Technology to Ensure Energy Security in Development of Russia's Energy Strategy

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***Abstract* — The paper discusses the primary challenges facing Russia's energy security in the context of energy development plans presented in the Energy Strategy of Russia until 2030. The study examines the development of a methodological framework for the identification of areas in which the suggested solutions for Russia's energy development must be adjusted to meet the energy security requirements. The paper involves research based on a multi-criterion model via combinatorial modeling. The research findings make it possible to formulate the energy development direction that best meets the requirements of energy security. An algorithm for the research and an illustrative example are presented.**

***Index Terms* — energy security, energy strategy, threats, modelling.**

I. Introduction

Energy security in terms of the economy and population of a country is understood as a condition of being protected against shortage of economically accessible energy resources of acceptable quality, and against energy supply disruption. For normal operation of the energy sector the condition of being protected implies, in a long-term context, satisfaction of the country's demand for electricity, heat, boiler and motor fuel. In extraordinary situations, for example, severe emergencies at energy facilities, the condition of being protected supposes assured minimum necessary energy supply to the country's vitally important consumers.

One of the most important goals of Russia's national policy is to ensure energy security. This goal has become considerably more urgent in the last 20 years due to internal and external factors. The transition to a market economic model is complete, and the adverse effects of the 1990s have been mainly overcome. However, signs of crisis are still observed in some sectors and regions. Studies on energy security are a significant component of the national security policy.

The energy sector is the most important component of the Russian economy, providing employment for the population, the functioning of productive forces, the consolidation of regions and a considerable part of government revenues and currency receipts. In 2017, the share of value added by energy industries of the GDP of Russia was more than 31 percent, while that of exports was 67 percent and that of tax proceeds to the Russian Federation budget system was more than 49 percent. In our estimates, Russia's fuel resources comprise approximately 6 percent of the world's oil, 18 percent of its coal and 24 percent of its natural gas reserves. Furthermore, the energy sector is the largest consumer of products made by other branches of the economy and should play a leading role in its technological development and upgrading.

For Russia, as a major exporter of energy resources (more than 10 percent of global exports), energy security also means energy sovereignty and nondiscriminatory access to external markets, which could minimize the impact of noneconomic factors on the activity of Russian companies.

II. Research Methodology

A. Main targets of the Energy Strategy of Russia until 2030

The concept of long-term national development underlying the Energy Strategy of Russia until 2030 (ES-2030) envisages large-scale structural transformations in the economy in terms of both GDP and the sector of industrial production. The market demand is supposed to foster the outpacing development of less-energy-intensive sectors of industrial production that specialize in high-technology and science-intensive products, while energy-intensive production will develop much more slowly, which should result in the structural transformation of Russia's economy towards less-energy-intensive sectors and industries.

According to the ES-2030, in the first stage of its implementation (2010–2015), prospecting work will be

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activated in the traditional areas of energy resource production. Moreover, all necessary conditions (normative, including legal, tax, institutional, etc.) will be created to develop a mineral resource base of the energy sector in remote and difficult-to-access areas of the country, including East Siberia and the Far East, the shelf of the northern seas and the Yamal Peninsula. A centralized vertically integrated system for the control of mineral resources will be created to allow their most efficient and comprehensive development. By the end of the first stage, the ratio of the annual additions to reserves and the volume of energy resources production will near 1.

In the second stage (2016–2022), active development of oil and natural gas will start in East Siberia; the Far East and shelf areas, including the areas in the Russian sector of Arctic; on the Yamal Peninsula; in the Gulfs of Ob and Taz; the European North; and the Caspian Region. The prospecting work will be performed by advanced technologies using 3D seismic methods. The volumes of prospecting will rise, and its efficiency will be enhanced. This will provide a steady re-production of the mineral resources of the main industries within the energy sector.

In the third stage (2023–2030), the development of the new areas will be continued based on advanced exploration methods and technologies, through public-private partnerships and the attraction of investment, including that from foreign investors. Maintenance of the production volumes of energy resources will call for considerable capital investment in advanced technologies for their exploration and production. Energy resources in the main areas of their production will decrease.

It must be noted that Russia has long faced serious problems hindering the accomplishment of the plans formulated in ES-2030. These are strategic threats to energy security.

B. *Strategic threats to Russia's energy security*

Despite the stabilization of the gross energy indicators and their subsequent increase, there are some negative trends in Russia's national and regional energy development:

- the quality of hydrocarbon resources involved in the economic turnover steadily decreases, the efficiency of exploration is insufficient, and the share of difficult-to-extract reserves rises;
- the wear of fixed production assets in the energy sector is impermissibly high, while the rates of their renewal and creation of construction reserves are low, the service life of most of the facilities has expired, and there is an obvious lag between the domestic energy sector and the world scientific and technological standards;
- emergency situations affecting the fuel and energy supply systems of the country and its regions arise;
- no progress has been made in energy conservation;
- investment shortage in the gas and electric power industries (no more than 70 percent of the funds envisaged in ES-2030 are invested in their development);
- the diversification of the energy balance structure remains insufficient (the natural gas share in the primary energy balance exceeds 50 percent, and that in the fuel balance amounts to approximately 70 percent). The energy sector of European Russia is characterized by uneven availability of natural energy resources;
- the price and tax policies remain inflexible, which leads to a considerable rise in energy carriers' prices for final consumers. The high prices of energy resources and low efficiency of their use decrease the competitiveness of products made by Russian enterprises and bear heavily on the budgets of all levels.

The key strategic threats to the energy security of Russia were discussed in [1-4 and others]. These threats are wasteful energy consumption, slow elimination of gas and coal price distortions, a lag between additions to the explored reserves of hydrocarbons and their production volumes, a reduction in gas production due to the economic risk of the developing gas resources of the Yamal Peninsula and shelf of the northern seas, an extremely high share of natural gas in the energy balance of Russia's European regions, an insufficient level of investment in the energy industries, severely worn equipment and low equipment upgrading rates in the energy sector.

C. *Possibilities of satisfying the domestic demand for fuel and energy in Russia*

The negative consequences of the considered strategic threats are applicable to the entire country and all entities of the Russian Federation. Realization of the threats in the considered time horizon can considerably change the estimates of the level of development required for various industries within the energy sector presented in the documents that underlie the Energy Strategy of Russia until 2030. The studies carried out in [2] show that the potential realization of strategic threats to energy security may be assessed through the indicators of primary energy production in Russia.

The comparison of the targets set in the Energy Strategy of Russia until 2030 and the prospective production volumes of primary energy resources in Russia in the event that the strategic threats to energy security materialize shows that the realization of strategic threats to energy security may cause serious problems with the achievement of the targets for the production of primary energy resources outlined in the Energy Strategy of Russia until 2030. Thus, the attainment of an acceptable level of energy security for Russia in the medium- and long-term future requires considerable additional efforts by the State, energy companies and consumers.

The energy security of the country can be ensured and obligations to the world community fulfilled provided that the strategic decisions are made at the governmental level. To overcome the shortage of investment in the energy sector (including prospecting work) and intensify the upgrading of worn and obsolete equipment in the energy industries and the expansion of their capacities, it is crucial to create a favorable investment climate for and enhance the economic efficiency of energy enterprises. It is also necessary to restructure the energy balance of the country, by increasing the shares of coal, nuclear energy and, where possible, renewable energy sources, and reducing the predominant role of natural gas. To ensure energy security, it will also be very important to enhance the energy efficiency of the economy, which can be implemented through the upgrading of the basic production assets in the energy industries.

It is essential to consider the issues of energy security when addressing the problems of energy development management in different countries. The national energy development options to be generated for the medium- and long-term future should give comprehensive consideration to the realizability of different strategic threats to energy security and the issues of reliable fuel and energy supply to consumers, particularly in emergency situations. In this case, energy security means that the population and economy of a country are protected from the threat of shortage of economically available energy resources of acceptable quality both currently and in the long term, and in both normal and emergency situations [1-4].

The level of energy resource self-sufficiency from an energy security standpoint differs from country to country. However, the following key factors are common:

- the ability of the economy and energy sector to supply energy carriers continuously and in sufficient amounts, thus creating the energy prerequisites for the sustainable functioning and development of the economy and for the maintenance of an adequate standard of living for the population;
- the ability of consumers to consume energy efficiently and limit its demand, thus decreasing the energy imbalance;
- the balance between energy supply and demand, considering the economically sound volumes of energy export and import;
- favorable socio-political, legal, economic and international conditions for the implementation of the indicated abilities by producers and consumers of energy resources.

How can we take into account the energy security interests in a variety of probable scenarios of economic and energy development of a country?

D. Energy security monitoring and indicative analysis

It appears that one of the necessary conditions to solve this issue is to develop an energy security monitoring system with corresponding indicators characterizing the most critical aspects of energy sector operation and potential development.

The values of these indicators should adequately describe the composition and degree of energy security threats to a country to make it possible to analyze emerging or fading negative trends. Complex interrelations and interdependences in the energy sector can bring about a rather large number of such indicators. Some of them can be specific and are calculated on the basis of primary data on the state of some process, and the others can be integrated to generalize some close or interrelated processes.

Many researchers in the world have identified the most significant indicators. In Europe, this issue is covered in [5-10], among others. In [11] the authors describe possible strategies to improve the situation with energy security by reducing the use of carbon in the Irish energy system. In [12], the authors describe a new energy security indicator. The paper presents a case study involving 28 European Union countries, as well as determines the level of impact of six different indicators on energy security. In [13], the authors discuss the topic of short- and long-term energy security assessment methods and indicators. The authors of [14] report the findings on the following: energy security definitions, changes in the themes of these definitions, energy security indexes, specific focused areas and methodological issues in the construction of these indexes, and energy security in the wider context of energy policy. The authors of [15] provide an overview of methodologies used for quantitative evaluations of security of supply. The research in [16] is devoted to the influential approach – the "four As of energy security" (availability, accessibility, affordability, and acceptability). The authors of [17, 18] consider the vulnerability approach which focuses the attention of policymakers on the assessment of risks associated with natural, technical, political and economic factors.

In Russia, the issue of the formation of energy security indicators is most fully covered in [1, 4].

To effectively comprehend the large number of energy security indicators of a country, we focused on the following most significant indicators for Russia as determined by an expert:

- the average physical depreciation of fixed assets in the energy industries;
- the share of the predominant fuel type in the structure of consumed fuels (or in the energy balance);
- the relationship between the expected undersupplies

of energy resources to Russian consumers and the total demand for them;

- the relationship between the annual increase in commercially recoverable reserves of primary energy resources and their production;
- the relationship between the actual excess of production capabilities of energy industries to supply the corresponding resources and the total demand for them (including export);
- the relative decrease (increase) in the energy consumption per unit of GDP.

Unlike Russia, an energy-independent country that exports its energy resources, for many countries, it is crucial to follow not only the share of fuel dominating the energy balance but also the share of imported energy resources and especially the share of the largest energy supplier (company, region, country) in their total import.

Naturally, the values of indicators themselves without proper processing and interpretation do not indicate the critical or non-critical phenomena and processes. To estimate the values of indicators, it is necessary to substantiate certain threshold values, such as:

- a pre-critical value as a threshold between the acceptable and pre-critical states of the energy sector in terms of the aspect described by this indicator;
- a critical value as a threshold between the pre-critical and critical (unacceptable) states.

Comparison of the estimated value of indicator with its threshold value points to a qualitative state (degree of a crisis) of the considered process or phenomenon. This is how an individual indicator (an individual phenomenon) can be estimated. However, to estimate the energy security level for a state or a scenario of economic and energy development, it is necessary to develop a mechanism for the integration of the values of all of the considered indicators, that often interact with one another directly or indirectly. In other words, an integrated estimate of the energy security level is necessary. It should take into account, where possible, expected changes in most of the indicators for the studied time horizon.

E. Integrated estimate of energy security

General scheme of the study.

The aforementioned integrated estimate can be obtained by mathematical models that adequately reflect the most important points of operation and development of the energy industries and their interrelations. First of all, these are the models of the national energy sector operation and development. They consider the operation and lines of development of all energy systems as a single complex and take into account the energy needs of the economy. Specialized simulation models are applied to provide information support and make the studies on the balance models of the energy sector closer to the operation and development of real energy systems.

Studies based on such a package of models consider the inter-industry aspects of energy sector reliability and make it possible to comprehensively assess the energy sector capabilities to meet the consumer demand for final energy resources under different operating conditions and in different development scenarios. The capability to diversify the fuel and energy supply and fuel interchangeability are also taken into account.

The general scheme of these studies has two levels:

1. Comprehensive assessment of the implications of possible changes in the operation of energy systems and the entire energy sector, determination of vulnerable points in the fuel and energy supply and the generation of possible solutions for the energy security of the country.
2. Assessment of energy development options in terms of energy security requirements and identification of the areas in which these options should be adjusted to provide national energy security.

Level of the energy sector.

The studies on validation of the adjustment areas of energy development scenarios (based on the comparison of the values of the indicators corresponding to a specific scenario and threshold values) can be conducted on the economic mathematical model of the energy sector [1]. The model assesses the current state of the energy sector in normal and emergency situations and determines the areas for the adjustment of the suggested scenarios of the national energy development from an energy security standpoint.

Mathematically, the optimisation problem of energy balances for Russia's regions solved by this model is a classical linear programming problem. Conceptually (in an energy and economic sense), the problem is based on the territorial- production model of the energy sector with the modules of electric power industry, heat, gas and coal supply, and oil refining (fuel oil supply).

The optimisation calculations for the considered situations make it possible to determine

a) the level of possible shortage in individual energy resources for the considered categories of consumers in different areas and the country as a whole (as a value of the discrepancy between the specified demand for an individual energy resource and the possibility of its production taking into account its reserves, the ability to source the energy resource from other regions or countries, its substitution by another energy resource, etc.);

b) the changes in transfer capabilities of inter-area transport ties, which are determined by comparing the respective indices of the considered and initial option;

c) the rational use of the production capacities of energy facilities as well as the distribution of the main energy resources by consumer category. This is achieved by the analysis of specific interacting economic indices that characterise the costs of additional demand for each type of fuel and energy by federal district.

Level of energy systems.

The second component of the research tools is industry-related simulation models of the oil, gas and electricity supply. It is shown in [3]. Unlike the balance model of the energy sector, these models are mainly oriented toward a day-long interval and allow us to study all possible changes in the fuel and energy supply in the case of emergency situations and to identify the technological flaws that hinder normal fuel and energy supply.

Research into a certain scenario of energy development makes it possible to obtain the cost of the solution and potential physical amounts of energy undersupply if a threat to energy security materialises. An additional study provides us with the cost of measures to be taken to fully meet the demand for energy resources in this situation. This cost represents the difference in the functional values of the first and the next solutions. Undoubtedly, to obtain adequate estimates, it is necessary to pay special attention to the formation of financial and production indicators used in the calculations. The most important indicators considered here are the indicators of equipment wear, the energy resources situation and the dynamics of changes in the energy: GDP ratio as well as the potential costs of importing the deficient energy resources.

Integrated estimate.

After determining the cost of the measures to meet the demand specified in the studied scenarios of energy development, we can obtain comparative characteristics of different options. The main subject for comparison here will be the sum of the following components:

– the cost of the solution for the conditions dictated by the studied option of energy development, considering the realization of energy security threats (with a possible shortage of energy resources for consumers);
– the cost of meeting all demand for energy resources under the existing conditions.

The studies based on the economic and mathematical model of the energy sector provide an adequate description of the processes, which enables us to take into account the values of most of the indicators that describe the technological, financial and economic characteristics of the energy sector operation. As a result, we obtain an integrated estimate of the energy security level in terms of the part and the aspect described by a set of indices considered in the model.

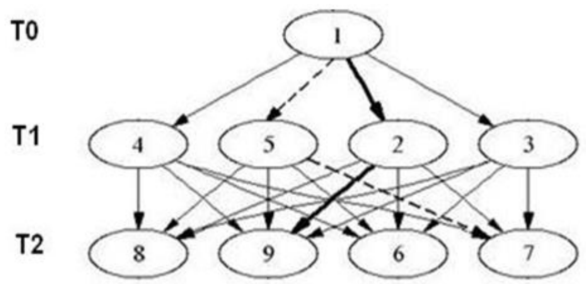

Figure 1. Graph of the energy development.

III. Formation of Specific Directions for the Energy Development Correction in Terms of Energy Security

It is extremely important to follow the values of the most important indicators and their dynamics and to use this analysis to develop ways to solve the corresponding problems to maintain an acceptable level of energy security in the country. This can be carried out only by considering all possible scenarios of energy development in terms of energy security and by choosing the solutions that meet the energy security requirements and, of course, comply with sensible investment limits. In addition, based on expert analysis of such rational, in terms of energy security, scenarios of the national energy development, we can identify specific directions for the adjustment of the national energy development scenarios in terms of energy security.

A. Formation of a complete set of all possible energy development scenarios

In principle, very little is left to do; we must only form a complete set of all logically possible future scenarios of the national energy development. This can be performed by combinatorial modeling ([9], among others), which make it possible to

– identify energy development options and estimate their admissibility in terms of resource, financial and other constraints;
– compare the variants based on different criteria to choose the most suitable;
– identify the trajectories of energy development that are rational in terms of energy security.

In the initial stage of research, the structure of the energy sector is divided into several parts, for example, in terms of territory. For each part, experts construct a graph of development by reference years. Next, by combining the states of different parts of the energy sector that belong to the same time interval, we obtain a set of energy sector states for a definite time moment. The obtained energy sector states correspond to the nodes of the energy development graph, which are then connected with one another by arcs (transitions) (Fig. 1.).

Each transition from state to state represents a trajectory of energy development with the cost of this development and its specific features of fuel and energy supply. In

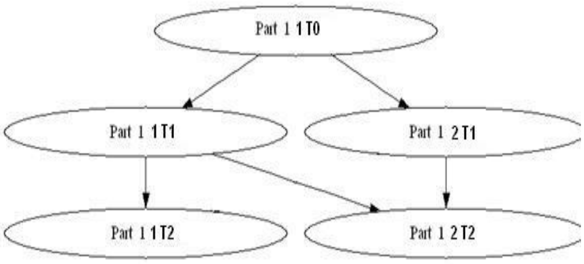

Figure 2. Potential nuclear energy development in the European part of the country.

Figure 1, the trajectory running, for example, through vertices 1, 5 and 7 (dashed line) is more preferable financially and provides the minimum shortage of energy resources for consumers compared to the other trajectories. However, states 5 and 7,

for example, may fail to meet the energy security requirements because the values of the most important energy security indices exceed the threshold values (for example, the threshold of energy import from one supplier is considerably exceeded). Therefore, a slightly more costly variant can be chosen, which consists of states 1, 2 and 9 (bold line) but meets the energy security requirements.

B. Example of the usage of the energy development correction principle in terms of energy security

Let us illustrate how this module works. We will make a simplified analysis of potential levels of development for three energy industries: nuclear energy, gas and coal. Suppose that in the time horizon until 2030, the production capabilities of these industries can develop moderately or remain at the same level (designating such a development intensity by symbol 1) and can develop intensively (designating such a development intensity by symbol 2). The main time samples are the initial state 2016, 2020, and the final time sample 2030.

The territory of Russia will be conditionally represented by three main economic areas: part 1 (European part of the country and the Urals), part 2 (Siberia) and part 3 (the Far East).

For each conventionally considered part of the country, each of the three chosen energy industries may develop with characteristic 1, i.e., moderately, or characteristic 2, i.e., intensively. There can be transitions between other states at different time points. For example, Fig. 2 depicts the possible nuclear energy development in the European part of the country. In the parameters assumed for the example, the graph of development of any energy industry in any economic zone will be identical.

For each of the considered parts of the country, we can now construct a graph of potential options for its energy development until 2030. Within the considered example, in such a graph for one zone, we can consider the transitions between eight energy sector states (three energy systems, each with two potential states) at each of the future time samples. Thus, in such a graph, it is necessary to analyze 16 prospective states of the energy sector in terms of energy security for each economic zone.

By combining different states of the energy sector of these three conventionally separated parts of the country, we can obtain a graph of development for the entire national energy sector. Even for the simplest example at one-time sample, it is necessary to calculate 512 different combinations of states of the individual energy industries. Hence, for two time samples, it is necessary to make calculations for 1024 prospective states. Because it is impossible to display the complete calculated graph, Fig. 3 presents its fragment characterizing only four potential prospective states of the national energy sector at each time sample.

C. Estimation of a rational trajectory in terms of energy security

Estimating the cost of each of the potential options of the national energy development, we can identify a trajectory that is rational in terms of cost minimization and potential shortage of energy resources for consumers from the complete graph, Fig. 4.

We can comment on the selected trajectory as follows.

In 2016, Russia generated approximately 197 bkWh of nuclear power, of which Siberia produced 0 kWh and the Far East - 0.2 bkWh. According to the selected trajectory, by 2020 the total generation of nuclear power could make up nearly 210 bkWh, including 208 bkWh in European part, 1 bkWh in Siberia and 1 bkWh in the Far East. As the trajectory suggests, by 2030 the total production of nuclear power could amount to 250 bkWh including 247 bkWh in European part, 1 bkWh in Siberia and 2 bkWh in the Far East.

The trajectory of moderate development of nuclear power in Russia's European part is less favorable from the production of nuclear energy in the European part could amount to 200 bkWh by 2020 and no more than 210 bkWh by 2030. This situation does not allow us to approach the better structure of the incoming part of the national energy balance.

In 2016, Russia produced approximately 641 bcm of gas, including 589 bcm in European part and in the Urals (including the Tyumen region), 19 bcm in Siberia and 33 bcm in the Far East. According to the chosen trajectory, by 2020 the total production of natural gas and associated petroleum gas could be around 660 bcm, including 590 bcm in European Russia and in the Urals, 30 bcm in Siberia and 40 bcm in the Far East. By the year 2030, the total production of gas could approximately make up 700 bcm, including 600 bcm in European part and in the Urals, 50 bcm in Siberia and 50 bcm in the Far East.

Intensive development of natural gas production in Russia's European part would be too expensive. Given the reduction in natural gas production at the currently operating fields, it is practically impossible to intensively increase gas production. The trajectories of moderate development of natural gas production in Siberia and the Far East are less favorable from the standpoint of energy security. With other (in comparison with the chosen) development trajectories, the production of natural gas in Siberia could be 20 bcm by 2020 and no more than 30 bcm by 2030. In the Far East, these values could be 35 bcm and 40 bcm, respectively. Such a situation does not allow us to achieve a better structure of the incoming part of the energy balance in these regions of Russia.

In 2016, Russia produced 386 mln t of coal, of which 330 mln t was produced in Siberia and 40 mln t - in the Far East. According to the chosen trajectory, by 2020 the total coal production could make up 400 mln t, including 20 mln t in European part, 330 mln t in Siberia and 50 mln t in the Far East. By 2030, as the trajectory suggests, the total coal production could be about 450 mln t, including 40 mln t in European part, 340 mln t in Siberia and 70 mln t in the Far East.

The chosen trajectory indicates the need for an intensive increase in the production of steam coals in Russia's European part and the Far East. This should lead to a better structure of the incoming part of the energy balance of the regions and the strengthening of their energy security. With moderate development, the production of steam coal in the European part of the country by 2020 could be 18 mln t, and by 2030 - no more than 30 mln t. In the Far East, these values could be 45 mln t and 50 mln t, respectively. These values are not enough to achieve these goals. Given the limitations on the railways capacity, intensive development of coal production in Siberia is inappropriate.

IV. Conclusion

It is not necessarily the case that the obtained trajectory (for example, the one presented in Fig. 4), which is "rational" from the viewpoint of energy security, will be rational for the national energy development. The characteristics of the trajectory only demonstrate that, for all of the considered conditions, the other lines of development will be either more expensive or worse in

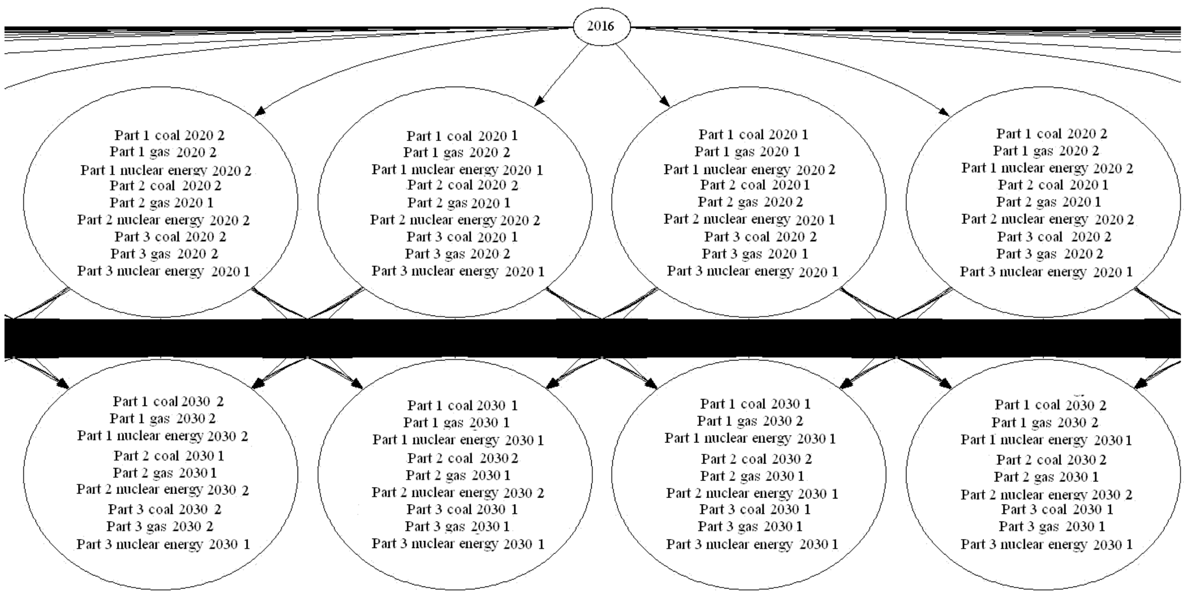

Figure 3. Fragment of a graph of possible energy development in the country.

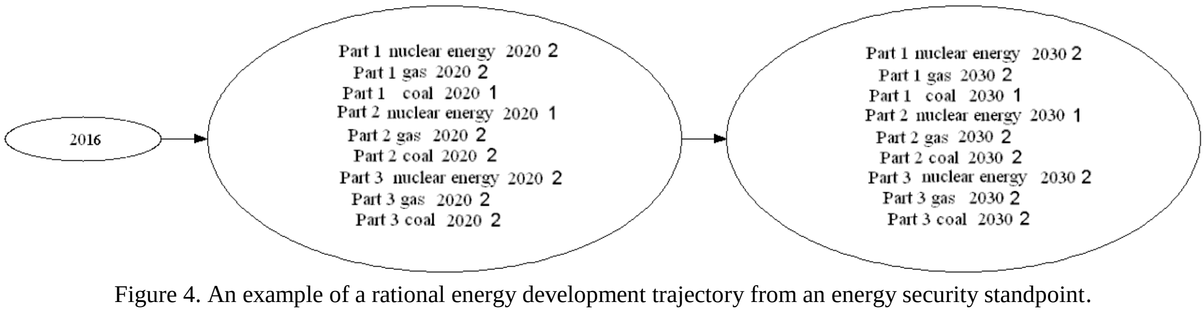

Figure 4. An example of a rational energy development trajectory from an energy security standpoint.

terms of energy security in certain aspects. Experts may consider the lines of development close to the "rational" trajectory to be even more interesting in terms of the country and its future economy. However, this is the goal (and the final stage of the algorithm suggested above) - to develop as many trajectories of energy development, which are rational in terms of energy security, as possible, and determine the general lines for the adjustment of the suggested solutions (prepared by the corresponding governmental institutions) for the national energy development, which would take into account the energy security requirements.

In the given example oriented towards Russia, the determining elements for the construction of possible trajectories of energy development were represented by certain regions and their energy strategies. The approaches suggested above can also be applied to other countries, where other elements can serve as determinants. For instance, in countries importing fuel and energy resources, where energy security issues are especially urgent, these determinants can be represented by the types and amounts of the used fuel and energy resources, places and amounts of their purchase at different time points, and necessary levels of diversification of fuel and energy supplies.

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