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Assessment of Factors Impeding Technological Development of the Electric Power Complex (The Russian Case Analysis)

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Abstract
The research covers the factors that hinder technological development of the electric power complex. The purpose of it is to assess the significance of these factors further to consider while the industrial policies targeting. The research is realized by means of matrix models and mathematical processing of statistical data methods, the ranking, grouping, and comparative analysis incl. The analysis methodology is based on the analysis of the topical publications considering the classical matrix models and metrics of factors impeding the technological development modeling.

Key-words: Electric Power Complex, Technological Innovations, Matrix of Obstacles, Sectoral Variability, Rank.

1. Introduction

Nowadays, the development goals of the global energy industry, with the electric power industry being an important part thereof, are determined by the so-called "energy trilemma" (WORLD ENERGY COUNCIL, 2013), promoted by the World Energy Council (WEC). It is an extension of the three-pronged sustainability concept which involves economic, social and environmental components along with the solutions to tackle them (UNITED NATIONS, 1992) to the power industry. The energy trilemma is meant to integrate the following dimensions:

- security and reliability of power supply.
- access to energy resources for different segments of the population.
- mitigating environmental harm from energy systems.

Based on the energy trilemma, the World Energy Council performs an annual quantitative assessment of national energy systems using three indices: Energy Security, Energy Equity and Environmental Sustainability of Energy Systems. Within this framework, the final World Energy Trilemma Index (WORLD ENERGY COUNCIL, 2019b), indicating the rankings of countries on the Trilemma scale is defined. In 2019, according to the value of this index across a sample of 128 countries, Russia, which provided evidence for this case study of the electric power industry, ranked 42 (WORLD ENERGY COUNCIL, 2019a) between Bulgaria (rank 41) and Singapore (rank 43). Russia performed well in the Energy Security index (rank 25) and the Energy Equity index (rank 18). At the same time, there is a major setback in Environmental Sustainability (rank 96). Note that its "neighbour" Bulgaria has shown more balanced results: the rank values of all three indices do not exceed the range of 30 to 50. As for the second "neighbour" Singapore, there is a setback observed in the Energy Security index (rank 123) against the background of good results in the Energy Equity index (rank 10) and the Environmental Sustainability index (rank 37). These indices enable to assess the overall balance of national policies across the three dimensions of energy development that compete for investment and compare the result to that of other countries. A specific index (i.e., the Environmental Sustainability) being at a disadvantage relative to other countries can be validly interpreted as a signal for priority government actions.

Following the Energy Trilemma requires finding of cost-effective means of its practical implementation, including the development and adoption of innovative solutions, specifically in the electric power complex. In terms of practical implementation, an important extension to the Energy Trilemma is the formulation of energy development goals through four elements: energy efficiency and the so-called "three D" – decarbonization, decentralization and digitalization (DI SILVESTRE et al., 2018). Decarbonization occurs due to the development of effective technologies using RES – renewable energy sources (BARINOVA; LANSHINA, 2016; BORISOV, 2018; SHEINA; PIROZHNIKOVA, 2016). This leads to the acceleration of decentralization. The need to effectively manage complex distributed systems increases the demand for digital technologies (MOREVA, 2019).

A number of works are devoted to the introduction of new technologies in the electric power sector. For instance, the paper (ALEXANDROV, 2013) analyzes knowledge-intensive technologies as a basis for implementing innovative development programs (IDP) in Russian electric power companies. At the same time, special attention is paid to the prospects of the Smart Grid concept. In (ALMASTYAN; RATNER, 2018), the issue of technological modernization of power generation capacities through the introduction of eco-innovations is considered, which is relevant, in particular, for Russia. The paper (DULOV, 2011) is devoted to the analysis of technological innovations that contribute to the sustainable development of the Russian electric power complex and its sectors. The study (AMAKHINA, 2017) focuses on technologies that form the basis of technological development of electric distribution companies in the world. Based on specific examples, the author demonstrates the importance of technological solutions that are driven by demand-side requirements. The issue of introducing new technologies is considered in this paper in conjunction with the optimization of management systems. The research (PWC, 2016) provides an overview of breakthrough technologies that will determine the future of the world's electric power industry in the next 5-10 years.

The pressing challenge of implementing technological innovations in the electric power industry requires identifying and removing key obstacles on this path, the object to be discussed below.

2. Methods and Models

The research method used in this paper for the electric power complex is based on a matrix of obstacles to technological development. The matrix under consideration is the result of combining classical matrix models. Statistical data processing, ranking, and grouping methods are used to calculate matrix elements.

Matrix models are used in economics to solve various problems. Depending on the functional destination, several groups of matrix models can be distinguished. The first group is intended for solution of strategic analysis problems. It includes: Ansoff matrix (ANSOFF, 1957), BCG matrix (MADSEN, 2017), SWOT analysis matrix (GÜREL; TAT, 2017), McKinsey matrix (TSAKALEROU, 2015), etc. An overview of this group of matrices is given in the paper (GOLDSTEIN, 2000). The following group of matrices is used when analyzing trade flows (BECK et al., 2006) or demographic flows (VAKULENKO, 2015) between regions. Another group of matrices is used in the analysis of material and financial flows between industries or institutional sectors of the economy. It includes: input-output matrix (LEE, 2006) and Social Accounting Matrix (MAINAR-CAUSAPÉ et al., 2018).

The matrix of obstacles to technological development used by us for the electric power complex combines structural categories from classical matrices.

One of them is to display obstacles potentially significant to technological development of the electric power complex. This includes obstacles that are internal to power companies, for example, the lack of personnel with the required qualifications. If we draw an analogy with the SWOT analysis matrix, the area of internal limitations of a company's development should be applied to. It is also necessary to take into account the obstacles external to electric power companies. One example would be non-optimal legislation in the national energy regulatory framework. Here, one can draw a parallel with another structural area of the SWOT analysis matrix: external threats to a company's development.

The second structural area of the matrix we are interested in is to account for sectoral variability of obstacles in the electric power complex. It is to display the sectors of the electric power complex. Here one can trace an analogy with matrices, in which the object is divided by sectors of activity to form rows and columns and to result in a square matrix. For the matrix of the electric power complex in question, in addition to the structural division by sectors of activity, it is also necessary to perform a structural division that reflects the obstacles to technological development, as indicated above. This matrix, unlike, for example, the input-output matrix, is rectangular. We used a similar matrix to analyze the agro-industrial complex (OBOLENSKAYA et al., 2019).

Considering the above, the *matrix of obstacles* to technological development is to constitute a rectangular m*(n+1) matrix. The matrix elements at the intersection of (m) rows and (n+1) columns are ranks that characterize the significance of factors that hinder technological development of the electric power complex and its sectors. Each of m rows in the matrix corresponds to a specific factor. The first column in the matrix corresponds to the electric power complex as a whole and the remaining n columns correspond to its sectors.

Selecting the rows in the matrix of obstacles. For developed countries international standards for monitoring innovative development (including technological development) are set by the Oslo Manual (OESD, 2005). These standards are to a large extent followed by Russia and are analyzed in the case study of the electric power complex in this paper.

The Oslo manual can serve as a methodological basis for selecting the rows in the matrix of obstacles when analyzing the electric power sectors of the countries which follow its pattern. According to it, it is recommended to include information about factors that hinder innovative development in statistical surveys of national companies. Thus, the five typological groups of factors have been identified for regular observation.

The first group contains financial factors: financial and investment risks; insufficiency of a company's own funds to invest in innovations; scarce opportunities to raise external funding, etc.

The second group involves factors related to a company's lack of knowledge: information obstacles (including knowledge of markets and technologies); skills shortages; weak research groundwork, etc.

The third group covers factors that characterize the (non-) optimality of market parameters: uncertainty of demand for new products; difficulties in entering potentially promising markets due to their engagement by competitors.

The fourth group includes institutional factors: infrastructural barriers and legal and regulatory constraints.

The fifth group is reserved for factors that fall out of the four main groups.

Factors from the five groups can be applied to form rows of the obstacle matrix related to the electric power complex. The content of the matrix rows is to be determined by the extent of coverage of these groups in a country's national monitoring system.

With this a number of developing countries rely on the Bogota Manual for monitoring innovation development (UNESCO, 2001). It summarizes the peculiarities of countries revealed in practice outside the OECD and the EU. The relevance to track them is recognized in the Oslo Manual also. It notes that in developing countries information support for national economic policies constitutes the essential ground for monitoring innovation activities. Such task is apprised to be of higher priority than ensuring that national statistics as comparable to other countries. This can also be attributed to the problem of selecting the obstacles which are to be examined on a regular basis.

Bogota Manual can serve as a methodological basis for selecting the rows of the obstacle matrix when analyzing the electric power industries of countries oriented towards these standards. According to them, it is recommended that information on factors affecting innovation be included in statistical surveys of national companies. Three groups of factors have been identified for regular monitoring. Each of them corresponds to a certain level of management: micro-level, meso-level, macro- and meta-level.

The first group contains microeconomic factors: a company's groundwork for innovation; availability of qualified personnel; organizational challenges; aversion to new developments; risks associated with innovations; payback periods of innovations, etc.

The second group includes meso-economic or market factors: market size and structure; industry dynamism; marketing difficulties; consumer response to new products and services; opportunities for cooperation with potential partners; availability of new technologies; incentives for innovation; financial and investment opportunities, etc.

The third group is of macro- and meta-economic factors: availability of information about markets and technologies; regulatory institutions including those related to science and technology, standards, taxation; physical infrastructure; protection of intellectual property rights; sophistication of centers for professional development, etc.

The factors of the three groups are to contribute for the rows in the matrix of obstacles for analyzing the electric power complex and its sectors. The content of the rows is determined by the extent of coverage of these groups in a developing country's national monitoring system.

The opportunities to consider the recommendations of the two manuals when elaborating a list of obstacles for the development of national monitoring systems are discussed in (OBOLENSKAYA, 2016).

Selecting the columns in the matrix of obstacles. To form columns of the obstacle matrix, it is necessary to distinguish various sectors in the structure of the electric power complex. Given the specific nature of its companies and regulatory bodies in different countries, the structural models of the electric power complex will display national peculiarities. At the same time, several different structural models may be applied in the same country, depending both on how the electric power complex is decomposed and whether elements of the environment are considered. The same may be also applied to Russia, which is the case studied in this paper to analyze the electric power complex.

According to the structural model (GIBADULLIN, 2013), the Russian electric power complex includes: generating companies (wholesale generating companies (WGC), territorial generating companies (TGC), nuclear power plants, Hydro-WGC, etc.); Federal Grid Company; Interregional Distribution Grid Companies Holding; retail companies; maintenance and service companies, etc.

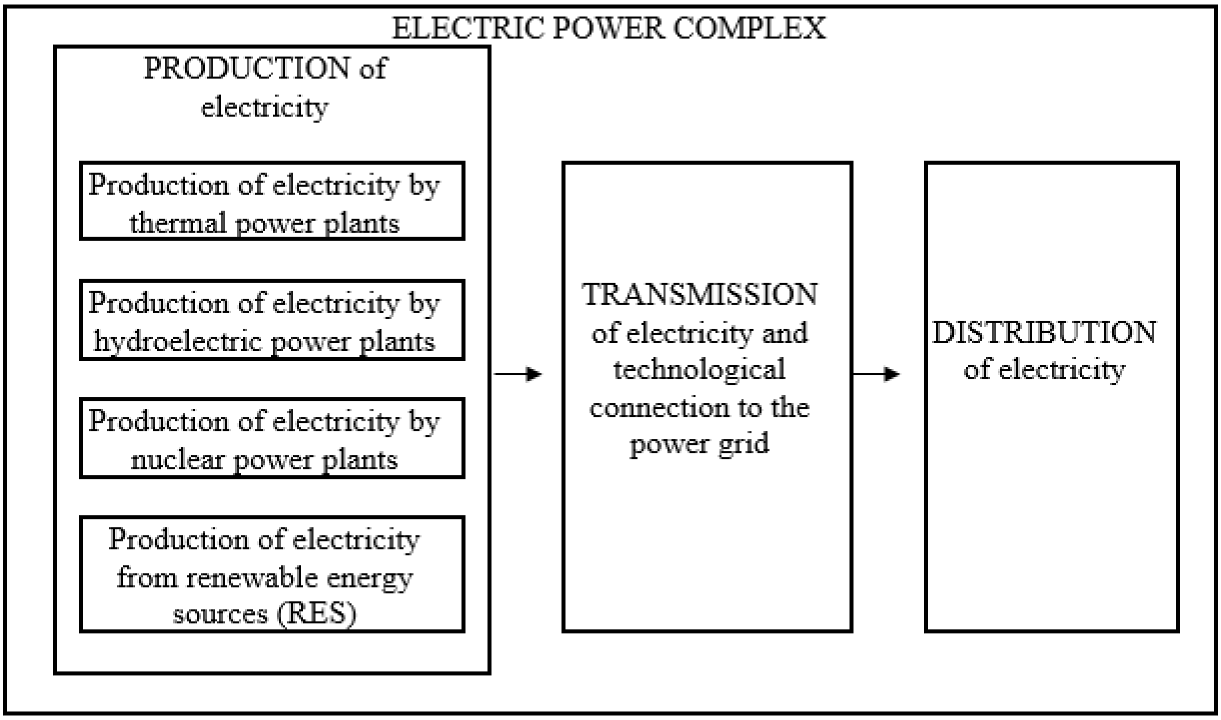
The article (DORONICHEV, GUSAK, 2012) presents the structure of the Russian electric power complex as follows: generation; transmission system with a separate indication of "FGC UES" JSC and RAO ES Vostok; distribution grid companies with a separate indication of "IDGC Holding" JSC and retail companies, as well as facility management companies and companies responsible for the infrastructure development.

Another structural model (URAZOVA; GALAGAN, 2017) provides the following segmentation of the Russian electric power complex: the sector of companies responsible for infrastructure; the sector of generating companies; the sector of electric grid companies and energy retail companies. The infrastructural sector is in turn split into two subsectors: the one focused on commercial infrastructure and the other focused on technological infrastructure. The study also provides details on the Federal government authorities that manage the electric power complex.

A more universal way to allocate structural elements in the electric power industry which is suitable for use in different countries is provided by the model based on the international statistical classification of economic activities NACE Rev. 2 (EUROSTAT, 2008). This classification system is used by national statistical monitoring systems of different countries to ensure international comparability and regularization of data collection in a particular country. It is advisable to use it when selecting columns in the matrix of obstacles intended for analysis of the electric power complex. The content of the matrix columns will be determined by the extent of coverage and completion of items from NACE Rev. 2 in a country's national monitoring system.

Russian national statistical monitoring system is based on the All-Russian classification of economic activities OKVED2 (2014), which is harmonized with NACE Rev. 2. Fig. 1 highlights the main sectors of the Russian electric power complex for which statistics are collected.

Figure 1 - The Main Sectors of the Electric Power Complex, Reflecting the Types of Economic Activities from OKVED2 Which is Harmonized with NACE Rev. 2



Source: compiled by the authors

While forming the columns of the considered matrix of obstacles for our case study of Russia, we will rely on the structural model of the electric power complex displayed in Fig. 1.

Calculation of the elements of the obstacle matrix. Elements of the matrix of obstacles (ranks) are calculated based on the following algorithm.

A column of the matrix corresponding to a certain sector of the electric power complex is selected. Upon processing of statistical data, the share of companies (% among all respondents in the given sector) that rated it as highly significant is determined for each obstacle factor. Rank 1 (highest significance) is assigned to the obstacle factor with the highest share. Accordingly, the rank m (lowest significance) is assigned to the obstacle factor with the lowest share. This algorithm for

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evaluating the obstacle ranks is applied one by one to each sector of the electric power complex, as well as to the electric power complex in general.

Such generated matrix may be used as a tool to analyze obstacles to technological development of the electric power complex, taking into account the sectoral variability.

3. Results and Discussion

Based on the above method, a matrix of factors impeding technological development of the electric power complex was elaborated for Russia. Statistical surveys on factors that hinder innovation development are conducted only in even-numbered years. Accordingly, we used the latest data provided by Russian companies in 2018 for the three-year period from 2015 to 2017 (ROSSTAT, 2017; 2019). The study covered a sample of Russian companies that have implemented technological innovations. The matrix in question is shown in Fig. 2.

Figure 2 - Matrix of Factors Impeding Technological Development of the Electric Power Complex: Russia

Obstacles to technological development		Electric power complex and its sectors: Electric power complex	Production of electricity	Transmission of electricity and connection to the power grid	Distribution of electricity
Most significant	High cost of innovation	1	1	1	1
	Insufficient own funds	2	2	2	2
	High economic risk	3	4	4	3
	Uncertainty of economic benefits from the use of intellectual property	4	5	3	4
	Insufficient financial support from the state	5	3	5	6
Moderately significant	Insufficient legislative and regulatory instruments that control and encourage innovation activities	6	6	6	5
	Insufficient development of the innovation infrastructure	7	7	7	8
	Insufficient information about new technologies	8	11	8	9
	Low innovative capacity of a company	9	8	11	7
Least significant	Lack of qualified personnel	10	9	10	11
	Low demand for new products, works, and services	11	10	9	13
	Lack of cooperation opportunities	12	13	12	10
	Insufficient information about sales markets	13	12	13	12

Source*:* calculations based on data from Rosstat (2019).

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The rows of the matrix correspond to 13 factors that hinder technological development of the Russian electric power complex. They are arranged from top to bottom in order of decreasing significance for the electric power industry as a whole. The obstacles are divided into three groups: the most significant for the electric power complex, the moderately significant and the least significant.

The columns of the obstacle matrix are: the electric power complex in general and the three major sectors in its structure. When setting the level of detail, the availability and integrity of statistical data have been considered.

It is convenient to analyze matrix elements using three blocks of obstacles: the most significant for the electric power complex in general, the moderately significant and the least significant.

Block of obstacles that are most significant for the electric power complex. The block under consideration includes financial and economic obstacles: related to finance and financial and economic risks.

Financial and economic obstacles turned out the most significant (ranks 1-5 with one exception) not only for the power complex in general but also for its sectors. At the same time, some isolated manifestations of sectoral variability are observed. For instance, insufficient financial support from the state was most significant for the "Production of electricity" sector (rank 3) and least significant for the "Distribution of electricity" sector (rank 6).

Block of obstacles that are moderately significant for the electric power complex. This block includes obstacles that are next in significance to the financial block (ranks 6-9). Here, the top significant obstacles are associated with:

- Legislation (rank 6);
- Innovation infrastructure (rank 7);
- Information about new technologies (rank 8).

In this block, sectoral variability manifested itself to the greatest extent. For example, ranks of "low innovative capacity of a company" vary across sectors from 7 to 11. This obstacle is most significant for the distribution of electricity (rank 7). At the same time, it is the least significant for the transmission of electricity and grid connection (rank 11). Another example relates to the lack of information about new technologies. Companies operating in power transmission and distribution are most deficient in this respect (ranks 8 and 9). This factor is less critical for the production of electricity (rank 11).

Block of obstacles that are least significant for the electric power complex. This includes obstacles that are least significant for the electric power complex in general (ranks 10-13 with a few exceptions).

There is also a manifestation of sectoral variability. For example, the factor of low demand for new goods, works, and services inhibits technological development of companies operating in power generation and transmission most strongly (ranks 9 and 10). For companies in the electricity distribution sector, "low demand" ranks last (rank 13) among all obstacles to technological development.

The approach we applied above to analyze the obstacles to technological development of the electric power complex of Russia can be applied to analyze these in other countries as well.

4. Conclusion

1. The paper reveals an approach of the analysis of obstacles to the electric power complex technological development formulated to consider their sectoral variability as well. The approach is based on a matrix interpretation of obstacles to technological development, developed by means of combining classical matrix models. Statistical data processing, ranking, and grouping methods are used to calculate matrix elements. Based on the proposed approach, the obstacles to technological development of the electric power complex have been analyzed considering the sectoral variability and using the data from Russia.

2. The analysis realized has shown that for the Russian electric power companies, the most significant obstacles are related to finance, financial and economic risks, including weak financial capabilities, high cost of innovations, and uncertainty of economic benefits from their application. Financial and economic obstacles are followed by the next three important obstacles associated with legislation, innovation infrastructure, and information about new technologies.

3. It is shown that along with general trends, there is a sectoral variability of obstacles to technological development. In particular, it refers to such obstacle as a lack of information about new technologies. Companies operating in the power transmission and distribution sectors suffer from a significant shortage of such information. This factor is less critical in comparison with other obstacles for the power generation companies. Another manifestation of sectoral variability concerns the low innovative capacity of companies. This obstacle is most significant for the distribution of electricity. It is the least significant for the transmission of electricity and grid connection.

4. The approach to analyze the obstacles to technological development of the electric power complex in Russia can be well applied to various countries. The information on the criticality of obstacle factors will be useful in determining the priority of industrial policies to neutralize them. The consideration of the sectoral variability will help to improve the targeting and effectiveness of these policies.

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