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WORLD NUCLEAR ENERGY DEVELOPMENT TRENDS AND RUSSIA'S COMPETITIVENESS AT THE GLOBAL NUCLEAR MARKET

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Abstract

The paper is dealing with the world nuclear energy development trends and Russia's competitiveness at the global nuclear market. The problems of energy supply and energy security are among the most urgent in the modern world economy. The modern nuclear market consists of the natural uranium market, uranium conversion and enrichment services, nuclear fuel, the nuclear power engineering market, the electricity and capacity market, the market nuclear power plants construction and service. At all those specific markets Russia is competing with the number of developed nations and China. The regional development global nuclear market is based on diversification. Many new real and potential importers are emerging in Asia, Latin America and Africa. Russia needs a whole range of measures to strengthen its competitiveness, production and processing of nuclear fuel, nuclear technology, training highly skilled personnel. The authors are evaluating the level of Russian nuclear energy industry and its major company "Rosatom" competitiveness.

Keywords: nuclear power energy, global nuclear market, competitiveness, "Rosatom" company

JEL code: F5, F6, L1.

Introduction

Modern stage of the globalization processes is making rather contradictory impact on the national energy markets and the world economy as a whole. Major peculiarity feature of the current energy markets development in general, and nuclear energy markets in particular, is the tough competition at the following markets as the natural uranium market, uranium conversion and enrichment services, nuclear fuel, the nuclear power engineering market, the electricity and capacity market, the market nuclear power plants construction and service (including design and commissioning). The nuclear power development is gradually moving to the Asian region, as well as to the developing countries of Latin America and Africa. Among the states that enter the first stage of nuclear energy development are such countries as: Pakistan, Iran, Brazil, Argentina, Egypt, South Africa, Indonesia. For these markets, there will be a sharp competition between manufacturers of various nuclear power engineering technologies, fuel producers and the construction of nuclear power plants. Today, the issue of human access to electricity is one of the most acute, as it is clear from the report of the Center for Strategic Research lead by Alexei Kudrin (CSR) that currently about 1.3 billion people on Earth do not have access to electricity: "Potentially by 2035, new consumers will become 1.3 billion people who do not currently have access to electricity; 2.7 billion people who "cook on wood"; another 1.6 billion people - due to population growth in the world. This will lead to the fact that for the indicated period the consumption of electricity will grow by 40-50% "(TASS 2017).

The impact of the world economy globalization on nuclear energy is growing: the growth of concentration of capital, mergers and acquisitions in nuclear power, the creation of transnational corporations capable of large investments, innovations. Russian companies traditionally offering their services in the nuclear field are finding it increasingly difficult to compete with the world's largest giants from the US, France, Japan, and Germany in these regions. At the same time, the market for nuclear related services is becoming more competitive, customers demand, and companies offer a full range of services at low prices with high quality at short notice, new market players are emerging. Russia, which created its nuclear industry "behind the Iron Curtain" no longer remains in the nuclear power industry as a “separate island”. Internationalization of nuclear energy, integration with the largest participants of this market will allow Russia to get know-how, investments for the industry and additional opportunities to enter foreign markets.

The problems of energy supply and energy security are among the most urgent in the modern world economy and international economic relations. The stocks of traditional hydrocarbon energy deposits are limited by size, the contradictions between the exporting and the importing countries of various energy resources are exacerbated. In these conditions, the preservation of the existing structure of energy production is unacceptable. Including for economic reasons, since the search for efficient energy supply is impossible without the guaranteed energy security of national economies, controlling the cost of energy generation and tightening environmental requirements for energy production.

One of the problems solving directions is the large-scale development of energy production, which is not connected with organic fuel, which is taking place at the present stage. At the same time, the need to include a reliable, environmentally friendly and competitive source of electric power capable of carrying the basic load into the world energy balance allows us to talk about the non-alternative nature of the development of nuclear power energy (NPE) in the coming decades.

Russia is among the world leaders in the field of peaceful NPE use, and it is quite natural that its role in the global nuclear energy market should grow simultaneously with the increasing role of NPE in global economic processes. Currently, there is an acute competitive environment in the world market of NPE construction services. In this regard, Russia needs a whole range of measures to strengthen its competitiveness, production and processing of nuclear fuel, nuclear technology, training highly qualified personnel. For this, there are all possibilities. Russia is the largest nuclear power and has a large number of nuclear power plants (35 power units), facilities for the production and processing of nuclear fuel. The high technology presence, a significant raw material base, skilled labor, relatively low production costs, geographical location and stable economic growth of the industry are the competitive advantages of the nuclear power industry of the Russian Federation.

Starting from 2007, a major Russian nuclear industry reform is going on, aimed at consolidating the nuclear power industry of the Russian Federation within the framework of the State Corporation “Rosatom”. In accordance with the competitive market environment requirements, Rosatom should maximize and multiply existing NPE potential both within the country and globally. It is necessary to develop new uranium deposits, introduce modern highly efficient and environmentally friendly energy-efficient nuclear technologies, more efficiently and actively use the export potential in the construction and engineering of nuclear power plants, supply and reprocessing of nuclear fuel.

The relevance of the topic of this article also lies in the fact that new AE markets are already being formed and being formed, requiring appropriate technologies, fuel supply, financing and labor (China, India, Indonesia, Vietnam, Iran, Brazil, Venezuela, South Africa, Egypt , Malaysia, a number of states of the Persian Gulf and the Middle East, as well as the CIS countries). The competitive struggle for these markets will be a serious test for Rosatom, as its main competitors are the world's leading companies in France, Germany, the United States, Japan, the UK and, more recently, China and Kazakhstan.

Literature Review

The current state and probable directions of development of the world energy and in particular markets for products and services related to nuclear energy have long been the subject of theoretical and applied research, it is worth noting those of them in which one way or another affects foreign economic factors and the analysis of trends in the development of nuclear power plant construction markets. Rodionov (2010) considers the current state and possible directions of the development of the world energy in the conditions of the reduction of the reserves of fossil fuels. Sutyrin et al. (2018) discusses of competitiveness one of the largest energy Russian company Lukoil and its strategic investment decisions in Europe, the Balkans` case. Ogilvie-White (2010) in her report highlights the current state and considers prospects for the development of nuclear power in the Asia-Pacific region and in Taiwan in particular. Sullivan at al (2014) in their article are discussing the problems related to the energy balance structure future by nuclear and other types of energy in the US and other countries. Questions related to the public opinion when making decisions with the regards to the future of nuclear power are considered by Zhu et al (2016). Optimal control of "flexible" nuclear power plants by the example of the French Republic, as well as forecasts related to the future of nuclear energy and the future of alternative sources in their work are considered by Lykidi and Gourdel (2017). The authors focus on reducing the share of hydrocarbon energy sources in the world energy balance and note the expediency of placing "flexible" (dependent on demand for electricity) nuclear power plants that do not produce CO2 emissions and under certain conditions (operating conditions), flexible operation is necessary to ensure the stability of the electricity supply. In the part of the cluster analysis, the work of Kohonen (2012) is one of the special interest. It is also important to mention that the most of data used in the research provided by various International Atomic Energy Agency (IAEA) and International Energy Agency (IEA) reports, and RBC business portal materials.

Purpose, Hypothesis and Methodology

The article purpose is to evaluate the world nuclear energy development trends and Russia's competitiveness at the global nuclear market. The paper hypothesis is the following: the global nuclear power plants (NPP) construction market is shrinking, which leads to a slowdown in the world nuclear energy development in general and the NPP construction market in particular, and so greatly intensifies competition.

For the analysis and evaluation of the competitive environment, both classical methods of multidimensional statistical analysis (correlation, cluster and projection analysis) and methods of system data analysis (data mining) are used in the framework of the proposed methodology for extracting disconnected relationships and regularities in large data sets. One of the most effective methods for analyzing a competitive environment with a large number of competing objects are visual data mining methods with extensive possibilities for visualization of multidimensional data, for example, their mapping (Kohonen self-organizing maps) for

Identify interesting properties and patterns that are not available for conventional methods of system analysis of data. At the same time, the authors offer a comprehensive approach to solving various problems in the development of the nuclear industry through various types of analysis of a competitive environment: state analysis, dynamic analysis of changes and temporal analysis, based on methods for vector quantization, clustering, and visualization of multidimensional data. The complexity of the analysis of the competitive environment is summarized in the table of correspondences "the problem of the competitive environment - the data set used".

The methodological approach proposed by the authors to analyze the competitive environment consists of the following stages:

• formalization of the competitive environment in the form of a set of vectors in the characteristic space - to represent states or time series of competing objects in the form of multidimensional sets;

• vector quantization (in which the source vector is replaced by a model or referent vector averaged over a group of similar original vectors) - to remove noise and cut sharp emissions;

• visualization in space of smaller dimension - to facilitate the interpretation of clusters and trajectories;

• Clustering (separation of groups of objects with similar, similar states) - for grouping and interpreting competitive groups and multidimensional trends;

• rating (ordering of objects taking into account several evaluation characteristics) - to form rating categories on a set of competing objects.

Table 1. The set of initial data to be visualized and usage objectives in the competitive environment estimation task solving

The set of initial data to be visualized	The set of data usage objectives in the competitive environment estimation task solving
A (t)	1. To compare objects at the current time
A (t-1) + A (t)	2. For comparison of objects in the current t and the base t-1 times
	2.1. Comparison of objects by an individual feature p, analysis of the transition: AP (II) -> Ap (t;)
	2.2. Comparison of the states of an individual object x, analysis of the transition: AX (I) -> AX (1 :)
	2.3 Comparison of objects by all characteristics, analysis of the transition: [1,2, ..., T]
	3. For comparing objects in the period [1, 2, ..., T]
Sp = Sp (l) x ... xSp(T)	3.1. Comparison of objects along the time series: AP (1), Ap (2), ..., Ap (T),
Sx = Sx (l) + ... + Sx (T)	3.2. Comparison of the states of an individual object x along a trajectory: AX (1) ->, ..., -> AX (T),
S = S (l) + ... + S (T)	3.3. Comparison of objects along their trajectories AX (1)
S = S (1) x ... xS (T)	3.4. Comparison of objects by time series 8 (1), ..., 8 (T)

The above shown formalization and methodological approach to the competitive environment system analysis allow us to solve a wide range of tasks of the current, dynamic and trend analysis of the industry, including such tasks as:

– Definition of competitive positions, rating of competing objects, formation of competition groups;
– Assessment of positional and structural changes in a competitive environment;
– Identification of phases of development of competing objects, analysis of multidimensional development trends and convergence in a competitive environment.

Results

Reactors classification

The reactors classification is carried out to determine the distribution of industrial reactors for the most important characteristics: status and capacity. Since the status is a symbolic variable consisting of 3 values, it must be represented by four binary (0,1) variables: a status (closed) for its use in the construction of a classification model; status (under construction); status (acting). As a result, the initial data for the topological map are the current states of all reactors, given by 5-dimensional sets of characteristic values: power and 3 statuses. A combined map of the labels and a map of clusters is shown in Fig. 1.

Figure 1. Map charts and frequency map (bottom right)

All 677 reactors are reflected on the topological map with the help of name-labels, and according to the principle of location of objects on a topological map, similar reactors have close-lying labels.

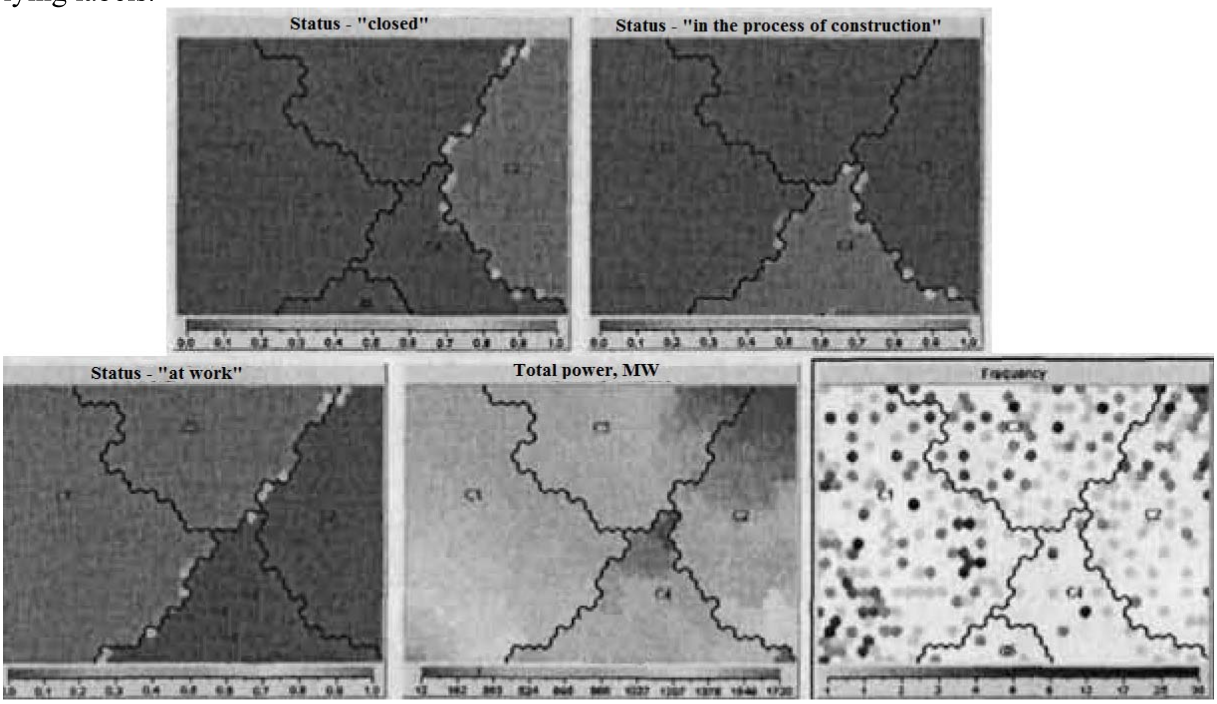

Figure 2. Clusters characteristics maps

By feature charts and cluster statistics (see Table 2), brief descriptions of the properties of clusters and the corresponding classification categories of reactors can be made.

Table 2. Cluster classification of reactors

Cluster	C1	C2	C3	C4	Result
Number of reactors	346	138	156	37	677
The share of reactors in%	51.2	20.4	22.5	5.8	

The first cluster C1 is comprised of 346 (51.2%) reactors and occupies the western part of the map, which is characterized by the status of "Effective" and high (at least 800 MH) power level. Cluster C2 consists of 138 (20.4%) reactors, occupies the eastern part of the map, which is characterized by the status of "Closed". Cluster C3 consists of 156 (22.5%) reactors, occupies the northern and central part of the map, which is characterized by the status of "Effective" and low (less than 800 MG) than cluster C1, capacity. Cluster C4 consists of 29 (5%) reactors, occupies the southern and central part of the map, which is characterized by the status of "under construction".

Assessment of the potential of the countries producing nuclear energy

We will carry out a comparative analysis of the energy potentials of the countries producing nuclear energy not only for the current (end of 2017), but also for their future development, that is, the reactors that are being built but not yet put into commercial operation. The comparative analysis is carried out according to the following set of parameters: manufacturing potential of producing countries, the number of reactors in different status (active, stopped, under construction), the total potential capacity of these reactors, including the stopped and under construction reactors, total energy production and NPE for 2016 year, as well as the percentage of produced NPE. The IAEA (2016) annual report says: "Today 30 countries possess nuclear power capacity, and approximately the same number of countries are studying the possibility of including nuclear power in the national structure of energy production ... Of the 30 countries, operating nuclear power plants, 13 are building new stations ..., 12 are planning Build new stations or complete suspended projects construction. According to forecasts made by the Agency in 2015 year, by 2030, the nuclear power capacity in the low scenario will increase by about 2% and with a high scenario - by 70%."

However, according to another source (Rosatom 2017):"After fulfilling the existing orders for the construction of new nuclear power plants abroad, Rosatom can remain without foreign orders, since this market is rapidly declining." This forecast does not consider a favorable growth scenario. Due to Sullivan at al (2014) "The use of nuclear fuel at nuclear power plants is not accompanied by the formation of carbon dioxide CO_2, and also does not create oxides of sulfur and nitrogen, leading to acid precipitation. Taking into account the calorific value, operation NPP around the world allows to save about 400 million tons of oil annually, which is a significant plus in favor of an optimistic scenario for the development of NPE”.

In forecasting, it is worth paying special attention to the current situation in Germany and Italy in the field of nuclear energy policy, as well as solutions using the so-called "flexible" NPP (See Zhu at al (2016)): "Technically, nuclear reactors are designed to be capable of switching an affordable operation." Italy constitutes a common example since rapid growth in the deployment of solar, wind and bio-energy in recent years, generating over 40% of its electricity from renewable sources and there are no plans for new nuclear reactors” (Italy 2017). Other countries however, such as the UK, China, South Korea and India are pursuing ambitious expansion plans for their nuclear power and many others are giving "serious consideration" to introducing nuclear power in their energy mix, Belarus) (See Anderson 2015). So, globally, it is important to maximize producers. Comparative analysis is carried out by means of preliminary multidimensional classification of producer countries using a topological map to identify groups (classification categories) of countries having similar characteristics (the above-described parameters of NPE potential). Comparative analysis of producing countries is based on ranking and rating of countries on the parameters of nuclear potential. Thus, it is possible to identify the leading countries and outsider countries in terms of nuclear potential and leaders by individual indicators.

Classification of producing countries

For the analysis 30 countries have been selected, however, Italy remained in the field of consideration. At present Italy, although it does not produce nuclear power (closed all its 4 industrial reactors), but expresses its intention to resume production of NPE at these stations in the near future, and also to start the construction of new nuclear power plants. In addition, after a preliminary analysis of the energy potential indicators, one indicator was removed from the list of performance indicators: "total energy production in the country" due to the obvious connection with a more informative indicator - the percentage of NPE production. Thus, the classification of 30 competing facilities - producer countries according to 6 estimated indicators: the number of operating reactors; number of closed reactors; number of reactors under construction; production of atomic energy, GW/h; share of production of nuclear energy,%; total reactor power, MW. To improve the quality of the classification model - the topological map, the following indicators were normalized: "production of atomic energy, GW/ h" and "total power of reactors, MGW". This was done in order to smooth out too large a gap between their values for individual countries. The topological map for producing countries is reflected in Figure 3, where all countries are divided into 6 independent clusters C1-C6.

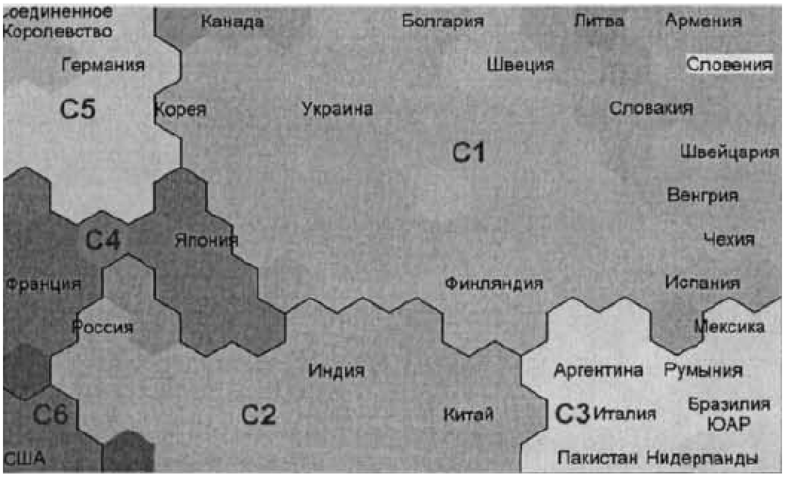

Figure 3. Map of clusters of producing countries

To describe clusters, so-called feature maps are used.

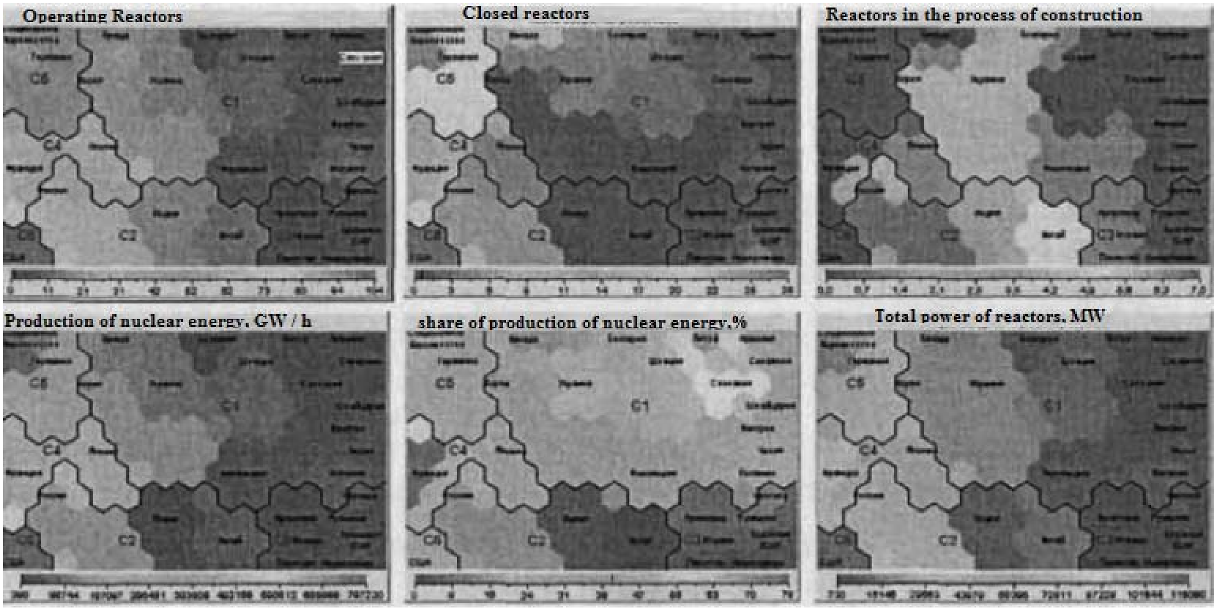

Figure 4. Characteristics Maps

The analysis of feature maps allows us to draw the following conclusions about the properties of each of the six clusters C1-C6. The first-largest cluster C1 is located in the north-eastern part of the map, where the values of almost all absolute indicators predominate: the number of reactors in all statuses, power and volume of production, except for% of the share of production of nuclear energy, which in this zone reaches average values. Cluster C1 contains 14 producing countries or 46.7% of all participating countries: Canada, Bulgaria, Lithuania, Armenia, Sweden, Slovenia, Korea, Ukraine, Slovakia, Switzerland, Hungary, Czech Republic, Finland, Spain. The second largest cluster C2 is located in the south of the map and is characterized by the largest values of the number of reactors under construction, having low or medium potentials for the remaining indicators. Cluster C2 contains only three producing countries or 10% of all participating countries: Russia, India, China. The next largest cluster C3 is located in the southeast of the map, where all the indicators of the production potential are very low. Cluster C3 contains 8 producing countries or 26.7% of all participants: Mexico, Argentina, Romania, Brazil, South Africa, Pakistan, Italy, the Netherlands. Cluster C4 occupies the western part of the map and has a high share of nuclear energy production and an average number of operating reactors. Cluster C4 contains only 2 producing countries or 6.7% of all participating countries: France, Japan. Cluster C5, located in the north-west of the map, it is characterized by a high number of stopped reactors and a low proportion of those under construction with average values of the remaining indicators. Cluster C5 contains 2 countries or 6.7% of all participating countries: United Kingdom, Germany. Finally, the C6 cluster, located in the lower left corner of the map, leads in all indicators, except for the number of reactors under construction and the % of the production of atomic energy. Cluster C5 contains one producer country or 3.3% of all participating countries: USA.

As can be seen in Fig. 5, the projections of centroids of clusters onto a diagonal are ordered by clusters in the following series: C6> C4> C2> C5> C3> C1 Compared to cluster ranking by the "first-place sum" method, the centroids method essentially changed only the order of the clusters C3 and Cb, leaving the rest of the clusters unchanged. To resolve the conflict between clusters C1 and C3, a pairwise comparison of their characteristics can be performed, rather than an order comparison. As can be seen C1 for all indicators above cluster C3. Apparently, the algorithm for constructing centroids has failed on the Cl cluster, incorrectly positioning its center, which is clearly visible in Fig. 5.

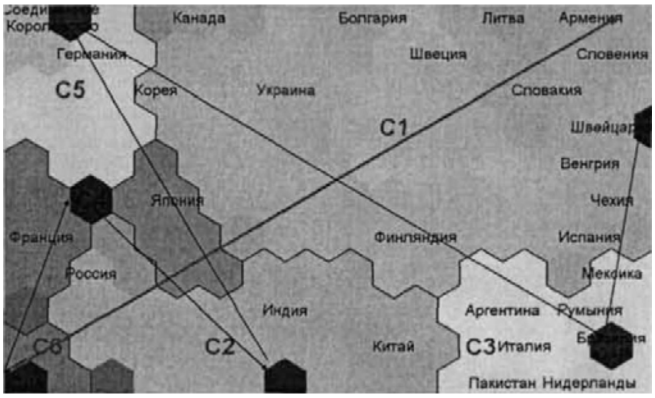

Figure 5. Rating of producing countries using centroids

Producers of AE can be rated as follows: Rating category A: USA; Rating category B: France; Japan; Rating category BB: Russia, India, China; Rating category C: UK, Germany; Rating category SS: Canada, Bulgaria, Lithuania, Armenia, Sweden, Slovenia, Korea, Ukraine, Slovakia, Switzerland, Hungary, Czech Republic, Finland, Spain; CCC rating category: Mexico, Argentina, Romania, Brazil, South Africa, Pakistan, Italy, Netherlands.

Analysis of world nuclear power industry development trends up to 2030

The authors will analyze the development trends of AE until 2030 in comparison with similar trends in total energy consumption and electricity consumption. Such an analysis is conducted at the level of all 8 regions of the world, including: North America, Latin America, Western Europe, Eastern Europe, Africa, the Middle East and South Asia, East Asia and Oceania, as well as the Far East. The analysis of development trends is carried out on absolute energy indicators, such as total capacity and total energy production, both for all power plants and nuclear ones, as well as for relative - % of nuclear energy among its other types, as well as the share of electricity per person in this region of the world. The forecasts are presented by time series of indicators for 2016, 2020 and 2030, and the forecast estimates for the period 2016-2030 are presented in two versions: optimistic (maximum value) and pessimistic (mini cial value). For the analysis of trends, a cautious development forecast is presented, that is, the minimum values of the indicators. First, the authors analyze the one-dimensional and two-dimensional trends in the development of energy in the regions of the world in terms of capacity and production. In addition, we perform a comparative analysis of the indicators in the initial year 2006 and the final year 2030 for assessing the change in the degree of concentration of world AE. Then we will estimate the prospects of AE growth by regions of the world in per capita terms and identify the leading regions.

The trends in the development of NPE are investigated according to 6 indicators: the total capacity of power plants (GW), the total capacity of nuclear power plants (GW), the share of NPP capacity (%), the production of electricity (TWh), the production of NPE (TVH), the share of production of nuclear energy (%). And the dynamics of these indicators is investigated in the following types of analysis:

• dynamic, when the values of indicators are compared at the beginning and end of the forecast period;

• one-dimensional trend analysis, when the time series of regions are compared by a separate indicator;

• multidimensional trend analysis, when the trajectories of the development of regions, including the dynamics of all the indicators at once, are compared.

Dynamic analysis. Let's see how the distribution structure of the regions of world production of nuclear energy in 2030 can change in comparison with 2016. For this, it is necessary to compare the Pareto diagrams in 2016 and 2030 (Fig. 6),

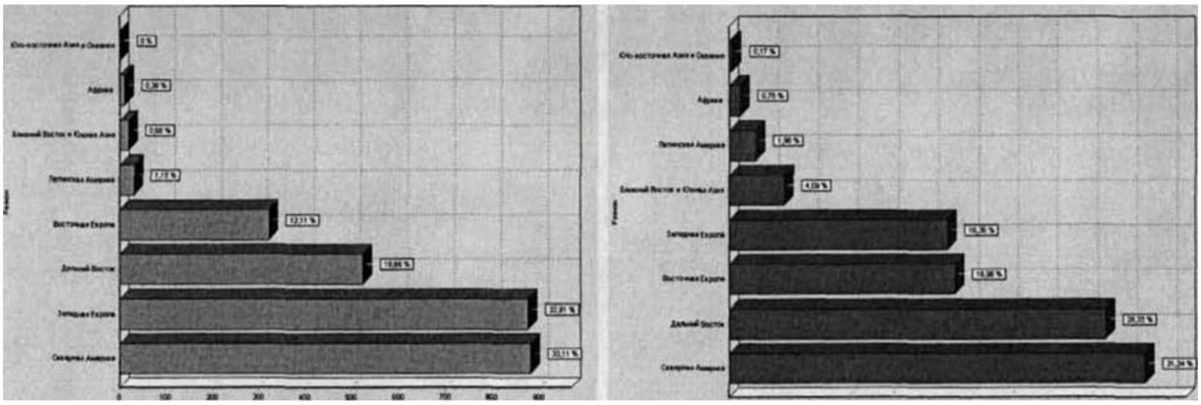

Figure 6. Pareto diagrams for the production of atomic energy

The diagrams show that North America (31.3%) remains in the first place in AE production in 2030, as in 2016, while the Far East (28.3%) left the second place, pushing Western Europe by 4 a place. The third place was occupied by Eastern Europe (17%), and the fifth place, pushing back Latin America, the countries of the Middle East and South Asia came out. In general, the structure of distribution of nuclear energy production by regions of the world will change towards a decrease in concentration, as seen in Fig. 6, which shows the Pareto curves for the years 2006 and 2030.

Conclusions

The world nuclear energy development trends are diversified and to some extant controversial. The global nuclear power plants construction market is shrinking, which leads to a slowdown in the world nuclear energy development in general and the NPP construction market in particular, and so greatly intensify competition.

Russian nuclear industry is very important part of the national economy. To keep the current level of competitiveness and especially to increase it Russian nuclear energy monopoly “Posatom” needs to pay a lot of attention towards the company efficiency, capacity building, strategy development, etc.

Acknowledgments

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