reflected in the Energy Strategies of the regions [8], according to which the share of renewable energy sources in the structure of electricity production by 2025 will be 13 %.

Features of the use of nuclear resources are noted in [9]. The main competitors of nuclear power plants are thermal and hydroelectric power plants. The advantage of nuclear power plants is based on the rejection of fossil fuels, the consumption of oxygen for combustion, thus, the preservation of this and the reduction of the amount of harmful emissions into the atmosphere.

Features of the operation of nuclear power plants are considered in work [10]. The disadvantages of nuclear energy include the consumption of uranium as a resource that needs specific preprocessing, and an increased level of danger in case of design accidents. The functioning of nuclear power plants is accompanied mainly by thermal emissions.

A diverse range of resources requires sustainable methodological support to answer the question posed. About 10 methods for analyzing the functioning of power supply systems in forecasting electricity consumption by regions, considered in [11], make it possible to compare certain aspects of the functioning of systems. It is noted that experimental and technological methods are mainly used while qualitative methods, in particular, the method of expert assessments, are not widely applied.

The indicative method of assessing energy security is the highest priority compared to others. It is based on the comparison of the actual values of security indicators with their threshold values [12]. The need for a set of different indicators in the development of a single assessment of the state of energy security requires the development of a single set of indicators. Estimates based on indicative analysis require the consideration of extensive and heterogeneous statistical information, which makes it difficult to carry out comparative analysis.

An assessment of the potential of individual regions for the use of solar [13] and wind energy systems [14] using combined heat supply schemes [15] seems to be an effective method of justifying the direction of development of renewable energy sources until 2030. The "resource footprint", which correlates all resources with the final consumer of products or services, regardless of their origin, makes it possible to devise, mainly, an economic, rather than a technological strategy for the development of regions. Therefore, its use to justify an acceptable energy resource is limited.

The methodology for assessing the technical condition of thermal power plants, shown in work [16], is more likely to assess the resource of objects, rather than energy resources. The analysis of effective techniques of thermal modernization of thermal power facilities, given in work [17], also does not make it possible to assess the prospects of the resource. Both techniques are based mainly on the analysis of technical and structural indicators of objects, excluding the consideration of operational and environmental characteristics.

The overview of the state of energy consumption in Germany, given in work [18], characterizes only the early decisions taken and, in fact, does not contain elements of comparative analysis.

Qualitative methods, especially the method of expert assessments, make it possible, with sufficient qualifications, to carry out a comparative analysis in order to substantiate the applicability of energy resources, taking into consideration their economic, environmental, and technological indicators [19].

3. The aim and objectives of the study

The aim of our work is to devise a procedure for choosing the type of energy-friendly and environmentally friendly energy resource for electricity and heat supply in the region under the conditions of shortage of traditional resources.

This will make it possible to form an objective idea of the acceptability of using a certain energy resource to ensure energy security, taking into consideration its environmental impact in a particular region of the country.

To accomplish the aim, the following tasks have been set:
– to form a list of indicators characterizing the technological, environmental, and other consumer properties of available energy resources;
– to determine the boundary values and allowable intervals for changing the indicators used;
– to perform a quantitative comparative analysis of available energy resources and technologies based on them.

4. The study materials and methods

4. 1. Research method

An important element of the study is the establishment of a comprehensive assessment of the effectiveness of the choice of the type of energy resource favorable for electricity and heat supply under the conditions of a particular region.

To conduct such an assessment, the method of expert assessments [19–21] was employed using a random number generator to form an information field about the values of the characteristics of energy resources.

The types of energy resources listed above are characterized by qualities, the totality of which, in a dimensionless form, can serve as a criterion for deciding on the prevailing acceptability of using a particular resource.

The construction of a comprehensive assessment of the effectiveness of the system is a sequence of procedures given in Table 1 [19].

Table 1

Stages of integrated assessment of the effectiveness of systems

Stage 1	Selection of a set of indicators characterizing the state of systems
Stage 2	Selection of reference systems by indicators.
Stage 3	Estimation of intervals of partial indicators of system functioning
Stage 4	Average scoring of the values of particular indicators of the functioning of the system
Stage 5	Estimation of weight coefficients for particular indicators
Stage 6	Integral assessment of the efficiency of the system

Indicators characterizing the state of energy security systems are distributed in 6 groups of factors (Table 2).

Table 2

Factors that reflect the applicability of a resource

Technological	The existence, availability and development of technology
Environmental	The interaction of resource and habitat
Reliability	Technical, software, operational interaction of the system and environment
Weight and size	Estimates of the need for space for implementation
Technical	The need for resources for own needs
institutional	Management, regulation

27 indicators were selected that have a positive (+) or negative (−) tendency to influence the applicability of the resource.

The method of scoring involves assigning a numerical value to each analyzed (j-th) indicator in accordance with its impact on the system. Our paper adopts a 50-point evaluation range, which makes it possible to differentiate the degree of influence in narrow ranges.

In the case of a negative trend in the influence of the indicator, the residual difference between the upper limit (the highest possible value of points – 50) and the number of points selected by the "expert" (random number generator) during the assessment is taken into consideration.

4. 2. Materials

In the Odesa region (33314 km^2, population: 2.368 million people) until recently, the only internal source of energy supply was the Odessa TPP, with a capacity of 68 MW, commissioned in 1950.

The energy saturation of the region is provided by the generating capacities of the South-Ukrainian NPP and the Moldavian State District Power Plant. Both stations located outside the region (Fig. 2) should be decommissioned in the next 15 years as having exhausted the service life [1].
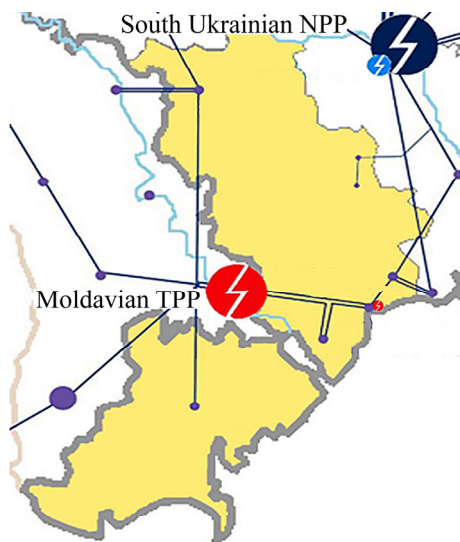

Fig. 2. Distribution of power plant capacities throughout the region

The estimated power supply capacity of regional consumers of the agglomeration until 2040 will be 2225 MW.

The emergence of domestic sources based on renewable resources has enriched the energy-to-weight ratio of the region. For example, as of the beginning of 2019, a renewable electric power industry with a total capacity of about 260 MW was operating in the region. In total, the region produces more than 10 % of the "alternative" electricity of Ukraine at 13 solar stations with a capacity of 1 to 40 MW, about 100 MW of wind installations. Until 2030, the possibilities of electricity production based on renewable energy sources are expected to double. In a favorable situation, up to 25 % of the needs will be provided. However, the problem of increasing capacity remains relevant and requires certainty in the choice of energy resources.

5. The results of the justification for the choice of the type of energy resource

5. 1. List of indicators characterizing the properties of available energy resources

For a comprehensive assessment of the acceptability of the resource, the indicators that characterize the system and are distributed among groups of factors are arranged in the sequence of reducing the degree of its influence on acceptability.

Table 3

Indicators that reflect the impact on the applicability of the resource

No. of entry	Group of factors	Indicator		
		No.	Impact trend	Designation
1	Techno-logical	1	+	Availability of resource in the region
		2	−	The need to import resources
		3	+	Availability of delivery vehicles
		4	+	Availability, readiness
		5	+	Performance
		6	+	The quality of the supplied resources,
		7	+	Final coal intensity of energy
2	Envi-ronmen-tal	8	−	Waste volume
		9	−	Overall emissions
		10	−	CO_2 emission level at TPES
		11	+	Waste recycling
		12	−	Waste dumping
		13	+	Service safety
3	Reliabil-ity	14	+	Reliability, failures
		15	+	Maintainability
		16	+	Duration of operation
		17	+	Asset renewal level
		18	+	Maintaining the life cycle of objects
4	Weight and size	19	−	Capital investments
		20	−	Dimensions
		21	−	Material consumption
5	Techni-cal	22	−	Own energy costs
		23	−	Reagent Consumption
		24	+	Possibility of recycling
6	Institu-tional	25	+	Wage level
		26	+	Quality of management
		27	+	HR quality

The selection of indicators, the indication of the trend of their influence, and the position in the list are determined by experts. Of the 27 indicators, a positive trend is inherent in 17 indicators, the rest are characterized by a negative one.

5. 2. Boundary values and allowable intervals for changing indicators

For each type of resource, the permissible intervals for changing each indicator are set by experts: 15–20 units.

At the stage of working out the methodology, a random number generator operating in the specified intervals of indicator values was used as a point expert assessment of each indicator type for each type of resource. All indicators are evaluated in points on a scale (Table 4).

Based on the results of the evaluation of the partial k-th values of the n-th indicator, the average score for each n-th indicator of the i-th resource is calculated according to the ratio:

$$\overline{B}_{ni} = \frac{\sum_{l=1}^{k} B_{ki}}{k}, \tag{1}$$

where $\overline{B}_{ni}$ is the average score of n-th indicators for each resource; B_{ki} is the score of the k-th expert of the n-th indicator for the i-th resource; k is the number of experts.

Average scores are standardized by the average score value of the indicator for all resources:

$$B_{ni}^{norm} = \frac{i \cdot \overline{B}_{ni}}{\sum_{l=1}^{i} B_{ki}}, \tag{2}$$

Normalized average scores are summed up for each resource. The degree of influence of each indicator on the system takes into consideration the introduction of weight coefficients KP_n, which are formed expertly, taking into consideration the influence of each indicator. In this case, ranking procedures were used by paired and sequential comparison. According to the received amounts, the average values of the normalized values of the sums of indicators are calculated, taking into consideration their weight:

$$\overline{P}_i = \frac{\sum_n Kp_n \cdot B_{ni}^{norm}}{n}. \tag{3}$$

The acceptability index is defined as the ratio of the normalized values of the sums of indicators to their average value of the sum over all resources:

$$Id = \frac{i \cdot \overline{P}_i}{\sum_i \overline{P}_i}. \tag{4}$$

Table 4

Scale of the point system for assessing the factors of applicability of the resource

No. of entry	Indicator	Energy resource									
		1	2	3	4	5	6	7	8	9	10
1	Availability of resource in the region	0–10	0–10	0–10	20–40	30–40	0–20	10–20	10–20	10–20	0–10
2	The need to import resources	30–40	30–40	30–40	10–20	10–20	10–20	10–20	10–20	10–20	30–40
3	Availability of delivery vehicles	20–30	20–30	20–40	10–30	10–30	10–30	10–20	10–20	10–20	20–40
4	Availability, readiness	10–30	10–20	10–30	20–40	30–40	30–40	10–20	10–20	10–20	40–50
5	Performance	30–40	20–30	30–40	10–20	10–20	10–20	0–20	0–10	0–10	40–50
6	The quality of the supplied resources	20–30	20–30	30–40	30–40	30–40	30–40	15–20	10–20	10–20	40–50
7	Final coal intensity of energy	30–50	30–40	30–40	30–40	30–40	30–40	10–20	10–20	30–40	40–50
8	Waste volume	20–30	20–30	10–20	0–10	0–10	10–20	20–30	10–20	10–20	0–10
9	Overall emissions	20–30	20–30	10–20	0–10	0–10	10–20	20–30	10–20	10–20	0–10
10	CO_2 emission level at TPES	20–30	20–30	10–20	0–10	0–10	10–20	20–30	10–20	10–20	0–10
11	Waste recycling	20–30	20–30	20–30	20–30	20–30	20–30	20–30	20–30	20–30	40–50
12	Waste dumping	20–30	20–30	10–20	0–10	0–10	10–20	20–30	20–30	20–30	0–10
13	Service safety	20–30	20–30	20–30	30–40	20–30	20–30	20–30	20–30	20–30	30–40
14	Reliability	10–30	10–30	10–30	10–20	10–20	15–30	10–20	10–20	10–20	30–40
15	Maintainability	40–50	40–50	40–50	10–20	10–20	10–20	20–30	20–30	20–30	40–50
16	Duration of operation	30–40	30–40	30–40	20–40	20–40	30–40	20–30	20–30	20–30	40–50
17	Asset renewal level	10–20	10–20	10–20	30–40	30–40	30–40	20–30	20–30	20–30	10–20
18	Maintaining the life cycle of objects	20–30	20–30	20–30	10–20	10–20	20–30	10–20	10–20	20–30	40–50
19	Capital investments	20–40	20–40	20–40	10–20	10–20	30–40	20–30	20–30	20–30	30–40
20	Dimensions	20–40	20–40	20–40	10–20	10–20	30–40	20–30	20–30	20–30	30–40
21	Material consumption	20–40	20–40	20–40	10–20	10–20	30–40	20–30	20–30	20–30	30–40
22	Own energy costs	10–20	10–20	10–20	0–10	10–20	10–20	20–30	20–30	30–40	10–20
23	Reagent consumption	10–20	10–20	10–20	0–10	0–10	0–10	20–30	20–30	20–30	0–10
24	Possibility of recycling	10–20	10–20	10–20	0–10	0–10	0–10	20–30	20–30	20–30	0–10
25	Wage level	10–20	10–20	10–20	10–20	10–20	10–20	20–30	20–30	20–30	30–40
26	Quality control	10–20	10–20	10–20	10–20	10–20	10–20	20–30	20–30	20–30	30–40
27	Quality of personnel (technical and managerial)	20–40	20–40	20–40	10–20	10–20	10–20	20–30	20–30	20–30	30–40

Note: 1 – coal, peat; 2 – oil; 3 – gas; 4 – solar; 5 – wind; 6 – hydropower; 7 – biogas; 8 – household waste; 9 – hydrogen; 10 – nuclear

The environmental conservation index is calculated as the ratio of the acceptability index, in the calculation of which indicators with a negative impact on the system and determined taking into consideration their impact are excluded.

5. 3. Comparative analysis of available energy resources and technologies

The processing of primary results was reduced to summation and standardization by indicators and types of resources. After the necessary treatment, the results presented in the diagram (Fig. 3) are obtained.

The values of the acceptability index differ in absolute values for different types of resources and different methods. At the same time, the trends of change in resources remain.

The lowest values of the acceptability index in the region under consideration are characteristic of traditional solid and liquid fossil resources, as well as for part of those made from waste and natural raw materials (0.8–0.9). Fossil gas and hydropower are characterized by an acceptability index slightly higher. A noticeably higher value of the index (about 1.2) distinguishes the renewable resources (solar and wind energy). The most promising resource for the region was the nuclear energy resource, which reached an acceptability value of 1.3.

The comparison of trends in the acceptability index and the environmental conservation index (Fig. 4) makes it possible to note their synchronicity. In this case, the module of the environmental conservation index is slightly larger than the index of acceptability for nuclear energy. The comparison suggests that the acceptability of an energy resource for the region under consideration is largely regulated by the environmental characteristics of the resources.

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The reliability of the results is assessed by the degree of consistency of positions relative to each indicator [22]. The concordance coefficient values, obtained from Kendall's formula, are shown in Fig. 5:

$$W = \frac{12 \cdot S}{n^2 \cdot m \cdot \left(m^2 - 1\right)}, \qquad (5)$$

where S is the sum of the squares of deviations of all rank estimates of each object of examination from the average value; n – the number of experts; m – the number of objects of expertise.

The concordance coefficient (Fig. 5) varies in the range of $0 < W < 1$, with the value $W=0$ indicating complete inconsistency and $W=1$ indicating complete unanimity.

For different indicators, the value of the concordance coefficient does not exceed 0.6. There is no definite tendency in the change in the coefficient, which confirms the random nature of the analyzed data.
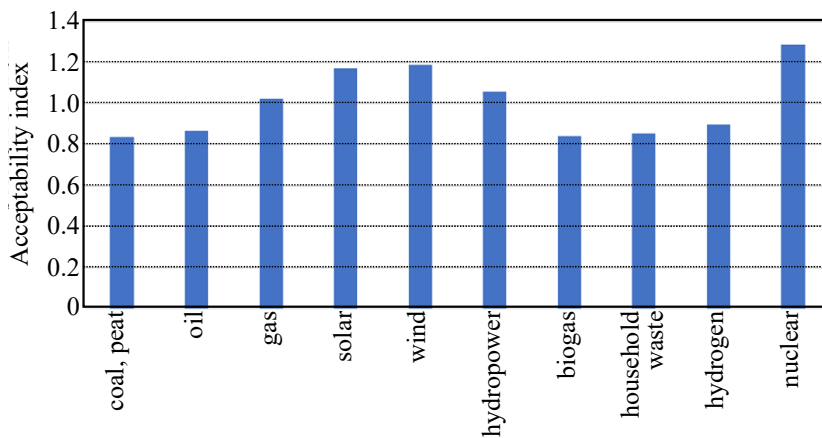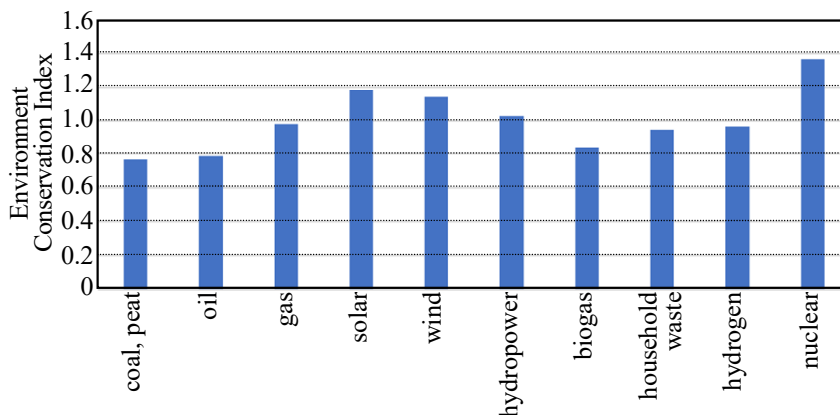

Fig. 3. Energy acceptability index values

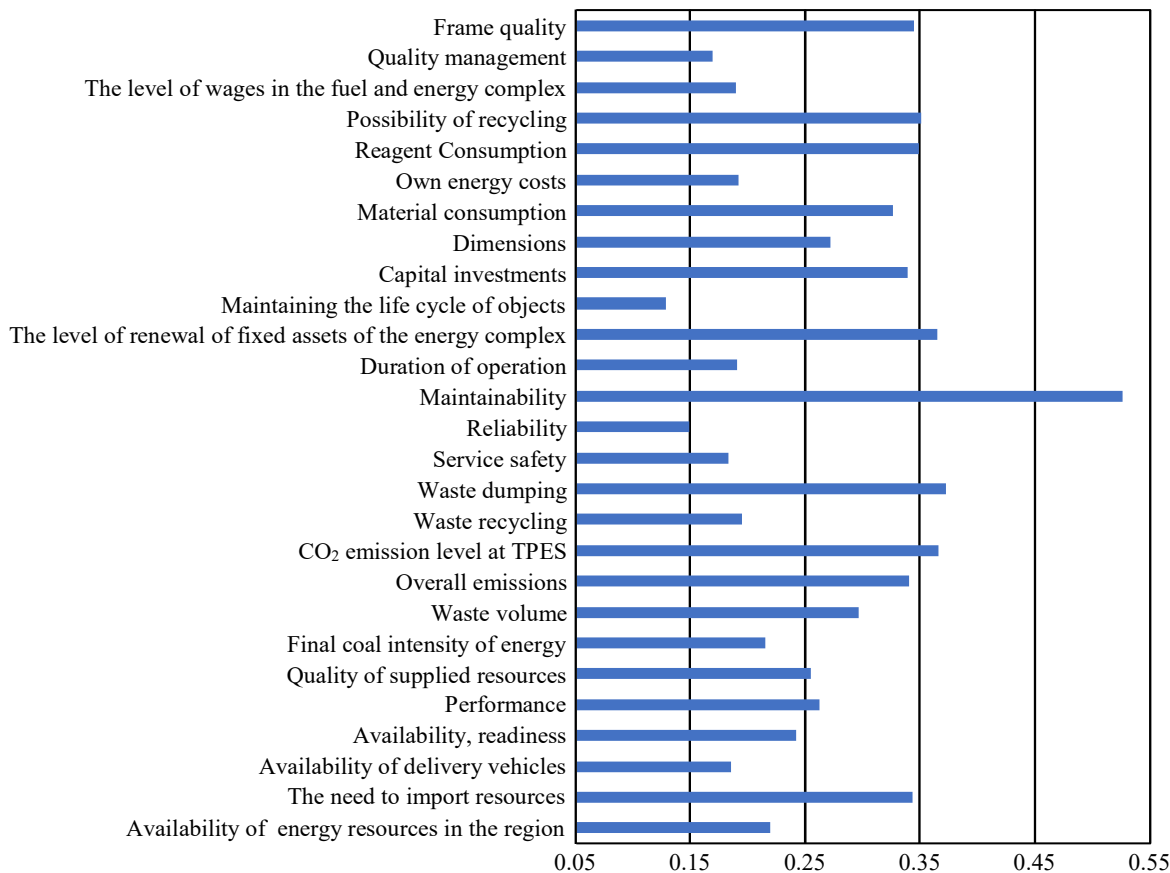Fig. 4. Environmental conservation index values

Fig. 5. Concordance coefficient

6. Discussion of results of the application of the method of expert assessments in justifying the choice of the type of energy resource

The generated list of factors for expert analysis of the functioning of the energy system is distributed in six groups that characterize the specific aspects of the applicability of the resource (Table 3).

Such a representation is due to the fact that the resources under consideration have a different physicochemical nature and can be compared with indicators that display qualitative indicators common to all resources. The formed six groups are characterized by universal indicators characteristic of multi-natural energy resources. Owing to the set of these indicators, it has become possible to carry out a comparative analysis to substantiate the acceptability of energy resources.

Features of the method of expert assessments used in this study is the possibility of obtaining the necessary result with limited analytical information about the processes in the system. The use of an extended scale of point marks (Table 4) increases the reliability of the results obtained. This is achieved because it is this scale that eliminates the inherent disadvantage of the traditional five-point scale of the inability to differentiate the positions of experts at single allowable intervals of change in indicators.

It is advisable to use the results obtained according to the described methodology at the stages of preliminary development of projects for the development of energy security of the regions in the processes of reform (Fig. 3, 4). When planning reform projects in the regions, especially in terms of the development of the economic system, the primary task is to substantiate the resource provision. The considered procedure makes it possible to solve this problem with its limited informativeness.

The use of a random number generator as experts at the stage of testing the technique may be acceptable, which is confirmed by the assessment of the concordance coefficient calculated according to Kendall's formula, the calculated values of which are shown in Fig. 5. However, when using the methodology while solving a problem for an actual region, it is necessary to take advantage of the opportunities of professional experts. When staffing an expert group, preference should be given to specialists with professional qualifications in related fields of knowledge: technology, ecology, reliability, management, etc. It is advisable to form expert groups by groups of factors separately, and the Kendall ratio makes it possible to assess the consistency of their position quite reliably.

Our study should evolve towards substantiating the intervals of the point system of factor assessments, which requires coordinated actions of experts of special qualification.

7. Conclusions

1. A list of 6 groups of factors has been devise and built, including 27 indicators characterizing the technological, environmental, and other consumer properties of available energy resources. This makes it possible to perform a comparative analysis of energy resources of different nature for a wide range of indicators and assess their impact on energy supply and security of the regions.

2. The maximum and minimum values, as well as the allowable intervals of change and weighting coefficients of

the indicators used, have been determined. Minimum values range from 0 to 30 points. The maximum values, respectively, are 10–50 points. For indicators with a negative trend of influence, the differences between the maximum number of points (50) and the values appointed by the experts were taken into consideration.

3. A quantitative comparative analysis of available energy resources and technologies based on them has been carried out. It is shown that the acceptance index and the environmental conservation index exceeds 1 for nuclear, solar, wind, and hydropower. This allows us to assume that they are the most promising resources for the region from the non-fossil group.

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