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Article

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Improving the Economic Performance of Russia's Energy System Based on the Development of Alternative Energy Sources

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ABSTRACT

An upward trend in conventional energy consumption and the exhaustibility of its resources, volatility of the prices for hydrocarbons in the global energy market update the development of scientific approaches to justification of the commercial efficiency of alternative energy in the Russian Federation. Integrated economic performance and environmental safety coefficients for generating companies in Russia were calculated through taxonomic analysis. Trends in the expenditure level for energy production in the context of alternative and conventional energy resources were forecasted by means of neural modeling technologies. Using an integrated assessment method, global priorities for the use of energy resources in Russia that would enhance the national energy system operation efficiency were identified. A forecasting integrated model of the Russian energy system development was elaborated, taking into account the commercial efficiency of alternative energy. Measures to stimulate energy production based on the use of alternative energy sources were proposed. Practical implementation of the research findings would contribute to Russia's energy system restructuring and meeting the energy needs of the national economy to the fullest extent possible.

Keywords: Alternative Energy Sources, Alternative Energy, Energy System, Economic Performance of Energy Production, Energy Resources, Conventional Energy

JEL Classifications: L98, L16, O25

1. INTRODUCTION

According to BP Energy Outlook 2018 for 2016-2040, 100% increase in global gross domestic product (GDP) and 24% increase in global population are projected, which in turn will drive up consumption of the world's energy resources by 23% (BP Energy Economics, 2018a). It should be noted that modern economic systems mainly operate on conventional energy that is not only characterized by the exhaustibility of resources, but the production and use of which significantly despoil the ecological environment. In this regard, the world is witnessing a gradual expansion of alternative energy types. There is not only environmental friendliness among the main advantages of alternative energy, but also its economic expediency in terms of costs (Barreto, 2018, Behzadi et al., 2018; Guo et al., 2018; Malysheva, 2013). To date, the cost of energy generated from renewable sources, such as wind and solar power, is 25% and 38% lower than in 2015, respectively (Lazard, 2018). In 2017, the global unconventional power was estimated at 178 GW (Chestney, 2018). According to projection data for 2016-2040, the alternative energy consumption will increase by 195% (Exxon Mobil, 2018). These trends are also highly relevant for the Russian Federation

(Executive Order of the RF Government N 1-p, 2009, Decree of the RF Government No. 449, 2013; FZ-35, 2018). Today, Russia is one of the countries dominating the world in the availability of potential alternative energy sources in its territory – about 0.3 million tons of oil equivalent (Foreign Policy Analytical Agency, 2018). Development of unconventional energy in Russia can become the basis for solving the energy supply decentralization problem in the country; it would allow for reduction of expensive fuel transportation to remote and hard-to-reach areas while simultaneously increasing the energy supply reliability; it would discourage the construction of capital-intensive power lines and contribute to a major contraction in the cost of utility system due to a significant reduction in its length, while cutting energy losses, operating and repair costs, respectively. It would ensure the electrical energy conversion to high voltage in order to transport it for considerable distances, contribute to line loss saving and would reduce the dependence of the Russian economy on unstable prices for hydrocarbon fuel (Shvartsburg et al., 2017; Takhumova et al., 2018; Golovina and Parakhina, 2013). However, despite a high potential for the unconventional energy development in the context of an established structure of the national energy system (coal, gas, and oil account for almost 90% of the country's energy (BP Energy Economics, 2018b), and the lack of an appropriate regulatory framework for the use of alternative energy in Russia, its share in the country's energy production in 2017 did not exceed 0.5% (REN21, 2018), which calls for a scientific resolution of the issues of stimulating the alternative energy development in the Russian Federation in terms of economic performance and environmental safety.

The goal of the research was to substantiate focus areas of improving the efficiency of the Russian energy system, taking into account the economic and environmental benefits of power generation through the development of alternative energy sources.

Within the framework of the research, the following problems were solved: Major destructive factors and prospects for the development of unconventional energy in the modern Russian context were identified; a priority of ensuring the energy resource efficiency in terms of economic performance and environmental safety was substantiated; a model for improving the national energy system efficiency based on integrated priorities for the use of conventional and renewable energy sources was elaborated; a set of practical measures to stimulate the unconventional power development in Russia was reasoned.

2. MATERIALS AND METHODS

The study used the following methods of scientific knowledge: Taxonomic analysis, participatory expert assessment, and neural network forecasting.

Taxonomic analysis is a method of constructing a synthetic integrated quantity that was used to estimate the commercial efficiency of electric power sources based on disaggregated indicators of average cost (X_1), average investment cost (X_2), and production profitability (X_3). The method implementation procedure involved the following algorithm:

1. Taking into account that indicators X_1–X_3 have different dimensionality and units of measurement, the performance indicators were standardized according to the formula (Aslam et al., 2017):

$$X_{st_i} = \frac{X_i - \bar{X}_l}{\sigma_i} \tag{1}$$

   Where is the standardized value of the i^{th} indicator;
   X_i is the actual value of the i^{th} indicator;
   X_i is the mean value of the i^{th} indicator;
   σ_i is the mean-square deviation of the i-th indicator.
2. A reference vector was drawn based on a differentiation between incentive and disincentive indicators and finding the maximum value for incentives and the minimum for disincentives. An incentive stands for the indicators that improve the electricity production efficiency, while a disincentive stands for the indicators that lead to a decline in the economic performance of electricity production when increasing (Aslam et al., 2017).
3. The distance between the actual state of an object of research (the level of production efficiency of the i^{th} electric power type) and its reference state (corresponding to the reference vector) was found by the following formula (Aslam et al., 2017):

$$d_j = \sqrt{\sum (X_{st_{ij}} - X_{0_i j})^2} \tag{2}$$

Where d_j is the distance between the actual state of the j^{th} type of electric power and the reference one;

$X_{0_{ij}}$ is the reference value of the i^{th} indicator for the j^{th} type of electric power.

4. The integrated economic performance indicator was calculated as follows (Aslam et al., 2017):

$$\begin{cases} I_{\mathrm{EP}j} = 1 - {d_j}/{d} \\ d = \bar{d} \cdot \sigma \end{cases} \tag{3}$$

Where $I_{\mathrm{EP}j}$ is the integrated economic performance indicator of the j^{th} type of electric power;

$\bar{d}$ is the average distance between the actual and the reference state of an object;

σ is a mean-square deviation of the distances between the actual state of the object and the reference one.

The method of participatory expert assessment was used for numerical measurement of the environmental safety levels of electric power. Following a panel discussion and coordination on the issues related to the greenhouse gas emission levels, formation of acid precipitation, radioactivity, and an impact on the ecosystem made by each type of electricity production, the experts gave an overall score ranging from 1 to 10 to each type of electricity source. The higher the score is, the higher the environmental safety level of the electric power type is.

The global priority (the integrated economic performance indicator and the environmental safety index) of the j-th type of electric power was determined by the formula:

$$I_j = \frac{I_{EPj} \cdot I_{ESj}}{\sum_{j=1}^{n} I_{EPj}} \tag{4}$$

Where I_j is integrated indicator of economic efficiency and environmental safety of the j^{th} type of electric power;

I_{EPj} is integrated economic performance indicator of the j^{th} type of electric power;

I_{EPj} is integrated environmental safety index of the j^{th} type of electric power.

To forecast the development of alternative energy types, neural networks were used, which is a mathematical model that reflects the multifunctional and diverse relationships between the indicators under study. The neural network principle is based on acceptance and processing of the incoming spike of a model, which fires neurons – structural elements of the model. Neurons transform the incoming spike, determine the nature of its effect on the phenomenon under study and transmit it to the output. The type of neural network, the incoming spike influence power, and the activity of neurons are determined by the backpropagation method, whereby the model parameters are adjusted before the training and test network errors are minimized (Wang et al., 2018).

3. RESULTS

The geographical location of the Russian Federation generates significant potential of alternative energy sources. The country has the largest water resources in the world, with a total length of rivers exceeding eight million kilometers (MNRERF, 2018). Russia ranks third in the world in global hydropower potential estimated at 48GW (REN21, 2018). The energy potential is almost 5 times as high as the current capacity of the existing hydropower plants (HPPs) in operation and is mainly located in remote regions of Russia. In general, in the south of Siberia, the Far East, and Transbaikal, the number of sunny days reaches 300 per year. Moreover, the main advantages of HPPs include low cost of electricity and its short payback period. The cost price is approximately 4 times as low, and the payback period is 3-4 times as short as for thermal power plants (TPPs) (MSU, 2018).

Also, the Russian Federation has significant bioenergy resource endowments. About 1180 million hectares of forest, which is 1/5 of the world's area, is located in the Russian Federation (MNRERF, 2018). In addition, farming enterprises have a significant potential for biogas production for electricity and heat generation. In general, as of today, the bioenergy of the Russian Federation is characterized by an economic potential of 69 million tons of oil equivalent per year (BP Energy Economics, 2018b).

Solar radiation can be a significant source of energy in Russia. During the year, the total amount of solar radiation in the country reaches 35-45 kWh/m^2 per day, in particular, in the south-west and south regions (MNRERF, 2018). It stands for about 12.5 million tons of fuel equivalent per year, which is twice as high as in Germany, for example (Muravleva, 2015). At the same time, according to various estimates, the total amount of solar power generated in Russia at the moment does not exceed 5 MW (SISESEE, 2018).

The wind energy market in Russia also has a huge development potential as a source of alternative energy. The total wind potential of the country is estimated at 2000–3000 TWh per year. The prospect of its economically efficient use is estimated at 30% of the annual energy consumption. The Far East has about 30% of the total potential. Another 16% is located in West and East Siberia. North Siberia and the Far North have additional 14% of the wind potential (Foreign Policy Analytical Agency, 2018). However, under current conditions, the share of wind energy use does not exceed 0.1% of the generated energy sources (BP Energy Economics, 2018c).

The Russian Federation has considerable resources for the use of geothermal activity. Due to a cold climate in the country, more than 45% of the energy resources are used to heat cities, settlements, and manufacturing complexes. According to expert estimates, up to 30% of these energy resources in some areas can be provided by using heat from the Earth's interior. The total geothermal energy potential of Russia is estimated at 2 GW of electricity and more than 3 GW of thermal capacity (SISESEE, 2018). According to the scientists of the Institute of Volcanology of the Far East Branch of the Russian Academy of Sciences, effective use of Kamchatka's geothermal resources alone would provide the region with electricity and heat for 100 years (Institute of Volcanology and Seismology FEB RAS, 2018). However, despite the current prospects, the practical use of geothermal energy in Russia does not exceed 0.2% of the total amount of electricity generated, with a total output of 7 TWh.

The main problems of the underuse of alternative energy include the energy complex structure geared towards the production and export of conventional energy resources inherited from the Soviet period. An excess of energy resources in the country caused a lack of interest in the development of alternative energy sources. At the same time, in the context of global energy crisis of the 1970s, energy importing countries in Western Europe laid the foundations for the renewable energy development in that period. In other words, renewable energy in Russia is underestimated from the standpoint of its political, economic, and social importance. In addition, there is a rather low demand for alternative energy from the Russian population, primarily due to a lack of awareness of this sector advantages and the inaccessibility of respective opportunities.

One of the major barriers to promoting alternative energy in Russia is technical backwardness and poor development of domestic technologies. In accordance with the wind energy standards, for example, local manufacturing content should have been 55% in 2015, 65% in 2016, and 75% 2017 (Russian Social Ecological Union Friends of the Earth-Russia, 2018).

However, the prerequisites and practical technologies for local manufacturing content are in very short supply. The Russian industry produces neither towers, nor blades, nor generators, and the transfer of Western technology is not developing. The current situation significantly reduces and hinders the prospects for energy generation development through the use of renewable energy sources in the country.

Another one of the main problems of the alternative energy development in Russia is financing of new projects. Technologies for the use of renewable energy resources are still in their infancy. Since the majority of renewable energy sources are characterized by a low specific energy density per unit of receiving area or the respective device capacity, a considerable power facility must have large dimensions, which determines a high material intensity and cost of its production (Belokrylova and Kologermanskaya, 2017). In addition, given the volatility of renewable energy over time in terms of its natural characteristics, generating plants must compensate for the volatility of energy supply. To do this, they must have sufficient capacity and maneuverability, which again increases the capital intensity of production. In this regard, actual support for the renewable energy development is counter-balanced by an inertial policy, whereby support for conventional energy using tax incentives, financing R and D, subsidy assistance, geological exploration, etc. is recognized as a more profitable and economically viable way (Vasilyeva, 2017).

At the same time, the calculation results show that renewable energy sources are quite competitive in terms of economic costs and are advantageous for the development as a component of Russia's energy system in the modern context. Based on this hypothesis, the research developed models for efficient use of conventional and renewable energy resources in terms of the economic performance and environmental safety of the country.

The decision on the feasibility of conventional and unconventional types of electricity was premised on performance indicators. Quantitative indicators of the average production cost of 1 kWh of electricity, the average investment costs per 100 kW of actual power, and the electricity production profitability by types of power plants in Russia for 2017 were used as economic performance indicators (Table 1) (Khokhlov, 2017; Degtyariov, 2017; Kissin and Rakul, 2018; BP Energy Economics, 2018c; EY, 2018; Russian Social Ecological Union Friends of the Earth-Russia, 2018).

These types of power plants produce more than 95% of the electricity in the Russian Federation; therefore, the economic performance of the entire energy system in the Russian Federation can be inferred based on their efficiency.

The average cost and average investment cost reflect the current and capital costs for the production, transportation, saving, and ensuring uninterrupted supply of electricity by types of power plants. The profitability of production is the average profitability index for enterprises engaged in the production of electricity relative to the cost of production.

In order to assess the economic performance of electricity production, the integrated economic performance indicator (I_{ep}) was calculated in the research. The use of an integrated assessment is determined by the fact that it provides an unambiguous interpretation of the phenomenon under study with different trends in particular indicators. For example, HPPs have minimal current costs but are characterized by a high level of capital expenditures due to a high cost of production and equipment maintenance. Tidal power plants (TiPPs) involve the highest capital expenditures, with a medium level of operating costs for all types of power plants, etc. In addition, integrated assessment estimation makes it possible to determine the levels of manifestation of an investigated phenomenon with the numerical values of limiting values.

The integrated indicator is calculated by finding a deviation of the actual state of the research object (the level of economic performance of electricity production) to the reference one that corresponds to the highest level of economic performance out of those under consideration (Equations 1-3). When assessing economic performance, the cost and investment cost indicators are disincentives as their increase leads to a decrease in the performance, therefore, the reference values correspond to the minimum values of these indicators for the types of power plants under study. The profitability index is an incentive as its growth indicates an increase in the electricity production performance, and the reference state of this indicator is the maximum value.

Since the economic performance indicators (Table 1) have different dimensions of the data values, the standardized values of these indicators with weighting coefficients 0.33 were used to calculate the integrated indicator. Resulting from mathematical iterations, values of the integrated economic performance indicator of electric power production by types of power plants were obtained (Table 2).

Table 1: Economic performance indicators of electricity production by types of power plants

Power plant type	Average cost, RUB/kWh	Average investment cost, mln. RUB per 100 kW of actual power	Electricity production profitability, as %
Natural gas fired TPPs	0.4	0.3	20.6
Coal-fired power plants TPPs	0.65	0.52	15.9
Oil-fired power plants TPPs	0.7	0.41	13.6
HPPs	0.08	0.73	25.5
NPPs	0.4	0.52	19.4
WPPs	0.65	0.79	15.4
SPPs	0.75	0.66	12.7
BPPs	0.78	0.5	12.3
TiPPs	0.58	0.92	20.1

TiPPs: Tidal power plants, BPPs: Biomass power plants, SPPs: Solar power plants, WPPs: Wind power plants, NPPs: Nuclear power plants, HPPs: Hydropower plants, TPPs: Thermal power plants

Table 2: Single-factor regression models of Russia's GDP as a function of the category of energy resources, by the production calculation method

Power plant type	Integrated economic performance indicator value
Natural gas fired TPPs	0.88
Coal-fired power plants TPPs	0.53
Oil-fired power plants TPPs	0.42
HPPs	0.82
NPPs	0.80
WPPs	0.32
SPPs	0.22
BPPs	0.25
TiPPs	0.38

TiPPs: Tidal power plants, BPPs: Biomass power plants, SPPs: Solar power plants, WPPs: Wind power plants, NPPs: Nuclear power plants, HPPs: Hydropower plants, TPPs: Thermal power plants, GDP: Gross domestic product

Table 3: Qualitative and quantitative graduation levels of economic performance of electric power production, according to Harrington's scale

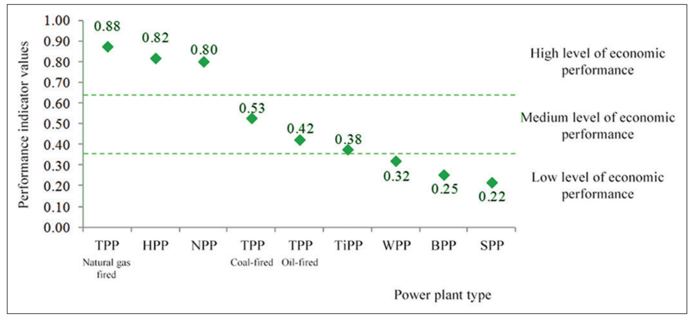
Indicator level	Indicator value
Very high	[0.8; 1]
High	[0.63; 0.8)
Medium	[0.37; 0.63)
Low	[0.2; 0.37)
Very low	[0; 0.2)

The integrated indicator is measured in the range [0; 1], the higher the indicator value is, the higher the performance level of electricity production is. To determine the economic performance levels of electricity production, Harrington's scale was used (Potapova and Mezenova, 2015) (Table 3).

Based on an integrated assessment, it was found that the production of electric power from natural gas fired TPPs (I_{EP} = 0.88), HPPs (I_{EP} = 0.82), and nuclear power plants (NPPs) (I_{EP} = 0.80) has a very high economic performance level (Figure 1 and Table 2). The power plants are characterized by the lowest level of production and investment costs, as well as the highest level of profitability. This statement is consistent with the real operating conditions of the national energy sector structure and the energy capacities available in Russia as of today.

A medium performance level was established for coal- and oil-fired TPPs (I_{EP} = 0.53, 0.42) and TiPPs (I_{EP} = 0.38). A low performance level is specific to Wind power plants (WPPs) (I_{EP} = 0.32), biomass power plants (BPPs) (I_{EP} = 025), and solar power plants (SPPs) (I_{EP} = 0.22). In other words, it should be noted that in- Russia to date, only TiPPs operating from the kinetic energy of Earth's rotation represent the most cost-effective way of generating energy at the expense of renewable resources. As of today, there is only one TiPP in the country in the Kislaya Guba of the Barents Sea near the village of Ura-Guba, which is a pilot project. The location for the TiPP construction was chosen because of the rise of tides in the Kislaya Guba, amounting to more than four meters. Its capacity is relatively small – 1.7 MW but upon condition of stable operation, the power plant can maintain power supply to the village with a population of about 5000. Since in terms of economic indicators,

Figure 1: The integrated economic performance indicator of electricity production by types of power plants in Russia



this type of power plant has a significant development potential, the development of projects for their construction are included in a long-term plan for the electric power industry development in Russia approved by the government (Progress of Technologies, 2018; Tarasova, 2018). It is planned to build TiPPs in the Penzhina Bay of the Sea of Okhotsk, in the Mezen Bay of the White Sea, and near the Shantar Islands in the Sea of Okhotsk. Nevertheless, the terms of construction and sources of its funding remain clouded as of today.

Proceeding from the research findings, it should also be noted that under current conditions, from the standpoint of economic performance, the use of solar and wind energy and biofuel is seen as inexpedient for the Russian energy system because of a high capital intensity of construction of this power plant type.

Based on the numerical values of the economic efficiency of power plant operation, a taxonomic model of an integrated assessment of the performance of the Russian power plants under study is presented:

$$I_{EP} = 0.19 \cdot Q_{TPPng} + 0.11 Q_{TPPc} + 0.09 \cdot Q_{TPPo} + 0.18 \cdot Q_{HPP} + 0.17 \cdot Q_{NPP} + 0.07 \cdot Q_{WPP} + 0.05 \cdot Q_{SPP} + 0.06 \cdot Q_{BPP} + 0.08 \cdot Q_{TiPP}$$

The model includes the average amount of electricity generated by a respective source (Q_{TPPng}, Q_{TPPc}, Q_{TPPo}, Q_{HPP}, Q_{NPP}, Q_{WPP}, Q_{SPP}, Q_{BPP}, and Q_{NPP}) in kWh weighted by the weighting coefficient of each electricity type. Weighting coefficients are determined as a proportion of values of the integrated economic performance indicator of electricity production by types of power plants. The principle of determining weighting coefficients can be explained by the fact that the higher the performance is, the more the use of an electric power source is prioritized and the more significant the level of its influence on the growth of Russia's GDP is.

The values of weighting coefficients are: 0.19 for natural gas fired TPP; 0.11for coal-fired TPPs; 0.09 for oil-fired TPPs; 0.18 for HPPs; 0.17 for NPPs; 0.07 for WPPs; 0.05 for SPPs; 0.06 for BPPs; and 0.08 for TiPPs.

In the face of an environmental disaster threat in the Russian Federation (Information and Analytical Center, 2018), in addition to economic performance in studying the sources of electricity generation, it is necessary to take into account the level of environmental safety of various production types.

Due to insufficient statistical information on indicators of the environmental efficiency of electricity generation depending on a power plant type, an integrated assessment of the environmental safety level was carried out by an expert method – the panel discussion method. The expert group included 10 members of the Center for Environmental Policy of Russia (2018). It is a professional public environmental organization whose mission is to provide expert support to the environmental movement, to ensure energy efficiency, and to develop recommendations for the legislative and executive departments in the area of environmental safety.

The following criteria were used for assessing the environmental safety of electricity production sources:
- The specific value of greenhouse gas emissions;
- The specific value of acid precipitation;
- The level of radioactivity and its effect on the ecosystem.

Representativeness of the expert assessment results is confirmed by the experts' competence in the subject matter and the fact that the assessment lasted until the experts' opinions were fully coordinated.

The experts were asked to assess the level of environmental safety of an electric power source within the range from 1 to 10 (1 stands for the lowest level of environmental safety, 10 stands for the highest level). The assessment results are presented in Table 4.

Thus, an NPP is the most dangerous source of electricity (1 point), since this power plant type operates on radioactive elements whose radiation causes mutation and cell death in vivo. There is also a risk of an accident with a release of lethal doses of radioactive elements and a problem with the disposal of radioactive waste, some of them having a decay time of more than 25,000 years. In addition, among other types of power plants, NPPs are the main source of water vapor emissions into the atmosphere, which results in a "greenhouse effect" (Peng et al., 2018).

The second most dangerous type in terms of the environmental hazard level is TPPs. They are the main source of CO_2 emissions into the atmosphere, consuming atmospheric oxygen the most; they emit significant amounts of water vapor. TPPs are characterized as energy sources with the largest overall level of "greenhouse effect" relative to the other types of power plants.

The most environmentally hazardous TPP type is oil-fired TPPs (3.5 points). When fuel oil is combusted, large amounts of sulfur oxides and nitrogen oxides are formed. Fuel oil contains a large amount of substances of the most hazardous categories that pollute the environment and pose a threat to human life.

The main risk from coal-fired TPPs to the environment is particulate emissions that are 3–5 times as high as the same emissions from fuel oil combustion. The estimate of environmental safety of coal-fired TPPs is 3.9 points.

Natural gas is the most environmentally friendly of the conventional fuels (5.6 points). When natural gas is combusted, hardly any particulate matter and sulfur oxides are released and the nitrogen oxide formation is low (10 times as low as when combusting coal) (REGNUM, 2018).

Table 4: Results of expert assessment of the level of environmental safety of electricity production by types of power plants in Russia

Power plant type	Integrated environmental safety index value
Natural gas fired TPPs	5.6
Coal-fired TPPs	3.9
Oil-fired TPPs	3.5
HPPs	7.2
NPPs	1
WPPs	10
SPPs	9
BPPs	9.8
TiPPs	10

TiPPs: Tidal power plants, BPPs: Biomass power plants, SPPs: Solar power plants, WPPs: Wind power plants, NPPs: Nuclear power plants, HPPs: Hydropower plants, TPPs: Thermal power plants

HPPs do not constitute chemical and radioactive danger. The risk of using HPPs is connected with possible dam failures, which can entail in manpower and material losses. In addition, massive construction of dams violates the natural ecosystem functioning (incurs changes in aquatic life and flora, as indicated in the study). The estimation of environmental safety of the HPP use for power generation is 7.2 points.

Among WPPs, SPPs, BPPs and TiPPs, SPPs pose the greatest threat to the environment (9 points). The threat is that cadmium is used to increase the efficiency of solar energy conversion into electricity in photocells, whereby the deactivation and disposal problem is updated. At the same time, however, this weakness of SPPs is counter-balanced by modern progressive technologies that operate on environmentally friendly cadmium alternatives.

Among the weaknesses of BPPs, experts have pointed out the fact that a significant part of agricultural fields is used to grow raw materials for biofuel-based power plants. However, according to the UN, every eighth person in the world suffers from chronic malnutrition.

With regard to WPPs and TiPPs, environmental experts emphasize that the use of these types of power plants leads to changes in the climate and ecosystem. Tidal stations inhibit the Earth's rotation and impede the movement of fish. WPPs, in turn, create problems for bird migration. Regarding the fact that WPPs inhibit the Earth's rotation, as noted by experts, this inhibition is rather miniscule and can be noticed only in thousands of years (Ryapolov, 2014; Jia et al., 2018; Özkale et al., 2017). Furthermore, scientists have managed to solve the problem of preventing the movement of fish and birds in the installation and operation of these power plant types. The diameter of TiPP turbines would allow fish to freely penetrate to the lagoon and back, and WPPs are proposed to be made enclosed in order to avoid collisions of birds with an electric installation.

The identified weaknesses represent a far lesser threat to the environment and people compared to the threats arising when conventional sources of electricity are used. Therefore, WPPs and TiPPs were awarded the highest priority of environmental safety by the expert group – 10 points.

Based on the numerical expert estimate of the environmental safety level of the use of conventional and renewable energy generation sources, a taxonomic model for the environmental safety of Russia's energy system was developed. The model was built by analogy with the economic performance model but with the specific weight of scores of the j-th energy source in the total sum of scores for all sources taken as weighting factors. The model of environmental safety of Russia's power system has the following form:

$$I_{ES}=0.09 \cdot Q_{TPPng}+0.07 \cdot Q_{TPPc}+0.06 \cdot Q_{TPPo}+0.12 \cdot Q_{HPP}+0.02 \cdot Q_{NPP}+0.17 \cdot Q_{WPP}+0.15 \cdot Q_{SPP}+0.16 \cdot Q_{BPP}+0.17 \cdot Q_{TiPP}$$

The taxonomic model of environmental safety level is characterized by a high efficiency of using WPPs and TiPPs with the weighting coefficient 0.17, 0.15 for SPPs, 0.16 for BPPs, and 0.12 for HPPs. It means that the use of power plants operating on renewable energy sources is not effective from the economic point of view but has a high level of environmental safety.

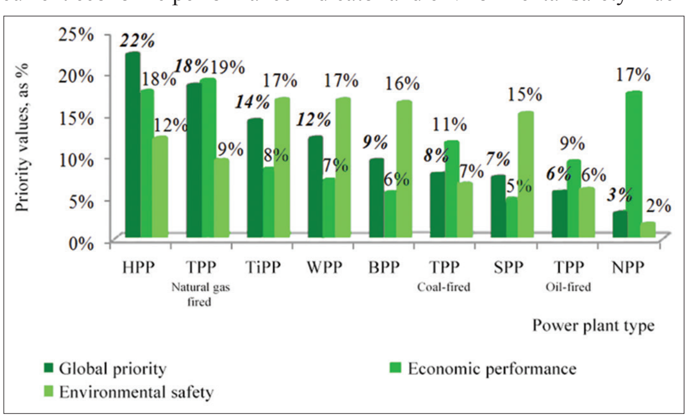
Power plants that operate on conventional energy resources have a low level of efficiency in ensuring Russia's environmental safety as a well-established fact.

The essence of the model for optimizing the structure of electric power generation sources is to prioritize the use of renewable and conventional energy sources, under which economic performance and environmental safety levels increase:

$$\begin{cases} I_{EP} = 0.19 \cdot Q_{TPPng} + 0.11 \cdot Q_{TPPc} + 0.09 \cdot Q_{TPPo} + 0.18 \cdot Q_{HPP} + 0.17 \cdot Q_{NPP} + \\ \quad +0.07 \cdot Q_{WPP} + 0.05 \cdot Q_{SPP} + 0.06 \cdot Q_{BPP} + 0.08 \cdot Q_{TiPP} \to max \\ I_{ES} = 0.09 \cdot Q_{TPPng} + 0.07 \cdot Q_{TPPc} + 0.06 \cdot Q_{TPPo} + 0.12 \cdot Q_{HPP} + 0.02 \cdot Q_{NPP} + \\ \quad +0.17 \cdot Q_{WPP} + 0.15 \cdot Q_{SPP} + 0.16 \cdot Q_{BPP} + 0.17 \cdot Q_{TiPP} \to max \end{cases} \quad (7)$$

To prioritize electric power generation sources based on the economic performance indicator and the environmental safety index, the study calculated a normalized global priority for optimizing the structure of electric power generation sources by Equation 4 for each energy source under study. The results are shown in Figure 2.

Figure 2: Priorities of electricity generation sources according to the current economic performance indicator and environmental safety index



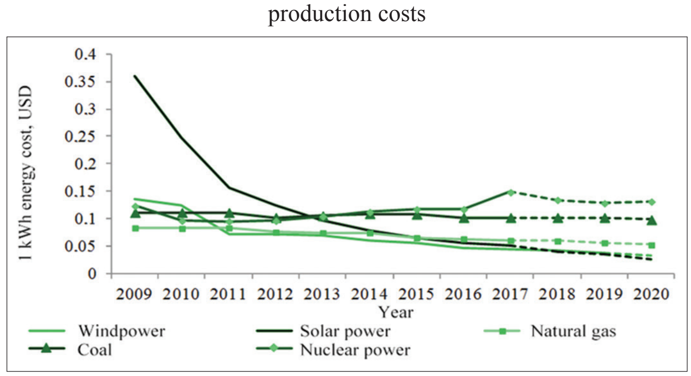
Such conventional sources as natural gas fired TPPs and HPPs (22% and 18%, respectively) have overriding priority due to their economic efficiency. The unconventional energy sources have a high level of environmental safety: 17% for TiPPs and WPPs; 16% for BPPs; 15% for SPPs. In addition, the unconventional energy sources have less priority than the conventional ones due to their low economic efficiency, a high level of capital expenditures required for the construction and maintenance of power plants, the storage and transportation of electricity, the provision of uninterrupted power supply in adverse weather conditions that all have a significant impact on the production of unconventional types of electricity.

According to Lazard, an international consulting firm (Lazard, 2018), there is a rapid decline in the production cost of unconventional types of electricity in the world. Over 2009-2017, the level of total (current and capital) costs for wind energy production decreased by 3 times, and for solar production – by 7.2 times. While the expenditure level for the production of conventional types of energy produced by combustion of natural gas and coal decreased by 1.4 and 1.1 times, respectively, the level of costs for the production of nuclear power increased by 1.1 times.

According to Lazard (2018), without taking into account the costs of transportation, saving, and ensuring continuous supply, the cost of producing 1 kWh of alternative types of electricity in the world in 2017 was lower than for conventional production. In this regard, to switch to alternative types of energy more extensively is becoming more expedient in economic terms.

In order to determine prospective trends in the development of alternative energy types in Russia, the expenditure level for electricity generation received as a result of conversion of wind and solar energy was forecasted to compare with an expected level of costs for the conventional energy generation produced by combustion of natural gas, coal, and atomic energy conversion. The forecast is based on data for 2009-2017 (Lazard, 2018) using neural networks in PP Statistica 10.0. The actual and projection data of the indicators are shown in Figure 3.

Figure 3: Dynamics of actual and estimated figures of energy production costs



For the forecast, neural networks such as MLP 1-2-1 (to forecast the expenditure level for conversion of wind and atomic energy to electricity), MLP 1-4-1 (to forecast the level of electricity production costs by SPPs), and MLP 1-5-1 (to forecast the level of electricity production costs based on combustion of natural gas and coal) were used. The adequacy of the models is indicated by the level of a training and test error of 2-5%.

As a result of the forecast it was obtained that the level of costs for the production of all types of electric power will decrease. The highest rate of decrease will remain for the unconventional energy sources: Wind power by 1.4 times and solar power by 1.9 times in 2018-2020 compared with the conventional ones: 1.1 times for gas, 1.04 times for coal, and 1.02 times for nuclear energy.

If the forecasted trends in the world energy market development are projected onto the Russian economy, the integrated economic performance indicator of production of alternative electricity types in 2020 will increase: To 0.43 for WPPs and to 0.35 for SPPs, while for the conventional ones – natural gas and coal-fired TPPs, as well as NPPs it will drop to 0.78, 0.45, and 0.75 respectively.

With regard to a change in economic efficiency, the global priority of electricity production by economic performance and environmental safety as of 2020 will redistribute as follows:
- Natural gas fired TPPs – 15.6%;
- Coal-fired TPPs – 6.3%;
- NPPs – 2.7%;
- WPPs – 15.4%;
- SPPs – 11.3%.

4. DISCUSSION

Thus, the expediency of unconventional energy development in Russia from the standpoint of environmental safety and economic performance was proved. Taking into account the trends towards reducing the energy cost using renewable energy sources and the rate of its reduction in price exceeding those of the conventional energy sources as of 2020, the highest production efficiency is expected for:
- HPPs – 21.1%;
- Natural gas fired TPPs – 15.6%;
- WPPs – 15.4%;
- TiPPs – 13.5%;
- SPPs – 11.3%;
- BPPs – 8.9%;
- Coal-fired TPPs – 6.3%;
- NPPs – 2.7%.

Integrated economic performance indicator and environmental safety index (a global priority) for each type of electricity were calculated by multiplying the economic performance indicator value by the environmental safety index value for a respective type of electricity and by finding the specific weight of this product in the total sum of integrated indices for all types of electricity. In terms of the energy sources, for which there is no statistical data on the economic cost behavior (oil-fired TPPs, HPPs, BPPs, TiPPs), the economic efficiency in the research remained at the level of 2017.

Based on the determinated global priorities of the utilization of renewable and conventional energy sources, the forecast model of Russian energy system performance has the following form:

$$I = 0.211 \cdot Q_{HPP} + 0.156 \cdot Q_{TPPng} + 0.154 \cdot Q_{WPP} + 0.135 \cdot Q_{TiPP} + 0.113 \cdot Q_{SPP} + + 0.089 \cdot Q_{BPP} + + 0.063 \cdot Q_{TPPc} + 0.052 \cdot Q_{TPPo} + 0.027 \cdot Q_{NPP} \rightarrow max$$

Where I is the integrated economic performance indicator and the environmental safety index of the country's energy system.

Thus, it is advisable to revise Russia's energy system structure at the present stage of its operation to develop and increase the share of alternative energy sources in the future. In particular, what will be the most effective for energy generation alongside with TPPs is an extensive use of water body in channel watercourses and tidal motions, the kinetic energy of the Earth, wind, and sun. In the short term, these energy sources can become equivalent in economic efficiency with energy production using natural gas. And, in turn, they would ensure the environmental safety of the country.

Improvement of the regulatory framework of the Russian Federation should be a basic measure that would stimulate the development of energy operating on renewable energy sources. For such statutory instruments to be of an incentive nature, it is necessary to elaborate them with regard to defining a procedure of increment to the wholesale electricity market equilibrium price while fixing the price for the electricity produced by using renewable energy sources. Also, the amount of reimbursement using public funds for the cost of utility connection of qualified generators of unconventional energy should be regulated.

In addition, the following should become a regulated economic leverage mechanism to stimulate the use and development of renewable energy:
- Determination of the status of consumers and producers of unconventional energy;
- Surcharges to energy tariffs as a state reimbursement of increased costs for the use of renewable energy sources by producers for a certain time;
- Provision of a preferential arrangement for connecting consumers to the unconventional power grid;
- Establishment of a mandatory mechanism for quoting the production and consumption of electricity from renewable sources;
- Establishment of a mechanism for granting tax benefits, concessional public loans, and investment subsidy programs to energy producers using renewable energy sources;
- Government support for industrial manufacturers of equipment for generating energy from renewable energy sources;
- Tariff settlement;
- Imposition of taxes on harmful emissions and environmental pollution by economic entities and their use as one of the sources to finance the development of unconventional energy;
- Establishment of accelerated depreciation for energy producers using renewable energy sources
- Formation of scientific potential for using renewable energy sources through public and private funding of research in the field of unconventional energy, allocation of research and

development grants, and holding project implementation tenders. The technological achievements would allow one to create power storage units, promote an increase in the efficiency factor of power stations using renewable energy sources and increase the chances to reduce the cost of their construction;

- Formation and implementation of government policy on Russia's international sectoral integration in the field of renewable energy. Development and intensification of cooperation with the International Renewable Energy Agency (IRENA) and other relevant international organizations would allow Russia to access the up-to-date best practices available in the area of renewable energy sources: Policy instruments, incentives, investment mechanisms, and advanced technologies in the area of renewable energy.

The development of renewable energy conversion technologies is of a highly intellectual, knowledge-intensive and innovative nature that ensures a steady increase in efficiency and a reduction in the material intensity and cost of the energy production. In this regard, training and professional development of relevant specialists engaged in the production of unconventional energy is taking on particular importance. Continuous training and professional development contribute to the growth of labor productivity, which helps to maximize the fulfillment of human potential through improving personal performance in the unconventional energy production. It is necessary to determine the needs of unconventional energy development in Russia and, based thereon, to create institutional capacity in the system of higher education and professional training and retraining of relevant staff. A coordinated approach needs to be applied to interlink planning, practice, and training in the use of renewable energy sources based on implementation of a transformational education agenda, as well as to encourage interdisciplinary training and collective practices.

Holding international trainings, conferences, international exhibitions, and developing international cooperation in the field of renewable energy sources would also improve skills of the workforce capacity.

- Attraction of private investments is another important factor in stimulating the development of unconventional energy in Russia. Introduction of a differentiated approach to taxation on the property of unconventional energy producers would incite to private investment activity, for example, granting tax holidays for tax payments when introducing innovative technologies to create conditions for improving the competitiveness of productive facilities; application of increased tax rates for taxation of worn-out and obsolete fixed assets in inventory, etc. However, such a position would be one-sided. Therefore, it is advisable to apply tax incentive methods not only to energy producers using renewable energy resources, but to venture companies and other investors that finance innovative projects as well. Implementation of such a mechanism would heighten the investor interest in supporting the unconventional energy development. It is necessary to draw upon the practice of foreign countries and introduce the following tax incentives for private investment for the development of renewable energy sources: Investment discounts on income tax; research tax credit; preferential conditions for depreciation of fixed assets; investment tax credit; investment subsidies; tax holidays; a wide range of preferential VAT rates for the sale of energy generated from renewable energy sources.

5. CONCLUSION

Based on the empirical research, the following conclusions were inferred from the study:

1. In the context of trends towards deterioration of the environmental situation in Russia, the question of developing the alternative energy production is being updated. Given the established energy system structure, the lack of development of appropriate innovative technologies, and a low demand with the population, the energy production using renewable energy sources has not been properly developed. At the same time, one of the constraining factors in the alternative energy development in Russia is erroneous interpretation of the level of its economic efficiency in comparison with the conventional sources of energy.
2. The developed projection model of a rise in Russia's energy system efficiency is based on substantiating the priority development of HPPs, TPPs and WPPs, TiPPs and SPPs. A combined energy production based on the use of renewable energy resources and natural gas would contribute to an increase in the economic efficiency of power generation and a growth of the country's environmental safety. Such a campaign would modify the national energy system structure of the country, based not only on accounting for economic benefits, but also with the focus on preserving the environment.
3. There are measures to be taken to develop the alternative energy production, to improve the regulatory framework, to improve the skills of personnel in the use of renewable energy sources, and to attract investment. Practical implementation of the proposed measures would ensure an increase in the interest of economic entities in the unconventional energy sector and increase the investment attractiveness of the production of renewable energy sources. This, in turn, would be a determining factor in improving Russia's environmental safety, especially for the recreational areas of the state.

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