Achievements and Challenges of Systems Studies on Energy Development in Russia, Their Possibilities in the "Digital" Society

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***Abstract* — The paper addresses major achievements, current trends, and challenges in systems studies on energy development. Further evolution of the methodology for these studies in the context of "digitalization" will depend on the development of artificial intelligence tools. The scope of planned work and possible means for its implementation in the systems studies on the energy development in the future information society are investigated for various forms of its organization.**

***Index Terms*: energy development, strategic planning, artificial intelligence, neural network, agent model, Russia.**

I. Introduction

The methodology and tools for systems studies on energy development, which originated in the USSR 50 years ago, were updated and modified 20-25 years later to fit the market conditions of the Russian economy. Until the mid-2010s, they had been effectively employed to formulate strategic planning documents for the national energy sector, including its sectoral and territorial systems. Paradoxically, but with the adoption of the Federal Law on strategic planning and on the threshold of a new energy transition in the world, the state uses the scientific justification of the country's energy development prospects increasingly less.

The digital revolution requires the transition of systems studies of energy (and economic) development to a new level. Some countries may build a **digital mobilization** economy when centralized planning furnished with artificial intelligence or a mega-set of production-territorial mathematical models will spread to households. An alternative concept of **liberal** «digitalization» of society focuses on the self-organization of market participants when foreseeing the future (they use agent models to iteratively develop mutually agreed scenarios for the evolution of the economy and energy). Based on these scenarios, the Market Council builds a preferred corridor of economic development, and each participant controls these processes using blockchain technologies, thereby identifying their opportunities and risks. The liberal digital economy will require traditional operations research methods to be supplemented with new tools, including a) neural networks, image recognition methods, and other artificial intelligence tools, b) agent-based models and methods for their interaction, c) distributed ledger technologies. To do that, however, one should find ways to overcome the theorem «On the impossibility of democracy» proved by K. Arrow.

II. Systems research overview

As shown in the review [1], the USSR embarked on working out the methods for systems studies of energy development as tools for centralized planning [2] in the early 1960s. Theoretically, they were comprehended [3, 4] and normatively fixed in planning [5, 6] in the early 1970s, and by the end of this decade, their original versions appeared in the USA and Europe [7-9].

The systems methodology was used in formulating the USSR Energy Program for the long term [10] and the section of Fuel and Energy Complex in the Comprehensive Program of Scientific and Technological Progress of the USSR. In the practice of annual and five-year planning, however, the energy subsystem of the automated system of planned calculations of the USSR State Planning Committee worked before the country collapsed only as an experiment. Although, the methods and models were widely used to optimize and justify decisions when designing the development of the fuel industries, the electric power industry (including nuclear power), and heating systems [1].

Russia's transition to market relations expanded its participation in the world energy markets and, despite the drop in domestic demand for energy, strengthened the

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energy sector as a donor to the economy. This circumstance required the formulation of the country's energy policy as a locomotive of the economy [11, 12], understanding its role in world energy [13], and the development of Russia's Energy Strategy [14]. The previous tools for systems studies of energy development in the country [15] and regions [16] and the relationship between energy and the economy [17] were radically updated and expanded.

Forecasts of the demand for various fuel and energy types across the country, along with the projections of financial, material, and labor resources that can be allocated by the economy for energy needs, are essential instruments for energy development. In the USSR, this information was provided by the State Planning Committee. In a market Russia, a system of economic development models (including agent-based ones) and the methods of their interaction with the energy development models were originated to obtain this information in a required amount [18, 19].

To work out the strategic planning documents for the energy development of the country and regions, the largest exporter must forecast the situation in the world energy markets. The information-model system [20] designed for this purpose became a part of the model and information complex SCANER (Super Complex for Active Navigation in Energy Research) [21].

The global economic crisis of 2008 brought down the size of Russia's GDP by almost 8% and the production of energy resources by 5%, completing the «golden decade» of the country's economic and energy development. In 2014, the previous goals of accelerating economic growth were replaced by the liberal paradigm of «sustainable» development with practically no GDP growth and an increase in the share of the poor, with the planning of energy development carried out increasingly more formally.

After many years of discussions, federal law on strategic planning [22] was adopted. It regulates the structure and scope of the planning process in the country. Formally, satisfactory compliance with the range and terms of development of the top-level strategic documents stipulated by the law is offset by the weakness of the planning process in the economy and its sectors, especially the energy sector. The adjustment of the Energy Strategy until 2035, which began in 2013, was not provided with up-to-date forecasts of the country's socio-economic development. As a result, after the approval of the document in 2020, the Government is now forced to make a decision to update it, along with related general schemes for the development of the energy sector industries. The state's requests for research to improve energy markets and enhance the energy security of the country and regions have also decreased in number.

As a result, since the mid-2010s, specialists in systems analysis have switched from practical applications of the developed tools to academic research on the issues of energy development in the world and Russia. In contrast to the United States and European Union, Russia does not have its vision of how world energy should evolve. Meanwhile, since 2012, Energy Research Institute (ERI) has been regularly updating the forecasts of the situation in the world energy markets and energy development scenarios in the world and Russia with its systems methods and tools [23] considering the expected technological breakthroughs, changes in the composition and behavior of the major players, and other uncertainties [24, 25]. These results, however, are not used in the strategic planning of the energy and economic development of the country.

According to the law [22], the Russian economic and energy development management was reorganized from *normative planning* used in the USSR to *indicative planning* of development goals, main objectives, and tools of achieving them with a limited range of quantitative indices of successful performance of economic agents with state participation. This is how forecasting has been organized in the United States since the 1990s. Socialist China switched to a similar concept of strategic planning of the economy (and energy as its constituent) at the beginning of the 21st century [26]. In Russia, however, indicative planning of the economy and energy, given the noted irregularity of the process, is hampered by control of the process by large businesses and low validity of documents developed. Indeed, in the United States (and to a lesser extent in China), the entire hierarchy of indicative planning is equipped with publicly discussed model calculations performed *on a competitive basis* by well-funded powerful research entities [26]. In Russia, the substantiation of strategies and programs for economic development is fragmented, their discussion is selective and formal, and the results are mostly ignored in the adopted documents.

The development of concepts and programs for the digitalization of industries and companies in Russia for the period until 2024, which has begun in recent years, is almost exclusively aimed at collecting and identifying available information and using it only in the operational management of enterprises and partially - in sectors of the economy. However, the fourth (digital) technological revolution, which is rapidly going on in the world [27], will not avoid managing the development of the economy in general and energy in particular. Whereas the access of researchers to computers in the 1960s gave impetus to the creation of a methodology and tools for systems studies of energy development, a considerable transformation of human society with its total «digitalization» will require (and will allow) the transfer of these studies to a qualitatively new level.

III. Trends, challenges, scenarios

Today we are witnessing a challenging environment in the field of systems research in the energy sector.

1. In the world, there are conflicting processes of absorption, specialization, and dispersal of systems

research in the energy sector (SRE): their methods and means are increasingly absorbed by the instruments of systems studies of the development of the economy and society at all levels of the hierarchy while specializing in the issues of climate, technological progress, and security, and being scattered to solve a number particular problems.

2. In contrast to the global trend toward expansion and «legitimization» of the use of systems research instruments, in Russia, with the adoption of the Federal Law «On Strategic Planning,» they, as noted above, are not used to substantiate forecasts and plans for the energy development.
3. The program «Digital Economy of the Russian Federation» until 2024 involves collecting, identifying, and using the information for the operational management of enterprises and, in part, sectors of the economy, ignoring management of their development.
4. The immanent systems research tools for control over the functioning and development of large-scale energy systems (mathematical modeling and optimization) are beginning to be threatened by artificial intelligence tools. In combination with total video and digital control, artificial intelligence can either replace or become a crucial tool for the development of systems energy research in a «digitalized» society.

Let us consider this alternative in more detail. Artificial intelligence is rapidly expanding its sphere of dominance:

- in the early 2000s, it beat champions in competitive games (checkers, chess, Chinese go);
- in 2017, artificial intelligence won the world poker tournament (already a much more difficult competitive game);
- in 2021, Facebook created an artificial intelligence algorithm (bot), which, as an anonymous participant, entered the 2 percent of winners in the competitive-cooperative game «Diplomacy.» This game suggests that you need to compete and cooperate with other players, deceive them and simulate their assessment of your strategy. Artificial intelligence is already ready to participate in the operational activities of the business.

The achievements of artificial intelligence make its victory in solving problems of managing the functioning of energy systems and problems of operational and short-term planning of their expansion a reality. A relatively stable set of objects to be managed and consumers require only periodic «retraining» of bots, which is not easy but can be done.

To discuss the **possible evolution of systems studies of energy development in the course of «digitalization,»** we will rely on recent publications concerned with the view of the coming information society [28-31]. Their generalization in the form of ***scenarios*** is given in the Table, which indicates the scope of planned works and possible tools for their implementation in the future (2030-2050) information society with various ways of its organization.

In an unfavorable geopolitical situation, some countries can build a **mobilization** digital economy, which suggests that centralized planning extends to a household level (column 3 in Table 1).

In ***the first version*** of this scenario, the economic (and energy) development plans are built by *artificial intelligence.* Its use in *the medium* and, especially, *long-term* planning, however, requires «self-tuning» of neural networks to various development scenarios of a planning object and its external environment. The centennial experience of the USSR and Russia's development [32] shows that the socio-economic conditions in the country

TABLE 1. A scope of planned works and tools for systems studies of energy development depending on the type of information society (2030-2050).

Scope of work		Required tools by type of society	
		Mobilization	Liberal
Planning of stages and tools	Depth of plan development	Planning down to the household level	No plan
	Planning tools	Version 1. Artificial intelligence Version 2. A system of economic and energy development models	Agent-based models of economic and energy entities
	Means of communication	Super-Internet	Super-Internet
	Coordination of decisions in the energy sector and economy	From the federal level to the enterprises	Model simulation of market operation
	Decision making	Top level of management	Decentralized
Information sources	Input data	Integral databases on energy and economy	Data are formed in the course of market operation simulation
Planning of results	Development plans, taxes, prices, investment programs	Optimal plans for the development of production and standardization of energy consumption	Market entities make their planned decisions and take risks of development
	Management rules	State	Market Council
	Improvement in planning	State	Market Council

changed dramatically every 10-15 years with non-recurring causes, nature, and frequency of crises. This factor does not provide sufficient historical data for artificial intelligence learning in strategic planning tasks. Therefore, the first version of a mobilization society until 2050 seems problematic. The efforts in this area are made by China and planned by Russia and other countries.

According to ***the second version*** *of the mobilization scenario*, plans for the economy (and energy as its subsystem) development are calculated on computer networks using a *mega-set* of production-territorial *mathematical models*. Input information for the models is generated by neural networks (time-tested artificial intelligence tools) using available *reported databases* and estimating their error. Based on optimization calculations, other neural network types generate representative *scenarios for the development of systems* and the corresponding *matrix* of established *indicative indices*. On this basis, the planning authority makes decisions, which are then automatically detailed into production and investment plans, prices and taxes for enterprises, and consumption rates for the population.

Here, the concept, which was developed in the USSR back in the 1970s and suggested using computers for planning the development of the economy and managing it, is outlined in terms of modern information technologies [33].

An alternative concept of **liberal** «digitalization» of the society reflects how futurologists from information science [34] see the trends in the development and use of information technologies to manage the development of the economy and energy (column 4 in Table 1). In the absence of even indicative plans, market participants are expected to *be self-organized* in a complex future foreseeing process. Neural networks generate input information for them. According to it, mutually agreed scenarios of the economy and energy evolution are iteratively developed with the *agent models* of participants in computer networks. Based on these scenarios, the Market Council forms (according to the criteria of the maximum rate and quality of growth at minimum systems risks) a *preferred corridor* of economic development (including energy). Each participant as a *decentralized autonomous organization* (DAO) [35] can use blockchain technologies [36] to control the decision-coordination processes and determine their *future opportunities and risks.* Meanwhile, the Market Council adjusts the rules of the community and improves the requirements for the tools.

Thus, the liberal digital economy will require that traditional methods for operations research be equipped with such new tools as a) neural networks, image recognition methods, and other artificial intelligence tools; b) agent models and methods of their interaction; c) distributed ledger technologies. It is unclear when and to what extent this concept will be implemented, but mastering these tools and technologies will significantly advance the methodology of systems studies of energy development.

In addition to these (basically technical) difficulties, the liberal concept of a «digital» society comes across the theorem "On the impossibility of democracy" proved by K. Arrow (1972 Nobel-prize winner) [37]. This theorem blocks the self-organization of agent models, i.e., the possibility of coordinating their decisions without a decision-maker. Apparently, for this reason, agent models are still used only in the tasks of operational control of the systems, where the involvement of dispatcher, as sole master, is mandatory.

The history of the market economy has confirmed the validity of Arrow's theorem. Indeed, the 18th century saw ten economic crises causing growing damage in 70 years. In the 19th century, their regularity was disrupted by the 2nd World War, but it seems that it will recover in the 21st century. Our history also confirms the validity of the theorem. The transition of the USSR in the 1950s to «collective management» increasingly more hampered its development and in 1991 destroyed it, and in the 1990s, «democratic» Russia did not get out of crises. After a short boom at the beginning of the century, the *global collapse* of 2008 threw the country into long-term stagnation.

The opportunity to overcome the effect of Arrow's theorem is seen in replacing the decision maker's functions with adequate and «digitized» ***legislation*** with *blockchain algorithms* for monitoring its execution. The success of work in this strand will affect whether or not the next generation of people will turn into gears of *a mobilization society*, and systems energy studies can and should contribute to overcoming this threat.

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