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Industrial Scientific and Technological Forecasting: From Image Building up to Studying an Uncertain Future

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ABSTRACT
Predictive studies traditionally appeal to a new scientific result. What does determine the level of uncertainty of predictive research: the future period *(time)*, future technologies *(object)* different from today's solutions or the methodology for conducting predictive research *(method)*? The task of scientific and technological forecasting of energy development can be defined in several directions. Changes in frontier technologies can be identified. But it is possible to anticipate the emergence of technologies that define alternative approaches to the use of raw materials, generation and distribution of energy, which will help to dramatically reduce the negative impacts on environmental and social systems. Finally, emerging new markets, trends, and demand indicators can be identified.

***Keywords**: Energy industry, Scientific and technological development, Methodology of scientific and technological forecasting, Prognostic research, Scenario forecasting, Uncertainty of the future.*

1. RELEVANCE OF SCIENTIFIC AND TECHNOLOGICAL FORECASTING FOR THE DEVELOPMENT OF THE ENERGY INDUSTRY

Traditionally, the industry forms forecasts that combine elements of technological forecasting, market analytics, research on traditionally important political changes and economic trends. The most authoritative and global publications, involving a comprehensive vision, include the papers of the International Energy Agency[1] *(Energy Technology Perspectives* and Energy *Technology Initiatives);* ERI RAS (*Forecast for the development of the energy sector of the world and Russia until 2040*); The U.S. Energy Information Administration[2], as well as the forecasts of companies and associations – *OPEC, BP, Shell, ExxonMobil, Greenpeace, IRENA, Goldman Sachs, Bloomberg, Deloitte.* There are also episodic industry studies (including foresight research, research studies and papers of scientific organizations – leading foreign and Russian universities, research institutes, communities, including youth ones) [5]. One of the forecasts is traditionally held within the framework of the Russian Energy Week – REW. The methodology for developing a forecast includes considering the maximum possible number of factors affecting sustainable energy development. As a result, for example, the main directions of technological changes can be determined in the following sectors: traditional hydrocarbon energy, sustainable transport of the future, distributed generation (DG), new renewable energy sources (RES) in comparison with traditional energy system, smart drives, technological trends and promising niches (for example, a niche in the market of the best available technologies (BAT) in the field of information technology, coal chemistry, ecology and RES; a niche in the market of batteries and energy storage systems with the prospect of creating its own technological base for the processing and disposal of batteries.

Recent years have demonstrated that technological development is decisive in the development of the energy industry. Technological development is formed within the framework of scientific research and is determined by the innovative potential of universities

[1] https://www.iea.org
[2] https://www.eia.gov

and industrial partners. It requires constant and changeable prognostic activity involving a large number of both opinion leaders and specialists who have not previously been involved in the analysis of the future and trends.

2. BASIC ASSUMPTION AND KEY RESEARCH QUESTIONS

The study is based on the analysis of publications and reports (secondary data) devoted to the current state and prospects for the development of the energy industry in Russia and the world energy sector. Moreover, the sample also included papers that contain the results and assessments of predictive research, as well as an analysis of scientific and technological development for several decades to come. The study was conducted in several stages, each of which included three main research questions.

Q1. *What is the basis of the forecast?* The answer to this question entailed the need for a more detailed analysis of the factors that can affect both the process of forecasting itself and its result. It is important to answer the following questions: what method was used as the basis for forecasting, whether it is possible to combine several methods, what criteria should be used.

Q2. *What forecasting horizon should be to eliminate the uncertainty of the future?*

Q3. *Where is or how to determine the point of bifurcation/joggers, "black swans" in the global scientific and technological agenda?*

Forecasting is associated with uncertainty, minimizing the risk of decision-making, therefore, it is necessary to take into account the conditions of decision-making under uncertainty.

Scientific and technological forecasting can be based on future scenarios for the development of the energy industry – a look from the past to the future. It can be based on the needs of society, academia, lobbying the interests of certain industrial groups, financial capabilities, resource base, etc.

Another option for the starting point of forecasting is the intention to avoid worst-case scenario of humanity development, for example, nuclear wars, the negative and large-scale effects of electromagnetic radiation (EMR), depleted fossil fuels and energy sources, famine and catastrophic epidemics leading to the total extinction of humanity. In this case the source of forecasting can be the world climate agenda, environmental protection, the principles of ESG-management of companies and etc. The basis can be formed by international agreements (for example, the Paris Agreement on limiting global warming to (1.5–2° C), the European Union's transition to a climate-neutral level by achieving zero CO_2 emissions by 2050). The future look at the required technologies and their development can be very different from the first option when using this forecasting option.

2.1. What is the basis of the forecast?

What is the basis of forecasting as the scientific material published about the most promising technologies? It's necessary to consider an array of articles and identify the most promising technologies by the most active reference and citation to answer this question.

Obviously, the more publications appear about a new technology, the more likely it is that this technology will continue to develop. The volume of publications on a given topic indicates the relevance of the topic, the existence of a discussion between researchers, the expression of alternative points of view, the search for a "grain of truth", and, therefore, an increase in the likelihood of finding it. More young scientists in universities and research centers and young specialists in the fields of practice are involved in cutting edge topics, which increases the chances for the development of the technology under discussion. For those technologies, which will enter the heyday of their development by 2050, are just emerging and have no quantitative estimates, except for publication activity. There is only one method in their assessment now: the expert assessment method.

But only interest in the topic is not enough. You need tools and skills to build forecasts. What do you need to be able to predict? Is it necessary to know what came before us? Is it necessary to track the nature of the changes? Then, what should be the parameters of the components involved in previous developments of technologies? This approach can be defined as extrapolative, and the depth of extrapolation is determined by the forecast horizon.

Researchers most often resort to generalized phrases in the process of analyzing the prerequisites for the development of technologies and industries, for example, "the accumulated experience of predecessors" or "previous experience". However, these phrases are extremely vague and do not carry even a share of reliable information about what was the impetus for the emergence and subsequent development of technologies.

Another interesting issue is the parallel emergence of technological ideas and solutions in different countries in the absence of communication between scientists (the *well-known effect of Popov*[3]). A fundamentally new technological solution can be the result of parallel research of those scientific schools and groups that

[3] Situation where inventions are discovered in different countries independently of each other

"work at the frontier" of the scientific and technological agenda.

The nature of the emergence of new technologies is extremely interesting. The idea of creating a databank suggests itself: as an assessment of previous experience, an analysis of the prerequisites for the appearance and resources spent by a community of researchers, scientists, industry analysts for each of the completed steps in scientific and technological development. The widest field for research based on multivariate analysis, working with Big Data are opening in this regard. The results are difficult to predict and therefore are very interesting.

What did it take to implement the technologies that had already been implemented? Was it just financial resources, previous technologies, availability of materials, lobbying by management, enthusiasm of developers, motivational packages?

2.2. How does it work?

When considering the factors affecting the scientific and technological outlook, it is possible to limit oneself both to individual countries (and then such factors as demographic shifts, socio-economic realities, a list of critical technologies that has country differences, regulatory and legal regulation are likely to be increasingly reflected) and take the global context as a whole (its will bring to the fore changes in energy demand in major regions of the world, world markets developments, etc.). It is important to consider the factors from at least two perspectives: critical technologies and a promising market. However, in any of the variants there are "windows of opportunity" [10], the use of which allows you to make leaps in development, such as the leapfrogging theory, well known since the eighties of the last century [11].

The step-by-step, methodical development of the technology can be predicted with a greater degree of probability [16, 17]. For some time, there will be a confirmation of previous predictions, until this technology is ahead of another technology – a direct competitor, or until certain drivers appear, for example, market drivers, as was the case with energy storage technologies. There are more than a dozen key research centers around the world in the nuclear power sector. It would seem that this sector should have developed faster than others, which are less significant on a global scale. However, the development of the market for mobile phones, laptops and similar gadgets, the actively growing demand for these devices has significantly accelerated the pace of development of new energy storage devices. As a result, the annual market volume of mobile devices is more than 20 times higher in cost than the cost of annually commissioned nuclear power plants. In this regard, mobile drives will achieve their progress many times faster than nuclear energy.

For clarity, this can be represented by the following example. Let's imagine the scientific and technological progress in the form of a ladder, each step of which means its own amount of work, in practice characterized by the number of man-hours and the amount of funding for this. Suppose that for significant progress in the field of nuclear energy 3 steps are needed, and for progress in the field of energy storage it's necessary to make 10 steps.

To illustrate the above situation, Figure 1 shows that the energy storage devices will pass their 10 steps of progress faster than nuclear power will make even 2 steps.

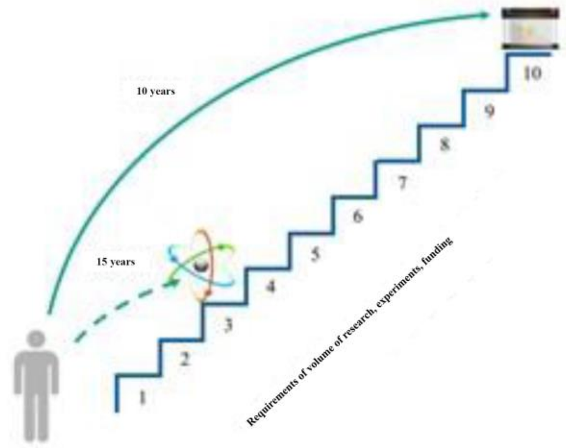

Figure 1 Speed of technology development under the influence of market drivers [12].

Similar drivers can be the opinions expressed by authoritative representatives of the professional community - scientists, high-tech industry, organizers of the world's leading exhibition venues, etc. They refer to intuitive methods (judgments, opinions), in other words, to the method of expert assessments. Such a method is applicable when the object is either simple enough, in which case the mathematical model is not required, or it is so complex that even a mathematical or statistical model cannot be applied. For example, it happens because of the unnecessarily complicating of the system when trying to describe mathematically non-mathematical phenomena. However, with all the subjectivity of the opinions of the professional community and experts, it is impossible not to mention the popular Delphi method developed in the 50-60s of the 20th century in the USA and the Foresight forecasting technology based on it. Foresight is focused not only on identifying possible development alternatives, but also on choosing the most preferable of those considered [13]. These technologies are widely used to make forecasts of scientific and technological development as for example, in Japan, a foresight session is held every 5 years, in which several thousand experts from different fields of science, business, government bodies participate), and corporations.

With the complication of the system or when the possibility of mathematical description appears, formal methods (mathematical models) are used: models of the subject area (for example, the energy industry as a whole), time series models (analysis of dependencies within the process itself).

However, any forecast is subjective. In many ways, the result of forecasting depends on the human factor, for example, on the scientific or instrumental preferences of the researcher. What methods he uses, what models the researcher prefers to use, how he combines their use in his works, etc. All these items are the questions to consider the decision-making process of a researcher. At each stage, an accuracy error arises as: at the stage of setting the goal and choosing the field of research, at the stage of considering qualitative characteristics, especially when choosing methods and forecasting models. The accuracy of the forecast also depends on the qualifications of the experts involved and the composition of the software and hardware at the disposal of researchers.

Fortunately, this does not affect the certainty of the method itself. The method itself as mathematical, statistical cannot be uncertain. Only the initial data and, in some cases, the probability of the forecast are uncertain. In this case, it is an expert opinion that has low reliability due to subjectivity and generally limited capabilities of the human brain.

Improving the accuracy of the forecast within the framework of the functioning of the monitoring system is not a fundamental issue. It is not the accuracy of the forecast that is of interest, but the correctness of detecting failures, although these are interrelated things. It is important to understand that the accuracy of forecasting is mainly a characteristic of the time series and for each time series there is a certain limit, more precisely than which it is impossible to predict on average for the period. We do not blame mathematical models and specialists where the problem has no solution: it is impossible to predict with zero error. [14]

Depending on the prevailing goal, preference is given to one or another method.

Table 1. Methods and objectives (elaborated by authors)

Destination	Method
New technologies being mastered, expected changes in infrastructure	Technology Foresight
Expected structural changes (positive and negative), possible consequences, technological threats	Technology Assessment
Policy briefs, reports, assessments of options for government and business	Technology Intelligence
Forecast of new generations of technologies, equipment and control systems, alternative technologies	Technology Forecasting
In various fields are used for large samples	Method of forecasting according to consumer judgments
In various applications of forecasting. When, as an experiment, the technology is sold in a limited market and a forecast of the market reaction is made based on the results of the implementation	Pre-market testing method
In various applications of forecasting. When an assessment of the possible demand for technology is done by a group of experts for various variants of market situations	Script writing method or peer review method
The method aims to develop different scenarios for the future of a certain technology, taking into account existing and future influences on the technology, in order to reduce future uncertainty	Scenario planning
In various applications of forecasting. To avoid the influence of group pressure or the dominance of an individual's opinion	Delphi Method
The analysis of direct and indirect effects is the emergence of a certain technology. The reality is possible with the involvement of experts	Future wheel
It is used as a new tool for medium- and long-term forecasting	Normative method
Collecting information from the environment (socio-cultural, political, environmental and economic entirety) on the phenomenon under examination	Environmental scanning
The method is actively used in companies to develop possible scenarios for the development of the technologies it deals with	Integrated roadmaps
The method allows the company to predict the challenges the company will face in the future	Corporate foresight

2.3. What are the results of the level of demand in certain sectors of the industry?

The demand for the technology being developed, as a rule, is completely absent. Either because of its uncertainty, misunderstanding where it can be applied, or because of its too high cost. As, for example, with fundamental research: there is a request for information on the qualitative breakthrough, not supported by significant funding, since the research data is very expensive and extremely uncertain.

An analysis of secondary data in the field of energy development forecasting showed a demand for breakthrough technologies that provide:

1. a significant increase in the energy efficiency of production systems and the reliability of power supply, in particular, in the construction of distributed generation facilities near large industrial consumers, with the use of intelligent sensors and metering devices, improving the efficiency of electricity storage devices, the use

of lithium-ion storages at solar power plants, supercapacitors, vanadium batteries;

2. reduction of production waste, in particular, the use of associated petroleum gas and crude oil for power supply to transport and oil and gas production facilities, combined refining of petroleum products, cryogenic utilization, pyrolysis of waste in;
3. digitalization, in particular, the development of active energy complexes, intelligent fields, the use of digital twins, predictive analytics and demand management, blockchain and smart contracts;
4. power supply to remote areas, in particular, the creation of transport and social infrastructure for the development of remote areas, microgeneration on renewable energy sources, use of innovative LNG (gas hydrates), gas engine fuels and fuels;
5. reducing the high accident rate and injury risk of work, preventing the education system from lagging behind industry trends, in particular, safety and production – connected personnel, connected and automated transport, digital technologies in training – immersion technologies: XR, VR, AR;
6. the need for new technologies and investment in R&D to increase the efficiency of technological processes, such as import substitution, large- and medium-scale gas turbines, development of new energy-efficient technologies in energy equipment, high-density geological exploration, seismic exploration, low-tonnage liquefied natural gas and compressed natural gas projects, construction of new steam-gas generation.

2.4. What is the implementation of certain technologies over the past 7–10 years?

Inertial forecasts don't work always. For example, diesels. They have come to the limit of their development in their technology. And if we look at previous decades, diesel has evolved in a seven-mile range. Therefore, if we talk about the need to find a way to increase the reliability of forecasts, the inertial method seems to be the most dubious. And taking into account environmental factors, the heads of energy companies began to declare the decline of diesel engines. The development of new ones in the context of tightening environmental standards is impractical [15].

But, as in all acute debatable issues, there is an alternative opinion on this matter. So, analysts predict that in the next five years the volume of the diesel market will grow to almost $ 265 billion, and this is confirmed in the calculations of the company in the *IMARC Group*. According to their data, the total volume of the global diesel market in 2020 reached $ 207 billion [15]. The authors of this article plan in the near future to conduct a comparative analysis of the methods that led to positive and negative forecasting results. Perhaps this will open another veil of secrecy of the reliability of forecasting. Additionally, it is intended to consider universities as the leading milieu for the emergence of technologies of the future.

2.5. Identification of technology development stoppers

As in any full-fledged analysis, in scientific and technical forecasting it is impossible to consider only positive dynamics. Subjectivity for the sake of subjectivity, it is necessary to remember about the negative factors that inhibit, hinder, and sometimes simply put an end to technology.

3. CONCLUSION

Scientific and technical forecasting, like a mosaic, consists of many components, each of which has its own level of uncertainty. A careful approach to the choice of each element will have a generally synergistic effect of increasing the reliability of the forecast: starting from the stage of determining the hypothesis of the upcoming study, in the criteria for choosing the methodology of scientific and technological forecasting, making a choice in favor of one or another approach and method.

The authors of the article consider that at the forefront, as a traditional pointer stone at the fork in the road, we can put the question of what we expect from technology: reducing risks and threats or adapting to changing conditions? The most striking example of such a question would be the topic of decarbonization: do we want technologies that urgently reduce emissions while continuing to adapt to warming that we cannot avoid because of the emissions of the past, or do we need technologies that will help us prepare for life on Earth, very different from the one we know well today?

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