Using normalized values of indicators to determine the level of energy security on the example of the Central and Southern federal districts

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Abstract. At ISEM SB RAS developed approaches to assessing the level of energy security of regions by convolution of qualitative indicators of its state of energy efficiency. At the same time, the relative weights of indicators in the overall system of their value were taken into account. The article presents a new approach to the formation of normalized values of energy security indicators, which was applied in the analysis of the main trends, scales, as well as the dynamics of changes in the state of energy security of the subjects of the Russian Federation located in the territories of the Central and Southern federal districts. Conclusions about its applicability are drawn on the example of the obtained results of indicative analysis.

Introduction

The concept of energy security (ES) is interpreted as "the state of protection of citizens, society, the state, and the economy from the threat of a shortage in meeting their energy needs with economically available energy resources of acceptable quality, from threats of disruption of uninterrupted energy supply" [1-6].

An indicative assessment of the ES level of a particular region of the country is carried out according to three, to a large extent interconnected, blocks of indicators: production and resource endowment of the fuel and energy supply system of the region; reliability of the fuel and energy supply system of the region; the state of the basic production assets (BPA) of energy systems in the region (Table 1).

Taking into account the peculiarities of the energy supply of individual regions, earlier [1,4,5, etc.], the threshold values of indicative indicators for different groups of subjects of the Russian Federation, as well as the relative shares of indicators in the general system of their values, were expertly determined. Using the method of convolution of the obtained values of the analyzed indicators, integral assessments of the state of the ES of the subjects of the Russian Federation were formed.

Table 1. The composition of the most important indicators of regional energy security.

1. The block of industrial and resource security of the fuel- and energy supply of the region
1.1. The ratio of the total available capacity of the region's power plants to the maximum electric load of consumers on its territory. 1.2. The ratio of the amount of available capacity of power plants and the capacity of inter-system connections of the region with neighboring consumers to the maximum electric load on its territory. 1.3. Opportunities to meet the needs of boiler heating oil (BHO) from the region's own sources.
2. The block of reliability of fuel and energy supply of the region
2.1. The share of the dominant resource in total consumption of BHO in the region. 2.2. Share of the largest power plant in the installed electric capacity of the region. 2.3. The level of potential supply of demand for fuel in the conditions of a sharp cooling (10% consumption of consumption) in the region.
3. Block of the state of the BPA of energy systems in the territory of the region
3.1. Degree of depreciation of the BPA in the energy sector of the region. 3.2. The ratio of the average annual input of installed capacity and reconstruction of power plants in the region over the previous 5-year period to the established capacity of the region.

Many indicators are measured in different units, and in order to obtain an integral assessment of the region's ES, the principle of normalizing the values of indicators can be applied depending on the ratio of their values to the threshold ones. For this, a modernized normalization apparatus was used, obtained on the basis of the one used earlier in [7].

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The approach proposed by the authors is universal, it differs from [7] in that it allows you to work with both increasing and decreasing values of indicators, that is, those indicators whose state improves as the value increases and with those whose state improves as they decrease. their meanings.

The conversion of indicator values expressed in different units of measurement into normalized ones is performed according to the following expression:

$$X_i^N = \frac{X_{PCi} - X_i^t}{X_{C,i} - X_{PC,i}}, \quad (1)$$

where X_i^N – is the normalized value of indicator i in the analyzed period, rel. units; X_i^t – is the actual value of the indicator in the system of initial units; $X_{PC,i}$, $X_{C,i}$ - respectively, the threshold values of the pre-crisis and crisis states of the indicator i in the system of initial units.

In accordance with the calculation algorithm, the normalized threshold value $X_{PC,i}^N$ is always equal to zero, since this value is the starting point for unfavorable conditions, and the value of $X_{C,i}^N$ is always equal to -1.

Below are the results of assessing the level of energy security of the constituent entities of the Russian Federation located in the territories of the Central (CFD) and Southern (SFD) federal districts, obtained using the previously applied approach. Then, in order to more conveniently compare the results and compare the dynamics of the ES state in different regions, the approach of normalizing the obtained quantitative estimates will be applied.

Results of indicative ES analysis by regions of the Southern Federal District

This section provides information on the qualitative state of energy security indicators for the subjects of the Russian Federation in the Southern Federal District, as well as a qualitative characteristic of the state of energy security of these subjects for 5 years: from 2016 to 2020, in accordance with [8-10] (Table 2 - 5). In this analysis, the Republic of Adygea is included within the Krasnodar Territory, and the city of Sevastopol is included within the Crimean peninsula.

Table 2. The status of indicators on the territory of the subjects of the Southern Federal District of the district for the block of production and resource provision of the fuel and energy supply system for 2016, 2020.

Region, area	Indicator	Dimension	The threshold values of the indicator		The meaning and status of the indicator, year			
			N	C	2016		2020	
Krasnodar Region and the Republic of Adygea	1.1	un.	0,5	0,3	0,46	PC	0,43	PC
	1.2	un.	1,5	1,2	1,78	N	1,66	N
	1.3	%	60	40	134,7	N	88,9	N
Astrakhan region	1.1	un.	0,5	0,3	1,14	N	1,62	N
	1.2	un.	1,5	1,2	3,99	N	4,58	N
	1.3	%	60	40	463,5	N	391,9	N
Volgograd region	1.1	un.	0,5	0,3	1,85	N	1,66	N
	1.2	un.	1,5	1,2	4,08	N	3,53	N
	1.3	%	40	20	24,13	PC	21,66	PC
Rostov region	1.1	un.	0,5	0,3	2,15	N	2,08	N
	1.2	un.	1,5	1,2	3,44	N	3,34	N
	1.3	%	40	20	32,45	PC	50,56	N
Republic of Kalmykia	1.1	un.	0,7	0,5	0,22	C	3,43	N
	1.2	un.	1,5	1,2	3,36	N	2,84	N
	1.3	%	60	40	18,92	C	19,29	C
Republic of Crimea and Sevastopol	1.1	un.	1,2	1,1	0,86	C	1,37	N
	1.2	un.	1,5	1,2	2,05	N	2,26	N
	1.3	%	100	80	35	C	35	C

At the end of 2020, according to the first block of indicators (Table 2), an acceptable situation is observed only in the Astrakhan and Rostov regions, due to the sufficient amount of electric power in the region and the presence of intersystem electrical connections.

In the Krasnodar Territory and the Republic of Adygea, there is a pre-crisis in terms of index 1.1, however, positive dynamics are noticeable due to an increase in the region's electricity generating capacity in 2020 due to the commissioning of a number of solar power plants. At the same time, ensuring the maximum electrical load is achieved by the presence of sufficient power of possible overflows of connections with neighboring regions.

In the Volgograd region, the pre-crisis situation is associated with insufficient opportunities to cover the required volumes of BHO from its own sources.

Heating oil production and natural gas production account for less than 30% of the required fuel consumption in the region.

In the Rostov region, there is an improvement in the situation on indicator 1.3, with an increase in the share of own sources in the balance of BHO from 30 to 50%. With a sufficient margin, the maximum electrical load is ensured.

The situation in the Republic of Kalmykia has changed significantly by 2020, and at the moment the region is sufficiently provided with its own sources of electricity to cover the required volumes. The production of BHO in the region is not enough, so the situation described by this indicator is assessed as a crisis.

The situation in the Republic of Crimea has improved, moving into the area of acceptable values, due to an increase in the installed electric capacity of the region.

According to the second block of indicators (Table 3) in the Krasnodar Territory and the Republic of Adygea, the crisis situation in the ind. 2.1 is due to the share of gas in the balance of BHO - 98%.

In the Astrakhan region indicators ind. 2.2 moved into the range of acceptable values due to a decrease in the share of Astrakhan CHPP-2 with an increase in the installed capacity of the region by 150 MW, due to the commissioning of a number of solar power plants. In the Volgograd and Rostov regions, the Republic of Crimea and Kalmykia, there is a crisis situation in terms of EB for indicator 2.1 due to too high a share of gas in the balance of consumption of BHO.

The transition from crisis values to the acceptable range was noted in the Republic of Kalmykia (ind. 2.2). Thanks to the commissioning of the Tselinskaya and Salynskaya wind farms with a total capacity of 200 MW, the share of the dominant source in the region's available capacity decreased from 95 to 28%.

Table 3. Characteristics of the state of indicators on the territory of the subjects of the Southern Federal District for the fuel and energy supply reliability block for 2016, 2020.

Region, area	Indicator	Dimension	The threshold values of the indicator		The meaning and status of the indicator, year			
			N	C	2016		2020	
Krasnodar Region and the Republic of Adygea	2.1	%	40	70	98,69	C	97,93	C
	2.2	%	50	70	45,8	N	45,54	N
Astrakhan region	2.1	%	>90		97,75	N	97,83	N
	2.2	%	50	70	51,08	PC	33,08	N
Volgograd region	2.1	%	40	70	95,41	C	86,71	C
	2.2	%	50	70	65,5	PC	58,9	PC
Rostov region	2.1	%	40	70	80,29	C	79,58	C
	2.2	%	50	70	36,07	N	30,49	N
Republic of Kalmykia	2.1	%	40	70	99,6	C	99,7	C
	2.2	%	50	70	94,7	C	28	N
Republic of Crimea and Sevastopol	2.1	%	40	70	93,54	C	96,77	C
	2.2	%	50	50	7,05	N	23,21	N

The composition of the most important indicative indicators includes another indicator - 2.3, which reflects the level of potential supply of demand for fuel and energy resources in conditions of a sharp cooling (10% surge in consumption) in the region. It is estimated based on the results of studies on the fuel and energy complex model [2,3] as the value of the provision of consumers with boiler and furnace fuel in case of possible cooling, which increases fuel consumption by 10%.

The subjects of the SFD belong to regions with a temperate (moderately cold) climate (the temperature of the coldest five-day period is from -20° to -30°C [11]). The crisis threshold for such regions is 90% [4]. The studies were carried out with a simultaneous hypothetical decrease in the average January temperature in most areas of the Southern Federal District.

For almost all subjects of the Southern Federal District, increased consumption can be fully ensured, which corresponds to the zone of acceptable states. The exception is the Krasnodar Territory and the Republic of Adygea, where the situation is assessed as pre-crisis. The Republic of Crimea belongs to regions with a relatively mild climate (the temperature of the coldest five-day period is -17°C [11]), however, due to too much dependence on natural gas for this indicator, the situation is in crisis.

According to the third block of indicators, the situation cannot be called completely acceptable in any of the subjects under consideration, Table. 4.

Table 4. Characteristics of the state of indicators on the territory of the subjects of the Southern Federal District in the block of the state of the BPF of energy systems for 2016, 2020.

Region, area	Indicator	Dimension	The threshold values of the indicator		The meaning and status of the indicator, year			
			N	C	2016		2020	
Krasnodar Region and the Republic of Adygea	3.1	%	40	60	37	N	44,7	PC
	3.2	%	2	1	13,6	N	1,4	PC
Astrakhan region	3.1	%	40	60	45,3	PC	51,7	PC
	3.2	%	2	1	7,4	N	2,7	N
Volgograd region	3.1	%	40	60	59,4	PC	62	C
	3.2	%	2	1	0,8	C	0,3	C
Rostov region	3.1	%	40	60	38	N	43,7	PC
	3.2	%	2	1	5,5	N	2,1	N
Republic of Kalmykia	3.1	%	40	60	51	PC	47	PC
	3.2	%	2	1	2,5	N	26,3	N
Republic of Crimea and Sevastopol	3.1	%	40	60	55,7	PC	42,7	PC
	3.2	%	2	1	8,3	N	0	C

In the Krasnodar Territory and the Republic of Adygeya, major overhauls and modernization were carried out at the Sochinskaya TPP and at the Krasnopolyanskaya HPP with a total increase in capacity by 10 MW, as well as the commissioning of wind turbines in 2020 at the Adygei WPP with a capacity of 150 MW and the commissioning of the Adygeiskaya SPP with a capacity of 4 MW. However, according to the results of the five-year period, the values of the indicators moved into the pre-crisis and crisis areas for both indicators of the block.

In the Astrakhan region, the values of the indicator of depreciation of the BPA of the energy industry are in the area of pre-crisis values. According to ind. 3.2 the state is acceptable, due to the development of renewable energy sources in the region, such as solar power plants: the commissioning of SPP Zavodskaya (15 MW) in 2017, in 2019 - Akhtubinskaya, Mikhailovskaya and Limanskaya, with a total capacity of 105 MW; 2020 Oktyabrskaya and Peschanaya SPP, with a total capacity of 30 MW.

In the Volgograd region, the situation in the third block of indicators is deteriorating. The lack of major overhauls, dismantling and decommissioning of equipment, insufficient modernization, all this, aggravated the general state of the BPA in the energy sector of the region. Of the latest commissioning of capacities until 2019, only the Volgograd SPP (25 MW) was put into operation in 2017.

The Rostov region has moved into a pre-crisis state from an energy sector that is acceptable in terms of depreciation of the BPA. At the same time, the commissioning of capacities over the past five years allows the region to remain within the range of acceptable values: commissioning of 324 MW of Novocherkasskaya SDPP, modernization at Rostovskaya HPP 2 (20 MW), in 2020 commissioning of four wind farms with a total capacity of 350 MW.

The Republic of Kalmykia is in a pre-crisis state in terms of the degree of depreciation of the BPA (Ind. 3.1). Thanks to the commissioning of a number of solar power plants with a total capacity of 330 MW, according to ind. 3.2 the situation is assessed as acceptable.

In the Republic of Crimea, the renewal and modernization of the BPA of the energy sector has been underway since 2016, however, by 2020, according to indicator 3.2, a crisis state has been noted in the republic. The energy system of Crimea was connected to the UES of Russia through the commissioning of an energy bridge with a capacity of 800 MW in 2015-2016. In 2019, 970 MW were commissioned (Combined Cycle Plant at Balaklavskaya, Tavricheskaya and Sakskaya TPPs). In November 2020, a 500 kV high-voltage line was put into operation to transmit power from the Rostov NPP to the south of the Taman Peninsula. As a result, the degree of depreciation of the BPA of the energy sector in the region has changed significantly, but the general condition is assessed as pre-crisis.

Integral assessment of ES by regions of the Southern Federal District

The results of the integrated assessment of the state of the ES in the regions of the SFD are presented in Table 5.

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Table 5. Integrated qualitative assessment of the state of energy security in the territory of the subjects of the Southern Federal District for 2016, 2020.

Years	The order numbers of the estimated ES indicators								The sum of the specific weights by state			Quality condition ES
	1.1	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**Boundaries of states**			
	Specific weights of indicators								**C**[1]	**PC**	**N**[2]	
	0,104	**0,138**	**0,133**	**0,120**	**0,079**	**0,170**	**0,127**	**0,129**				
1	2	3	4	5	6	7	8	9	10	11	12	13
Krasnodar Region and the Republic of Adygea												
2016	PC	N	N	C	N	PC	N	N	0,12	0,274	0,606	PC
2020	PC	N	N	C	N	PC	PC	PC	0,12	0,53	0,35	PC
Astrakhan Region												
2016	N	N	N	N	PC	N	PC	N	0	0,206	0,794	N
2020	N	N	N	N	N	N	PC	N	0	0,127	0,873	N
Volgograd region												
2016	N	N	PC	C	PC	N	PC	C	0,249	0,339	0,412	PC
2020	N	N	PC	C	PC	N	C	C	0,376	0,212	0,412	PC
Rostov region												
2016	N	N	PC	C	N	N	N	N	0,12	0,133	0,747	N
2020	N	N	N	C	N	N	PC	N	0,12	0,127	0,753	N
Republic of Kalmykia												
2016	C	N	C	C	C	N	PC	N	0,436	0,127	0,437	C
2020	N	N	C	C	N	N	PC	N	0,253	0,127	0,62	PC
Republic of Crimea and Sevastopol												
2016	C	N	C	C	N	C	PC	N	0,527	0,127	0,346	C
2020	N	N	C	C	N	C	PC	C	0,552	0,127	0,321	C

According to the results of the indicative analysis of the subjects of the Southern Federal District, an acceptable state of energy security can be noted in the Astrakhan and Rostov regions. The crisis situation in the Republic of Crimea is determined by the following factors: due to its own gas production, the republic provides only 35% of its needs; in the republic, the peak-increasing demand for fuel and energy resources cannot be met in the face of possible cold snaps; the share of gas in the BHO balance is 97%.

In the Republic of Kalmykia, the state passed into pre-crisis from the crisis due to the commissioning of a large number of solar power plants.

Normalization of EB indicator values

The next step in the work was the normalization of the obtained indicator values for all subjects of the Southern Federal District. On the basis of the obtained values for a 5-year period, graphs of the states of the ES of the regions were constructed for the corresponding blocks of indicators, fig. 1-3. The threshold values here were also taken into account as normalized; where "crisis" = - 1, "pre-crisis" = 0. Thus, all states that are in the range of values below "-1" are crisis, in the range from "-1" to "0" - pre-crisis and in the area above "0" - acceptable.

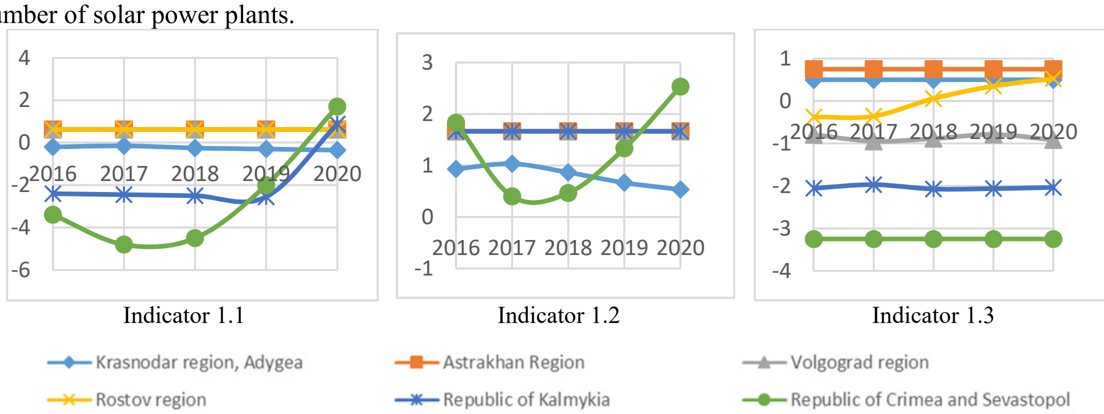

Fig. 1. Analysis of the situation with the provision of ES requirements for the first block of indicators in the regions of the Southern Federal District.

[1]The state of ES in the region is recognized as a crisis if the sum of the shares of indicators in the state "C" exceeds 0,4
[2]The state of ES in the region is recognized as normal if the sum of the specific weights of the indicators in the "N" state exceeds 0,7

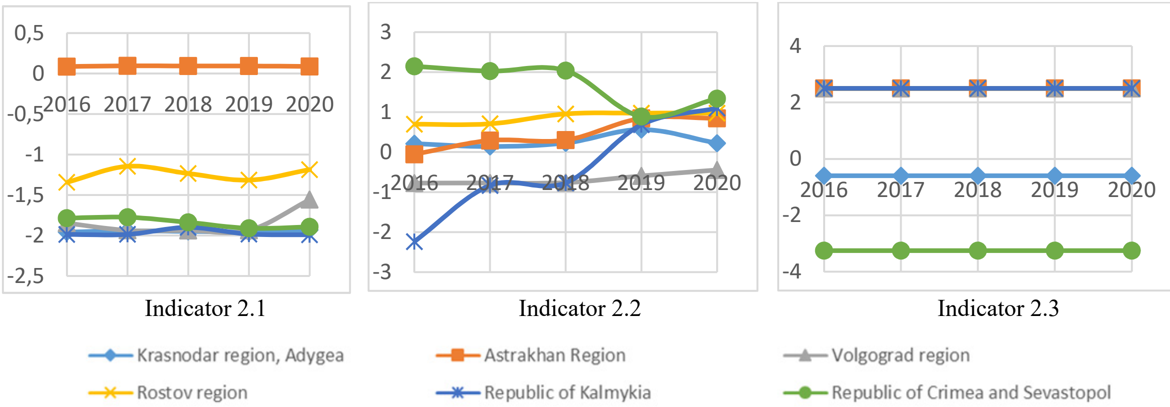

Fig. 2. Analysis of the situation with the provision of ES requirements for the second block of indicators in the regions of the Southern Federal District.

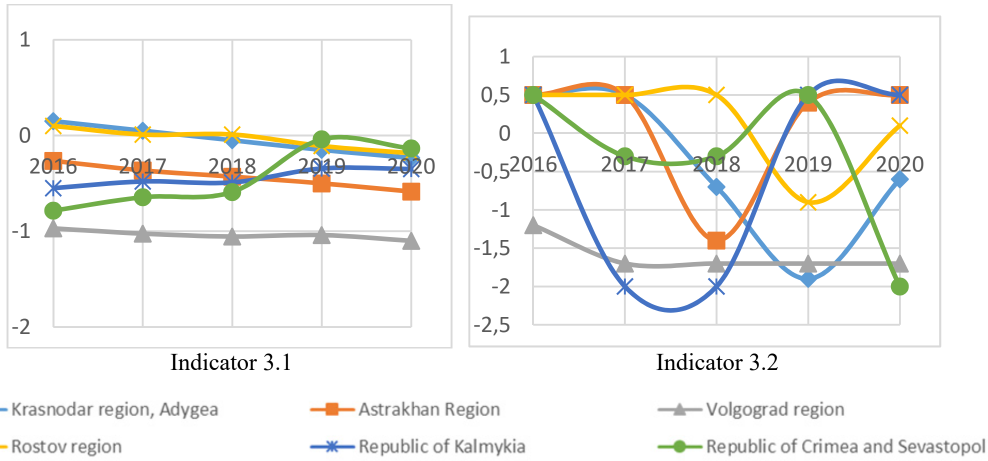

Fig. 3. Analysis of the situation with the provision of ES requirements for the third block of indicators in the regions of the Southern Federal District.

To obtain the final integral assessment of the level of ES, a convolution of the normalized values of the indicators was made, taking into account their specific weights. During the calculation, the resulting state graphs showed that too much overlap of the threshold values of individual indicators causes a bias in the overall assessment. In this regard, it was decided to reduce any significant overlap to a sufficient margin: 25% for acceptable conditions and 50% for crisis conditions. The resulting comprehensive integrated assessment of the state of the ES of the subjects of the Southern Federal District is shown in Fig. 4.

As can be seen from the graphs, in comparison with the tables, this approach allows you to track in more detail the dynamics of the state of the ES, both for each specific indicator, and in a complex way.

Results of indicative analysis of ES by regions of the CFD

The results of the indicative analysis for the CFD are presented below only in a normalized form. The state of indicators on the territory of the subjects of the Central Federal District of the district for the block of production and resource provision of the fuel and energy supply system is shown in Fig.5.

The analysis of the data obtained made it possible to identify the Ryazan and Yaroslavl regions as regions with an acceptable state of ES according to the first block of indicators. In most other regions, there is a crisis situation in terms of the level of opportunities to provide BHO from their own sources.

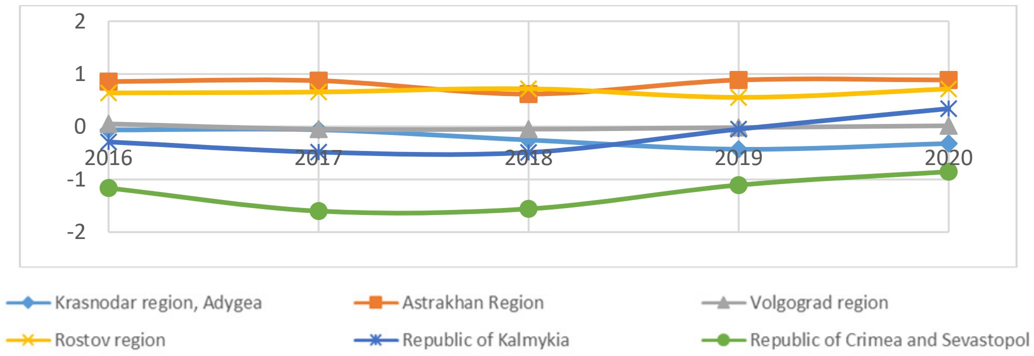

Fig. 4. Integrated qualitative assessment of the state of energy security in the regions of the Southern Federal District.

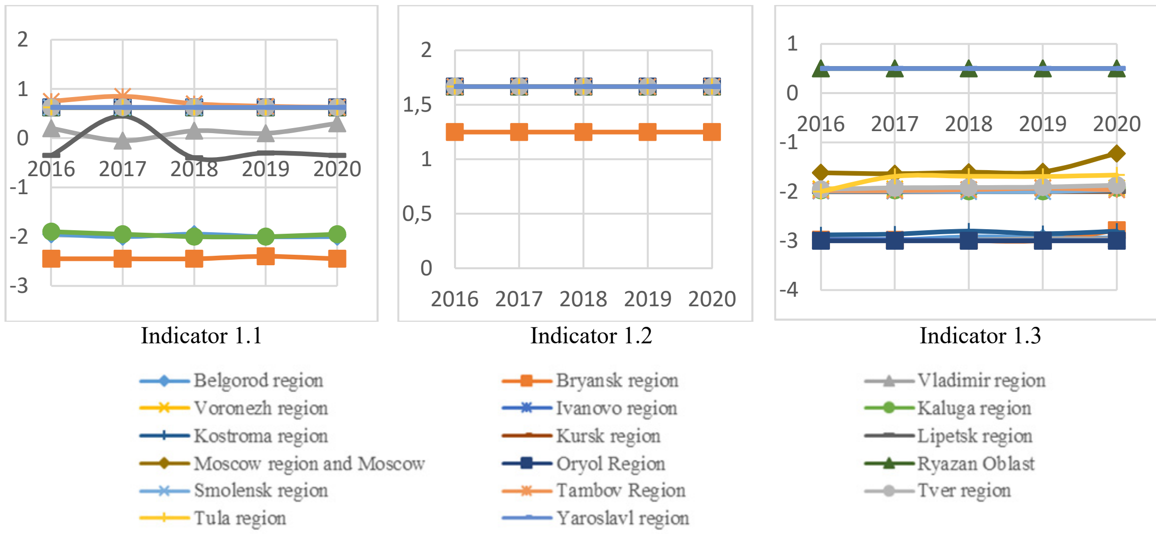

Fig. 5 Analysis of the situation with the provision of ES requirements for the first block of indicators in the regions of the Central Federal District.

According to the second block of indicators, the majority of subjects are in a crisis situation (Fig. 6). In the Bryansk and Tula regions, the situation worsened due to an increase in the share of the largest power plant in the total installed capacity of the regions. And in the Voronezh region the situation has improved and the indicators are in the area of acceptable values.

According to indicator 2.3, almost all subjects of the Central Federal District are located in the zone of crisis and pre-crisis values, since they belong to regions with a cold climate: the average temperature of the coldest 5-day period is from minus 20°C to minus 30°C [11]. At the same time, a high share of natural gas in the balance of BHO and dependence on external supplies with an insufficient amount of own fuel resources leads to insufficient coverage of the peak growing demand for fuel in conditions of sharp cooling in the European part of the country.

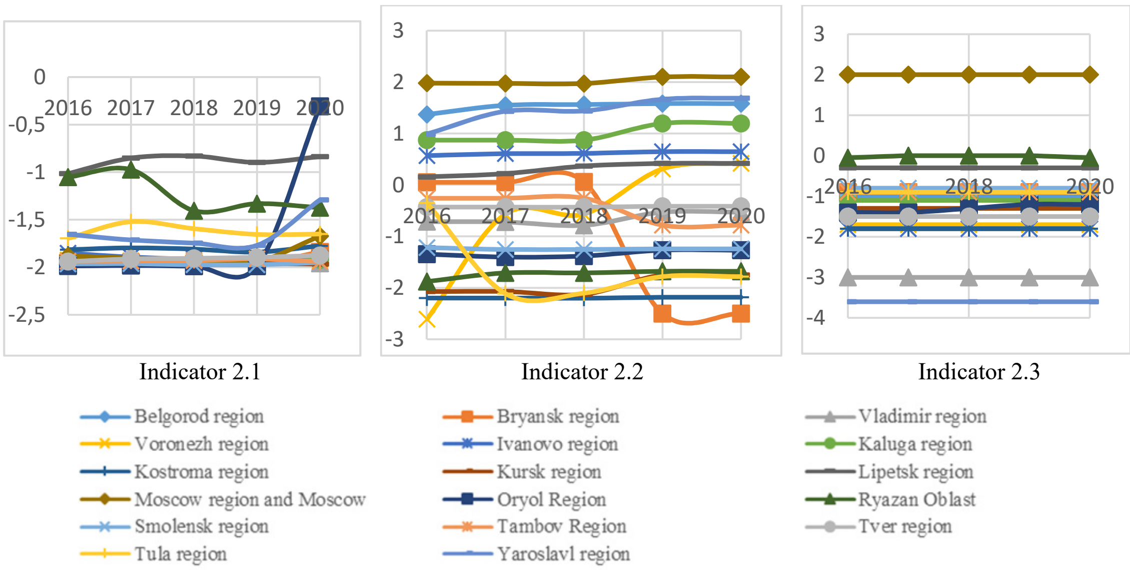

Fig. 6. Analysis of the situation with the provision of ES requirements for the second block of indicators in the regions of the Central Federal District.

According to the third block of indicators (Fig. 7), the values of indicators of the state of the BPA of the energy sector of the regions are mainly in the area of pre-crisis and crisis values.

The situation in the Voronezh and Yaroslavl regions has improved in terms of indicator 3.2, moving from the pre-crisis to the area of acceptable values. In the Voronezh region, reactor installations were launched at the Novovoronezh NPP with a total capacity of 2400 MW; in 2020, a CCPunit with a capacity of 220 MW was installed at the Voronezh CHPP-1. In the Yaroslavl region, a CCP unit was commissioned at the region's thermal power plants with a total capacity of 515 MW over a five-year period.

The results obtained are the basis for an integral assessment of the level of ES in the regions of the Central Federal District.

The final integral assessment of the level of ES in the regions of the Central District is shown in fig. 8. Based on the data, it can be concluded that, in general, the situation with energy security cannot be considered acceptable in any of the subjects.

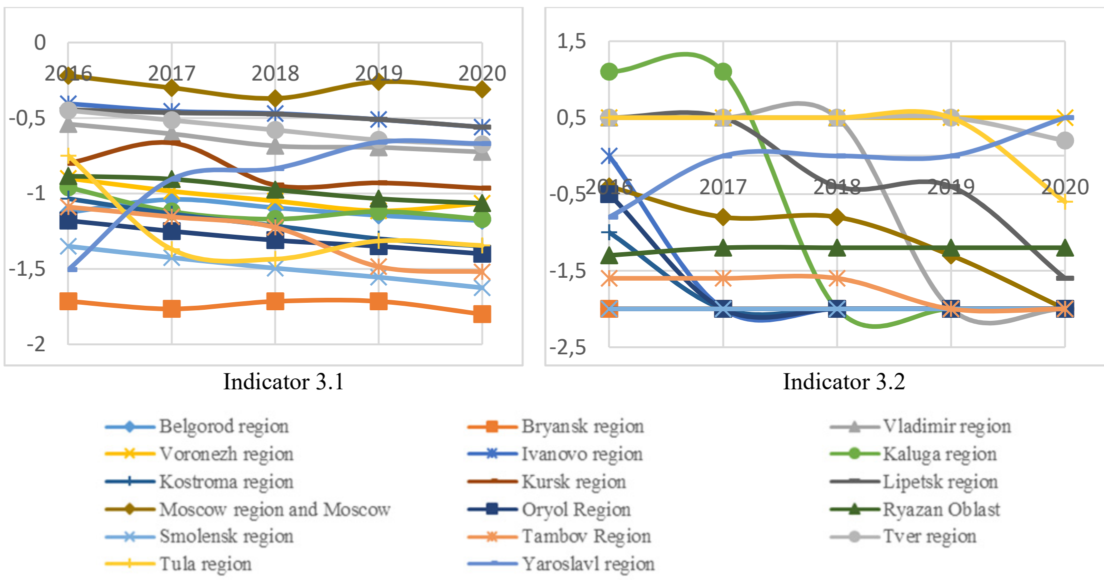

Fig. 7. Analysis of the situation with the provision of ES requirements for the third block of indicators in the regions of the Central Federal District.

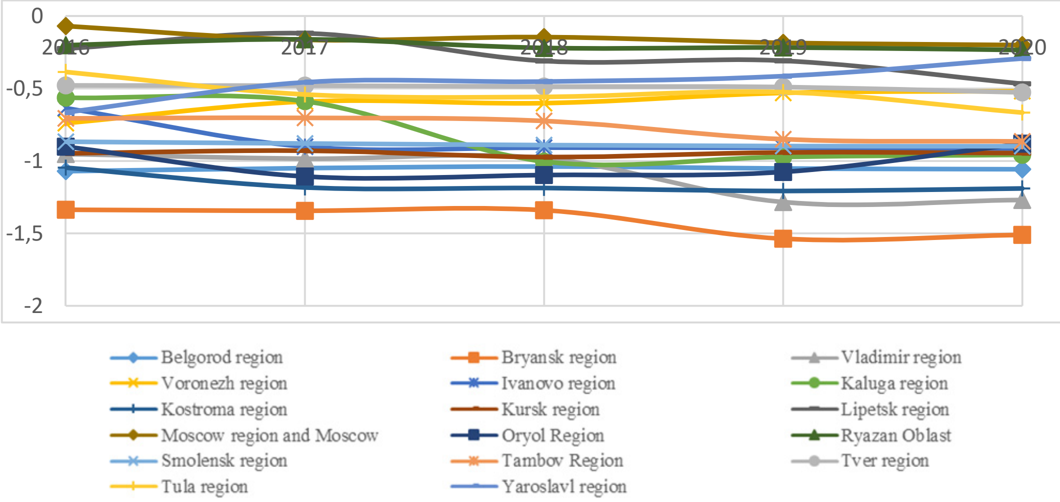

Fig. 8. Integral qualitative assessment of the state of energy security in the regions of the Central Federal District.

Conclusion

The approach considered in the article differs from the previous one in that the integral assessment takes into account not only qualitative, but also quantitative assessments of the situation with the provision of ES for individual indicators. The application of this approach makes it possible to obtain normalized values of indicators, which, in turn, correctly reflect the results of the assessment of the state of the ES in the regions, and also more clearly and in detail show the dynamics of changes in the situation with the provision of ES, both for each individual indicator and for the subjects as a whole.

The analysis showed that in the regions of the Central Federal District, which to a greater extent do not have their own sources of fuel and energy resources, the situation with the share of gas in the total consumption of boiler heating oil and with the share of the largest generating source continues to worsen. In the regions of the Southern Federal District, the situation has changed mainly in the first block of indicators, production and resource provision of the fuel and energy supply system of the regions.

In general, it should be noted that in almost all regions the situation with the aging of the basic production assets of the energy industry is deteriorating rapidly, and, consequently, with the possibility of increasing the number of emergencies with fuel and energy supply to consumers due to the failure of one or another equipment.

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10. Statistical form of Rosstat *Technical and economic indicators of power plants, district boiler houses*, 2015-2019
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