Arctic and North. 2022. No. 49. Pp. 20–32.
Original article
UDC [338.22+620.9](985)(045)
doi: 10.37482/issn2221-2698.2022.49.23

Strategic Trends in Energy Development of the Northern Territories of Russia

Sergey S. Vopilovskiy [1]✉, Cand. Sci. (Econ.), Associate Professor, Senior Researcher

[1] Luzin Institute for Economic Studies — Subdivision of the Federal Research Centre "Kola Science Centre of the Russian Academy of Sciences", ul. Fersmana, 24a, Apatity, 184209, Russia
[1] simonovich.63@yandex.ru ✉, *ORCID*: https://orcid.org/0000-0002-2873-1425

Abstract. The dynamic development of the energy market is the source of Russia's energy diversification processes. The study presents key areas in the development of the Russian energy sector, taking into account new trends and challenges. The Arctic zone of the Russian Federation is potentially becoming a growth driver for the energy market and opens up "new windows" for the country's economic development. It is determined that the structure of consumption, use of resources, generation and transmission of electricity is changing. Long-term trends in the energy transition demonstrate a change in the energy balance in favor of clean energy sources: wind, solar, nuclear, geothermal, hydropower, hydrogen, and bioenergy. The development of hydrogen energy, including in the northern territories of Russia, creates a reliable basis for integration into the global hydrogen infrastructure. The change in the energy balance in favor of renewable energy sources (RES) is presented. According to the International Energy Agency (IEA), RES will account for up to 95% of new energy capacity additions by 2026. The global climate agenda — the rejection of fossil fuels — creates new challenges for the Russian economy and the development of its Arctic investment projects. It has been established that the current situation in the context of global technological breakthroughs and climate change is shaping the transition from vertical integration to distributed generation and decentralization. The purpose of the study is to analyze current trends in the development of the energy market, based on the results of which it is necessary to adjust the approaches of the Russian energy sector to future development, making maximum use of the opportunities of the northern territories of Russia.
Keywords: *economics, energy, Russian Arctic zone, renewable energy source, nuclear energy, hydrogen energy, scientific and technological progress, generation*

Introduction

Modern trends of energy market formation, scientific and technological progress and political and economic relations determine the multi-vector trends of the progressive, sustainable development of the energy sector of the North and the Russian energy industry as a whole. The current large-scale energy system, which ensures the reliability and quality of power supply to the country's economy and household consumers, is economically justified and technically efficient. Nevertheless, modern economic incentives prescribe to the professional community of power engineers, with the consolidation of the scientific personnel of the industry, the need to minimize the payback period of investments. Economic interests, new technologies, new generation methods — solar, wind, modular gas with a high installed capacity utilization factor (ICUF), capable of competing with large power plants in these parameters — determine the vector of distributed generation development.

For citation: Vopilovskiy S.S. Strategic Trends in Energy Development of the Northern Territories of Russia. *Arktika i Sever* [Arctic and North], 2022, no. 49, pp. 23–37. DOI: 10.37482/issn2221-2698.2022.49.23

Managerial decision-making for further energy development is largely based on one of the fundamental factors — increasing energy efficiency. In turn, increasing energy efficiency causes additional contradictions: on the one hand, new energy-efficient technologies are being introduced and energy costs are being saved; on the other hand, energy consumption grows with increase of socio-economic level of society, which is a leveling factor. Consequently, there are many questions, directions — how should the country's energy industry develop and what is the role of the state in its renewal?

The energy community of Russia chooses an evolutionary path of development inherent to an institutional, stable state, based on the foundation of a built and reliable energy system (ES). The current energy legislation is necessary and sufficient for its further development, updated in a timely manner as new trends emerge, including those imposed from outside. Russia systematically and in a balanced manner implements the regulatory documents, which are based on: "Energy strategy of the Russian Federation for the period up to 2035" [1], "Strategy for scientific and technological development of the Russian Federation" [2], a comprehensive program "Development of equipment, technologies and scientific research in the field of the use of atomic energy in the Russian Federation for the period up to 2024" within the framework of the 14th national project for the development of nuclear science and technology [3], federal law No. 296-FZ of July 2, 2021 "On limiting greenhouse gas emissions" [4], order No. 2634-r on approval of the action plan "Development of hydrogen energy in the Russian Federation up to 2024" [5], "Strategy for the development of the Arctic zone of the Russian Federation and ensuring national security for the period up to 2035" [6], etc.

[1] Energeticheskaya strategiya Rossiyskoy Federatsii na period do 2035 goda [Energy strategy of the Russian Federation for the period up to 2035]. URL: http://static.government.ru/media/files/w4sigFOiDjGVDYT4IgsApssm6mZRb7wx.pdf (accessed 11 April 2022).

[2] Ukaz Prezidenta RF ot 1 dekabrya 2016 g. №642 «O strategii nauchno-tekhnicheskogo razvitiya Rossiyskoy Federatsii» [Decree of the President of the Russian Federation of December 1, 2016 No. 642 "On the strategy of scientific and technological development of the Russian Federation"]. URL: https://www.garant.ru/products/ipo/prime/doc/71451998/ (accessed 11 April 2022).

[3] Pravitel'stvo utverdilo 14-y natsional'nyy proekt po razvitiyu atomnoy nauki i tekhnologiy [The government approved the 14th national project for the development of nuclear science and technology]. URL: https://strana-rosatom.ru/2021/02/08/31102/ (accessed 11 April 2022).

[4] Federal'nyy zakon ot 02.07.2021 g. №296-FZ «Ob ogranichenii vybrosov parnikovykh gazov» [Federal Law No. 296-FZ of 02.07.2021 "On limiting greenhouse gas emissions"]. URL: http://www.kremlin.ru/acts/bank/47013 (accessed 11 April 2022).

[5] Plan meropriyatiy «Razvitie vodorodnoy energetiki v Rossiyskoy Federatsii do 2024 goda» [Action plan "Development of hydrogen energy in the Russian Federation up to 2024"]. URL: http://static.government.ru/media/files/7b9bstNfV640nCkkAzCRJ9N8k7uhW8mY.pdf (accessed 11 April 2022).

[6] Ukaz Prezidenta RF ot 26 oktyabrya 2020 g. № 645 "O Strategii razvitiya Arkticheskoy zony Rossiyskoy Fede-ratsii i obespecheniya natsional'noy bezopasnosti na period do 2035 goda" [Decree of the President of the Russian Federation of October 26, 2020 No. 645 "On the strategy for the development of the Arctic Zone of the Russian Federation and ensuring national security for the period up to 2035"]. URL: https://www.garant.ru/products/ipo/prime/doc/74710556/ (accessed 11 April 2022).

Priority areas of energy modification

Russia's geographical location provides challenging climatic conditions in which energy reliability is extremely important. The Ministry of energy of the Russian Federation [7], interacting with industry companies, has the appropriate competencies to ensure reliability. In particular, innovative development, real-time modeling of power systems, new diagnostic system, formation of action algorithms and prevention of impact of weather and other conditions make it possible to ensure the specified reliability. The digitalization of processes in the industry makes it possible to effectively monitor the state of networks and equipment and respond to emerging technological disruptions in a timely manner.

The issue of high-quality and reliable energy supply is especially acute in isolated and hard-to-reach areas of the Far North (Fig. 1). At the current stage, the situation is being resolved at the state level, from the "northern delivery" along the Northern Sea Route (NSR) [1] to the installation of small modular reactors (Small Modular Reactors — SMRs) with a capacity of up to 300 MW per unit. SMRs are one of the most promising emerging nuclear power technologies. The world's first Russian floating nuclear power plant (FNPP) "Akademik Lomonosov" was put into operation in May 2020 in the northern seaport of Pevek; it generates energy from two SMR reactors with a capacity of 35 MW each.

With the use of the latest technologies, there is a steady trend towards a gradual transition from centralized power generation to increased use of distributed generation, which is created and located directly at the consumer's doorstep. A stable situation has developed when households, small, medium and large businesses can have their own generation sources and do not connect to the centralized electric grid or connect to it in order to distribute excess energy to the general grid, as well as to provide a guaranteed and high-quality main/reserve power source.

At the current stage, the existing district heating systems of small and medium-sized cities of Russia, based on boiler houses and heat networks, are losing their significance. The noted phenomenon has many factors; one of them is the tariff regulation of prices for thermal energy by municipalities. Medium and small thermal power plants and individual boiler houses have received an economic advantage, as it is easier to get these energy facilities out of the regulator's control. Consequently, the prospects for the development of cogeneration are largely associated with the construction of medium and small thermal power plants: this is specifically important in the regions of the Far North.

For the Arctic zone of the Russian Federation (AZRF), the use of autonomous hybrid energy sources (AHES) — a combination of a modern diesel, a renewable energy source — a wind power plant (WPP) or a solar power plant (SPP) and an electricity storage unit controlled by a unified automated control system (UACS) — can be considered a promising solution. UACS minimizes the consumption of fossil fuel and maximizes the generation of electricity from renewable energy sources (RES) [2].

[7] Ministry of Energy of the Russian Federation. URL: https://minenergo.gov.ru/node/234 (accessed 11 April 2022).

In the Arctic port of Tiksi (Republic of Sakha, Yakutia), a new hybrid generation facility was put into operation in December 2020: wind-diesel complex (WDC) with a capacity of 900 kW; diesel power plant with a capacity of 3000 kW; energy storage system with a capacity of 1000 kW. The elements of the WDC are united by an automated control system (ACS) for the production and distribution of electricity. This hybrid generation facility is capable of generating more than 12 million kWh of electricity, thereby providing reliable and high-quality power supply to consumers. The use of the best modern technologies in the creation of new generation makes it possible to reduce fuel consumption by up to 500 tons per year and creates an opportunity to obtain a positive economic and environmental effect. PJSC RusHydro plans to build such energy complexes in the settlements of Yakutia (Verkhoyansk, Moma, Sasyr, Tebyulyakh, Tabalakh, Kulun-Elbyut), which are part of the Russian Arctic. The application of autonomous hybrid sources and new technologies used in the energy sector will eventually lead to a reduction in tariff growth and create conditions for a more efficient and reliable power supply.

The Japanese company Mitsubishi Power is working on a hybrid solid oxide fuel cell (SOFC) system with a microgas turbine. The name of the new technology is Hybrid System jf Solid Oxide Fuel Cells (SOFC) and Micro Gas Turbines (MGT). SOFC is a multi-fuel reactor that operates with various types of fuel (biogas, hydrogen, natural gas), generates energy and heat with high efficiency and is used in a decentralized manner and independently of the existing local power grid. The introduction of this technology is planned in Germany in 2022. SOFC is one of the elements in the formation of decentralized and diversifiable energy. *Methods of applying multifuel reactor technology (natural gas, hydrogen) in the future may find application in the regions of the Far North, where traditional energy sources are mined and produced.*

Particular attention in this context is paid to the global processes for the development of Small Modular Reactors (SMRs) with a capacity of up to 300 MW per unit. SMRs are one of the most promising emerging nuclear power technologies. The structural advantage of SMRs is that they are modular and small, as a result, their design is simpler and relies on built-in and passive safety elements, which will require lower costs and provide flexibility for local networks and integration with renewable energy and non-electrical applications such as hydrogen production and water desalination.

The global professional energy community and leading nuclear physicists believe that modern civilization cannot live and develop without nuclear energy. This is due to the fact that the world's population is growing, consumer demands are increasing as well as demand for energy capacity. *The forecast of world energy consumption up to 2100 shows an average growth of 1.5 times [3] (Table 1). Due to the fact that the Arctic zone of the Russian Federation has the potential to become an energy market driver, energy consumption growth in the AZRF alone could potentially amount to up to 50%*. The average growth is expected to be 1.5–2 times [3] (Table 1).

Table 1

Energy consumption forecast for 2020–2100 [8]

Year	TWh
2020	166926
2050	226792
2100	228501

Increasing scientific and technological progress and generating significant benefits for society require impressive energy consumption. The economic EROI coefficient, the ratio of energy received to energy consumed, determines its energy profitability. This coefficient must be above 1 (one), which determines the significant availability of goods to society. The Association of Scientists has determined the proper EROI for various activities of modern society [4]. In developed countries, to maintain the quality of life, EROI must be at least 20 units, and breakthrough scientific and technological progress requires an energy source with an EROI more than 25 units. The minimum EROI value is 8 units — elementary existence, without attempts at scientific and technical progress, improvement, etc. Studies by European scientists have expressed the EROI values of modern and promising energy sources. Table 2 presents the EROI values of an energy source, taking into account its generation.

Table 2

EROI of modern energy sources [9]

No.	Type of activity	EROI (units)
1	Nuclear power plants (NPPs)	75
2	Hydropower plants (HPPs)	35
3	Coal thermal power plants (CTPPs)	30
4	Gas thermal power plants (GTPP)	28
5	Wind energy systems (WES)	3.9
6	Solar energy systems (SES)	1.6

Analyzing the events of the previous few years and the latest trends in the electric power industry, it can be confidently stated that the development of the “peaceful atom”, giving nuclear power the status of a clean energy source is a legitimate, unmistakable vector for the development of the energy industry in Russia and the world as a whole. The results of the Joint Research Centre (JRC) study on the use of nuclear energy and the full cycle of its environmental friendliness have resulted in the JRC Report “Science for Policy” [10] with the evidence of the ecological safety of nuclear power plants. It ranks the environmental friendliness of energy types as follows: 1 — wind; 2 — hydro; 3 — nuclear; 4 — solar; 5 — gas, 6 — oil; 7 — coal; 8 — lignite. This Report provided a strong basis for the European Commission’s decision to classify gas and nuclear as clean

[8] Source: [3].
[9] Source: [5].
[10] JRC science for policy report. Technical assessment of nuclear energy with respect to the ‘do no significant harm’ criteria of Regulation (EU) 2020/852 (‘Taxonomy Regulation’). Petten, European Commission, 2021, 387 p. URL: https://ec.europa.eu/info/sites/default/files/business_economy_euro/banking_and_finance/documents/210329-jrc-report-nuclear-energy-assessment_en.pdf (accessed 11 April 2022).

energy sources. Gas power plants, according to the Taxonomy (document of the sustainable development of the EU economy until 2050), must replace facilities using coal, oil and other heavy fossil fuels, and ensure that emissions do not exceed 270 g CO2 per kWh. The nuclear power plants have received building permission up to 2024, with the expectation that they will use the "best available technology" and meet high safety standards that will minimize the amount of radioactive waste.

The closure of coal thermal power plants, the depletion of gas deposits in Europe have a negative impact on the acceleration of the further promotion of renewable energy due to the low installed capacity utilization factor (ICUF). For example, as of 01.01.2022, the installed capacity of power plants of UES of Russia amounted to 246,590.9 MW, which is 1,277.65 MW (+0.52%) more than in 2021. Table 3 shows the data describing the installed capacity of power plants of UES of Russia by CPS, not taking into account power plants of industrial enterprises [11].

Table 3

Installed capacity utilization factor of power plants of UES of Russia in CPS in 2020, 2021 (%) [12]

Power plants	2020	2021	Deviation
TPP	41.34	46.05	+ 10.23
HPP	47.33	47.89	+ 1.17
NPP	81.47	83.98	+ 2.99
WES	27.47	28.31	+ 2.97
SES	15.08	14.4	- 4.72

Based on the analysis of the Report data, it was found that the number of hours of use of the installed capacity of power plants across the UES of Russia in 2021 amounted to 4514 hours (51.53%) of calendar time (installed capacity utilization factor), including: nuclear power plants — 7349 hours (83.89% of calendar time); hydroelectric power plants — 4195 hours (47.89% of calendar time); thermal power plants — 4034 hours (46.05% of calendar time); wind power plants — 2480 hours (28.31% of calendar time); solar power plants — 1261 hours (14.4% of calendar time). In 2020, this coefficient was 4238 hours (48.25%), the ICUF growth in 2021 was 276 hours (+3.28%).

The next vector of energy development is the use of renewable energy sources (RES) [6]. In order to achieve carbon neutrality, many countries have announced a large-scale transition to "green energy" with a higher level of decarbonized energy production [7, 8, 9]. The goal of the transition to alternative energy sources is the decarbonization of the economy and the maximum possible reduction of CO2 emissions during energy generation and in all areas of economic activity [10, 11, 12]. In this regard, the renewable energy sector is scaling up rapidly and extensively with a large proportion of new solar and wind power capacity coming from China, the European Union, the United States and India. They are also the world's largest economies — producers of goods, works and services, and consequently consumers of energy. According to the International Energy

[11] Report on the functioning of the UES of Russia in 2021. URL: https://www.so-ups.ru/fileadmin/files/company/reports/disclosure/2022/ups_rep2021.pdf (accessed 11 April 2022).
[12] Ibid.

Agency (IEA), by 2026, RES will account for up to 95% of the increase in new energy capacity. At the end of 2021, solar energy is the driver of the renewable energy sector: capacity growth increased by 17% (to 160 GW), followed by wind and hydropower. The IEA predicts that global renewable capacity will grow by 60% by 2026, compared with 2020, to more than 4800 GW. China is expected to remain the leader in terms of RE growth over the next five years (2021–2026), reaching 1200 GW of solar and wind capacity by 2026. India plans to reach 500 GW of renewable energy capacity by 2030. The EU and the US also plan to accelerate the development of renewable energy. At this stage, these four markets account for 80% of global renewable energy capacity growth [13].

In Russia, the growth rate of renewable energy looks much more modest; at the end of 2021, the share of renewable energy sources was 0.5% in energy production [13]. The distribution of the annual volume of electricity production by types of power plants in the UES of Russia in 2021 was the following: wind power plants — 3621.7 million kWh (+161.7% from 2020), solar power plants — 2253.8 million kWh (+13.7% from 2020) [14]. In the North-West, electricity generation in the CPS by types of power plants was as follows: thermal power plants — 53.4%; WPP, HPP, SPP — 11.8; NPP — 34.9. However, the Kola WPP with a capacity of 200.97 MW, built by Enel Russia — controlled by Italian Enel, has not been put into operation in Murmansk Oblast. Murmansk wind park "Octagon. Severo-Zapad" of the Kola wind farm was supposed to deliver capacity to the market in December 2021, but due to "force majeure circumstances", the deadlines were shifted to 2022, but under the new circumstances, they were postponed to a later date [15].

Energy consumption in the world is growing steadily, as mentioned above, in particular, in Russia, electricity consumption increased by 6% in 2021 compared to 2020, and by 2.6% in 2020 from 2019; electricity generation increased by 6.6% in 2021. Electricity with a consumption share of more than 50% could potentially be the end product of the energy market in the future. Table 4 shows the prospects for world energy transitions, the 11.5^0 C trajectory [16].

Table 4

Forecast of final electricity consumption up to 2050 [17]

Energy sources	Balance of global final consumption, 2018 (%)	Projection of final consumption by 2050 (%) (in the 1.5^0 C warming containment scenario)
Oil	37	4

[13] Report of the International Energy Agency for 2021 and renewable energy pans for 5 years. URL: https://zen.yandex.ru/media/solarnews/otchet-mejdunarojnogo-energeticheskogo-agenstva-za-2021-god-i-plany-viena-5-let-61b21e4ddc065960a505f342 (accessed 11 April 2022).

[14] Report on the functioning of the UES of Russia in 2021. URL: https://www.so-ups.ru/fileadmin/files/company/reports/disclosure/2022/ups_rep2021.pdf (accessed 11 April 2022).

[15] Enel gotovitsya k vykhodu [Enel is getting ready to go out]. URL: https://www.kommersant.ru/doc/5270154 (accessed 11 April 2022).

[16] World Energy transitions outlook, 1,5° C pathway. URL: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/March/IRENA_World_Energy_Transitions_Outlook_2021.pdf (accessed 11 April 2022).

[17] Ibid.

Electricity	21	51
Gas	16	4
Coal	11	2
Conventional biomass (biogas, presscake, etc.)	8	-
New biomass (wood, peat, etc.)	3	18
Heat generation	3	5
Other RES	0.5	4
Hydrogen	-	12

In parallel with the changes in electricity production, the industry is being transformed, for which hydrogen will become the basis [14]. As a result, the use of renewable energy sources for the production of "green" hydrogen is increasing. According to IEA estimates, electrolysis capacity will increase from 0.3 GW in 2020 to 17 GW by 2026. In July, 2020 the European Commission adopted the hydrogen strategy up to 2050, which foresees the construction of electrolysis facilities based on RES with investments of €470 billion, as well as the construction of new wind and solar power plants with investments of €340 billion. Leading transport operators plan to upgrade the existing gas transport infrastructure and form a system of 6800 km of gas pipelines by 2030, which will connect the "hydrogen valleys" — consumption clusters H_2, and to increase the transportation system to 23000 km by 2040.

In accordance with the plans of the Energy development strategy of Russia, large-scale work is underway to modify the country's energy complex and introduce new technologies in energy, transport and industry that are related to decarbonized energy production, the basis of which are Law No. 296-FZ of 02.07.2021 "On limiting greenhouse gas emissions", Decree No. 2634-r on approval of the action plan "Development of hydrogen energy in the Russian Federation up to 2024", etc. Russia has an opportunity to become a reliable supplier of hydrogen for the domestic market, as well as an exporter of hydrogen with integration into the hydrogen infrastructure of Europe. Gazprom is currently able to move 20 to 70% of hydrogen to Europe through its pipeline network and, with the launch of Nord Stream-2, will be able to increase supplies. A bench-top hydrogen production test facility is being built at the Kola NPP in the Murmansk Oblast.

The Russian Federation has chosen the right course in public and corporate governance, and investments in nuclear power development, the core of which is the country's hydrocarbon resources, have allowed new technologies to be developed, generation 3 and 3+ reactors to be redesigned, bringing nuclear technology to the limits of humanity's technological development. Generation 3+ reactors are listed as the most highly advanced in terms of operational safety.

Rosatom State Corporation [18] has unique competencies and is the only Company in the world capable of providing a full cycle of construction, supply and disposal of irradiated nuclear fuel (INF) and nuclear power plants. Active and successful research by Russian scientists indicates the availability of technologies and competencies to start a unique experiment — closing the nuclear fuel cycle (CNFC), the next step in the development of nuclear energy, the implementation of which will solve the problem of spent nuclear waste: "waste" will be converted into new fuel and

[18] State Corporation Rosatom. URL: https://www.rosatom.ru (accessed 11 April 2022).

reused at nuclear power plants. As a result, radioactive actinoids are incinerated during repeated use.

Priority in the expansion of domestic carbon-free energy is focused on the development of nuclear technologies. The Proryv project implemented by Rosatom is aimed at creating nuclear power complexes that improve large-scale nuclear power and meet the basic requirements [15]. The launched modernized thermonuclear reactor TOKAMAK T-15MD is a unique installation for carrying out thermonuclear processes in terms of a number of physical characteristics; it is of great interest in scientific and energy terms.

Possessing the "best available technologies" that meet high safety standards, Rosatom intends to initiate the construction of more than 50 nuclear reactors in 19 countries in the near future. In the long term (up to 2030), more than 80 facilities will be created.

At present, there are 11 nuclear power plants in Russia, with 37 power units in operation. The total installed capacity of all power units exceeds 29.5 GW, the share of nuclear energy is about 20% of the total electricity generation. The prospect is to increase the share of nuclear generation in the country to 25%, with reactors (including those with spectrum control) being safer, better and more efficient.

For the sustainable development of the Arctic zone of the Russian Federation (AZRF), projects are being implemented to use autonomous energy, isolated from the unified energy system of Russia [16].

The floating power unit (FPU) "Akademik Lomonosov" was delivered to the Arctic seaport of Pevek in 2020 to provide remote areas with electricity and heat. The floating nuclear thermal power plant (FNPP) is a new class of mobile energy sources based on modern Russian nuclear technologies; its launch was a real breakthrough in electricity and heat generation. The power plant is equipped with two KLT-40 (water-cooled nuclear) reactors. Importantly, the main designer, manufacturer and supplier of modern technological equipment is JSC "Experimental Design Bureau of Mechanical Engineering named after I.I. Afrikantov", Nizhniy Novgorod, an enterprise of Rosatom State Corporation.

The Government of the Republic of Sakha (Yakutia) and State Corporation Rosatom entered into an agreement in December 2020 to fix the electricity tariff for the implementation of a low-power nuclear power plant (LPNPP) project. LPNPP will be the first project in the world to use nuclear energy and preserve the ecology of the Arctic. This project can become a "pilot" for our country and will allow it to work out new technologies for providing energy when creating isolated energy systems, to actively develop not only remote areas, but also in general to create new city-forming enterprises of the national economy in hard-to-reach areas.

The use of small modular reactors (SMR) for settlements in the Far North can have a number of advantages:

- compactness: these nuclear installations consist of separate modules, occupy a smaller area — the dimensions of the promising domestic reactor RITM-400 are 8.2*9*17 m, design features allow them to be installed on land and sea vessels;
- transportability: reactors can be assembled at the factory and then transported and installed on site;
- capacity: the ability to increase capacity depending on energy consumption; 1, 2 or more SMR units can be installed in a given region;
- serialization: reduces the cost of SMRs and makes them affordable for consumers [17].

Providing the population and production capacities of the Far North with guaranteed energy supply creates a favorable climate for socio-economic development and environmental safety.

Another promising area of scientific and technological development of the nuclear industry is hydrogen energy based on the country's nuclear power plants. The technologies used by Rosatom State Corporation in the medium term can ensure the production of hydrogen in industrial volumes, subject to environmental standards, as well as with highly competitive cost parameters.

The Kola NPP was chosen as a pilot site for creating a bench test complex (BTC) for hydrogen production and handling (Fig. 2). Nuclear energy experts are exploring options for using excess electricity from nuclear power plants to produce hydrogen and use it to fuel trains, cars and other hydrogen fuel cell vehicles [19]. The Kola energy system is energy surplus, which determined the choice of the Kola NPP as the BTC, and the availability of the entire necessary infrastructure, experience in hydrogen production for own needs and low energy costs created favorable economic conditions. It is planned to create a system for handling hydrogen on an industrial scale — production, compression/liquefaction and transportation, and to put into operation a complex with 1 MW electrolysis units in 2023, and subsequently to increase the capacity and output of the BTC to 10 MW. According to the results of the efficiency of the complex, this technology can get a large-scale expansion throughout Russia. Rosatom plans to start construction of the second Kola nuclear power plant, Kola-2, in 2028, two new PWR reactors with a capacity of 600 MW. The project is now at the preparation and development stage; a construction site has been selected and surveys have been carried out; the site is located a few kilometers from the existing Kola NPP.

According to the forecasts of experts from the Ministry of Energy, in the case of a favorable scenario, Russia can export up to 1 million tons of hydrogen in three years, and the volumes can grow thirty times by 2050 and bring significant income [18]. The markets of the Asia-Pacific Region (APR) and the European Union are considered the most promising. In order to supply the foreign consumers, an effective model of hydrogen transportation for medium and long distances by means of sea-going vessels and efficient modular hydrogen liquefaction unit is being developed. A

[19] Na Kol'skoy AES nachnut proizvodit' vodorod v 2023 godu [Hydrogen production to start at Kola NPP in 2023]. URL: https://www.rosenergoatom.ru/stations_projects/sayt-kolskoy-aes/press-tsentr/novosti/38627/ (accessed 11 April 2022).

special project is being developed to create a system based on liquid organic carrier for hydrogen accumulation, storage and transportation by ice-class maritime transport along the Northern Sea Route (NSR) to the Asia-Pacific region. As a result, hydrogen energy as a separate segment of the fuel and energy complex (FEC) may be formed by 2025 and will require investments of 2.2 to 4.0 billion US dollars per year.

Conclusion

The scenario of energy development in the XXI century, when mankind was predicted to master controlled thermonuclear fusion and start transition to thermonuclear energy, a powerful and clean source of energy, turned out to be out of reach in practice. The large-scale expansion of wind and solar energy, the entry of hydrogen energy into this field, both in the form of generation by means of fuel cells and direct use of hydrogen as combustible fuel, and in the future application of thermonuclear energy (TNPP) leads to the processes of diversification of world energy.

Breakthrough technologies and climate change are causing a structural market transformation. Energy is changing from a commodity to a service and modern trends are creating a shift from vertical integration to distributed generation and decentralization. Consumers are now ready to become market players along the entire chain: able to manage their demand in response to market signals; able to become solicitors, i.e. energy consumers at some hours and producers at others, with their own generation and the tools to release excess energy into the common grid. A new, active consumer, perhaps indirectly and to a small extent, but involved in managing and balancing the power system, is preparing to do without centralized energy supply.

Of great importance is the increase in electricity consumption, which in turn entails an increase in electricity generation. Generating companies ensure a reliable, high-quality and uninterrupted supply to consumers. The single-rate electricity price in the wholesale electricity and capacity market (WECM) changed in 2021 at a rate lower than inflation: the wholesale price growth was 5.3%, while the forecast inflation rate was 8%. For example, in Russia the single-rate wholesale electricity price in 2021 was about 30 euro/MWh; in France it was 443 euro/MWh, in Germany it was 432 euro/MWh, in Austria and Belgium — above 430 euro/MWh. In the Baltics and Finland, the wholesale electricity price reached 1,000 euro/MWh in different periods. In the face of these new challenges, the Russian wholesale market remains one of the least volatile and competitive segments of the energy market definitely insure consumers against sharp increases in electricity prices.

The global climate agenda creates acute issues for the Russian economy. Abandonment of fossil fuels, development of renewables and other challenges will create additional risks of reduced demand for hydrocarbons already in the medium term. For reference, the fifth set of sanctions against Russia included an embargo on coal imports from Russia and a ban on Russian-flagged ships entering European ports. A report by the Global Wind Energy Council (GWEC) fore-

casts that an additional 557 GW of wind farms will be built globally between 2020 and 2026, which means an average of over 110 GW per year will be produced.

The key trend of the energy transition is the development of hydrogen energy, and in the medium term, hydrogen technologies will develop at an accelerated pace. Russia has significant potential to become an exporter of hydrogen and integrate into the global hydrogen infrastructure. The introduction of hydrogen together with nuclear, solar, wind and hydropower will create the prerequisites for the transition to a new energy mode.

Innovative energy projects are being successfully and systematically implemented in the Arctic zone of the Russian Federation as part of the country's economic enhancement. Application of the latest nuclear power technologies and installation of Small Modular Reactors (SMRs) in the Far North contributes to socio-economic development of these territories and is an important foundation for the use of the “peaceful atom” and scientific research. Distributed generation creates additional incentives to improve the efficiency of business processes in the northern territories of the country. The application of green energy is a priority for all activities in the Arctic zone of the Russian Federation.

References

1. Vopilovskiy S.S. Foreign Economic Partners of Russia in the Arctic Zone. *Arktika i Sever* [Arctic and North], 2022, no. 46, pp. 33–50. DOI: 10.37482/issn2221-2698.2022.46.33
2. Basu S., John A., Akshay, Kumar A. Design and Feasibility Analysis of Hydrogen Based Hybrid Energy System: A Case Study. *International Journal of Hydrogen Energy*, 2021, vol. 46, iss. 70, pp. 34574–34586. DOI: 10.1016/j.ijhydene.2021.08.036
3. Degtyarev K.S. Dinamika mirovogo energopotrebleniya v XX–XXI vv. i prognoz do 2100 goda [Trends of World Energy Supply in XX-XXI Centuries and Outlook 2100]. *Okruzhayushchaya sreda i energovedenie (OSE)* [Journal of Environmental Earth and Energy Study], 2020, no. 2, pp. 35–48. DOI: 10.5281/zenodo.3930342
4. Lambert J.G., Hall C.A.S., Balogh S., Gupta A., Arnold M. Energiya, EROI i kachestvo zhizni [Energy, EROI and Quality of Life]. *Energy Policy*, 2014, vol. 64, pp. 153–167. DOI: 10.1016/j.enpol.2013.07.001
5. Weißbacha D., Ruprechta G., Hukea A., Czerski K., Gottlieb S., Hussein A. Energy Intensities, EROIs, and Energy Payback Times of Electricity Generating Power Plants. Preprint Submitted to *Energy*, 2013, no. 6, pp. 1–29.
6. Buyalskiy V.I. Povyshenie effektivnosti upravleniya vetroenergeticheskoy ustanovkoy na osnove ucheta vibratsionnoy nagruzhennosti privoda pri raznykh usloviyakh ekspluatatsii energoagregata [Improving the Efficiency of Wind Power Plant Control Based on the Vibration Load of the Drive under Different Operating Conditions of the Power Unit]. *Energetik,* 2021, no. 10, pp. 41–45.
7. Gielen D., Boshell F., Saygin D., Bazilianc M.D., Wagner N., Gorini R. The Role of Renewable Energy in the Global Energy Transformation. *Energy Strategy Reviews*, 2019, vol. 24, pp. 38–50. DOI: 10.1016/j.esr.2019.01.006
8. Eicke L., Wekoab S., Apergia M., Marian A. Pulling Up the Carbon Ladder? Decarbonization, Dependence, and Third-Country Risks from the European Carbon Border Adjustment Mechanism. *Energy Research & Social Science*, 2021, vol. 80 (4), pp. 102240. DOI: 10.1016/j.erss.2021.102240
9. Acar S., Aşıcı A.A., Yeldan A.E. Potential Effects of the EU's Carbon Border Adjustment Mechanism on the Turkish Economy. *Environment, Development and Sustainability*, 2022, vol. 24, pp. 8162–8194. DOI: 10.1007/s10668-021-01779-1
10. Verde S.F., Acworth W., Borghesi S. Achieving Zero Emissions under a Cap-And-Trade System. *Environmental Science*, 2020, pp. 1–12. DOI: 10.2870/343248

11. Porter M.E., van der Linde C. Toward a New Conception of the Environment Competitiveness Relationship. *Journal of Economic Perspectives*, 1995, vol. 9, no. 4, pp. 97–118. DOI: 10.1257/jep.9.4.97
12. Bashmakov I.A. Uglerodnoe regulirovanie v ES i rossiyskiy syr'evoy eksport [CBAM and Russian Export]. *Voprosy ekonomiki,* 2022, no. 1, pp. 90–109. DOI: 10.32609/0042-8736-2022-1-90-109
13. Porfiriev B.N., Shirov A.A., Kolpakov A.Yu., Edinak E.A. Vozmozhnosti i riski politiki klimaticheskogo regulirovaniya v Rossii [Opportunities and Risks of the Climate Policy in Russia]. *Voprosy ekonomiki*, 2022, no. 1, pp. 72–89. DOI: 10.32609/0042-8736-2022-1-72-89
14. Bartolucci L., Cordiner S., Mulone V., Pasquale S. Hydrogen Based Multi Energy Systems: Assessment of the Marginal Utility of Increasing Hydrogen Penetration on System Performances. *International Journal of Hydrogen Energy*, 2021, vol. 46, iss. 78, pp. 38588–38602. DOI: 10.1016/j.ijhydene.2021.09.108
15. Timokhin D., Bugaenko M., Putilov A. Use of IT Technologies in the Implementation of the "Economic Cross" Methodology in the "Breakthrough" Project of Rosatom. *Procedia Computer Science*, 2020, vol. 169, pp. 445–451. DOI: 10.1016/j.procs.2020.02.227
16. Esyakov S.Ya., Lunin K.A., Stennikov V.A., Voropay N.I., Redko I.Ya., Barinov V.A. Transformatsiya elektroenergeticheskikh sistem [Transformation of Electric Power Systems]. *Elektroenergiya. Peredacha i raspredelenie* [Electric Power. Transmission and Distribution], 2019, no. 4 (55), pp. 134–141.
17. Byk F.L., Myshkina L.S. Ekonomicheskaya effektivnost' sovremennoy elektroenergetiki [Economic Efficiency of Modern Electric Power Industry]. *Energetik*, 2022, no. 1, pp. 17–21.
18. Yamamoto H, Fujioka H, Okano K. Cost Analysis of Stable Electric and Hydrogen Energy Supplies Derived from 100% Variable Renewable Resources Systems. *Renewable Energy*, 2021, vol. 178, pp. 1165–1173. DOI: 10.1016/j.renene.2021.06.061

The article was submitted 18.04.2022; approved after reviewing 19.07.2022; accepted for publication 27.07.2022.

The author declares no conflicts of interests.