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Prospects for Nuclear Energy in the Framework of Implementation of the Sustainable Development Concept

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Abstract
The need to create an effective global energy structure that meets the current challenges of sustainable development and the growing demand for electricity implies an expansion of the use of nuclear energy potential and necessitates a more detailed study of the prospects for its development, taking into account the economic efficiency, high technology, environmental friendliness and safety of this method of power generation.
The purpose of the study is to reveal features of, and identify opportunities for, the global nuclear power development in the conditions of increasing influence of the concept of sustainable development.
The study substantiates the necessity and identifies features of the global nuclear power development, characterized by both intensification of capacity obsolescence processes and high degree of their significance in the overall energy structure under conditions of decarbonization.
Given the need to achieve the Sustainable Development Goals, the authors justify the necessity of development and implementation at national levels of financial and economic measures in the design of energy markets, taking into account clean energy and the attributes of energy security of low-carbon technologies, including nuclear energy, supported by the expansion of direct and indirect state participation.
The issues considered have practical significance and social implications in terms of solving socio-economic and environmental problems.

Keywords: *global energy industry, nuclear power, sustainability, green energy, decarbonization*

JEL: *H54, O13, P28, Q42, Q56*

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INTRODUCTION

In today's world, there are a number of key factors that define the development of global energy. The adoption of the Sustainable Development Goals in 2015 necessitated transformations in the energy sector[1]. The adoption and ratification of the Paris Agreements[2] by 192 countries has defined the need to reduce emissions by the mid-21st century thereby intensifying the necessity to match anthropogenic emissions with absorption of greenhouse gases from the atmosphere. Moreover, the COVID-19 pandemic has had a significant impact on key economic indicators and has showed the critical need for uninterrupted power supply to all systems, including social and medical.

This situation has aggravated the problem of finding new trends in energy development at the global level. [Kumar and Choudhary, 2021; Mahmood et al., 2020; Pearce, 2012; Pomponiand, Hart, 2021]. The dominance of green and sustainable trends within the global agenda is leading to major regulations in this sector[3] [Dai, 2019; Kabir, Yakovlev, 2022]. In order to comply with international climatic agreements, the industry and investors are actively expanding their investments in the development of technologies consistent with green energy policies [Yakovlev, Kabir, Nikulina, 2021; Ivanitsky, Petrenko, 2020].

The current period sees the active development of renewable energy within the solar-wind and hydropower sectors [Petrenko, 2021a]. It is important to note that nuclear energy has low-carbon parameters but is not included in the adopted classification so far. [Akcay, 2009; Anser et al., 2021; Danish et al., 2021; Elhegazy and Kamal, 2022; Engler, 2020].

It seems that the creation of an effective global energy structure that meets today's sustainable development challenges requires greater use of the potential of nuclear energy and necessitates a more detailed study of its development prospects.

In this regard, we can assume that preservation and further development of nuclear energy as one of the key segments of the global power industry will be able to ensure not only solution of decarbonization problems, but also implementation of global and national socio-ecological and economic objectives in the field of sustainable development.

Specific data from the International Energy Agency Enerdata, the International Atomic Energy Agency (IAEA), the Power Reactor Information System (PRIS), the Intergovernmental Panel on Climate Change (IPCC), and the International Renewable Energy Agency (IRENA) were used in the preparation of the article.

NUCLEAR ENERGY: DEVELOPMENT TRENDS

The first nuclear fission chain reactions were initiated in the 1940s. The first nuclear power was generated in 1951. The first nuclear power plant (NPP) was commissioned in Obninsk, USSR, in 1954.

The first discussion of the peaceful use of atomic energy at the global level took place in Switzerland in 1955, and nuclear power was officially acknowledged as a new area in the field of energy.

The current period of nuclear power development can be characterized by the following data. According to PRIS[4], in 2021 there were 442 active nuclear power units in the world

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[1] *United Nations. (2015). The Sustainable Development Goals. Available at: https://www.un.org/sustainabledevelopment/.*

[2] *United Nations. (2015). Paris Agreement. Available at: https://www.un.org/ru/climatechange/paris-agreement.*

[3] *European Commission (2021). EU Taxonomy for Sustainable Activities. Available at: https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en.*

[4] *International Atomic Energy Agency (2021). Nuclear Power Capacity Trend. Available at: https://pris.iaea.org/PRIS/WorldStatistics/WorldTrendNuclearPowerCapacity.aspx.*

(or 414 according to the World Nuclear Industry Status Report[5]) in 34 countries, with 53 reactors under construction. The average age of reactors is about 31 years.

Between 2001 and 2021 the number of operating reactors remained virtually unchanged (438 in 2011, 442 in 2020). The amount of power capacity increased insignificantly during this period (352.72 GW in 2011, 392.1 GW in 2020)[6].

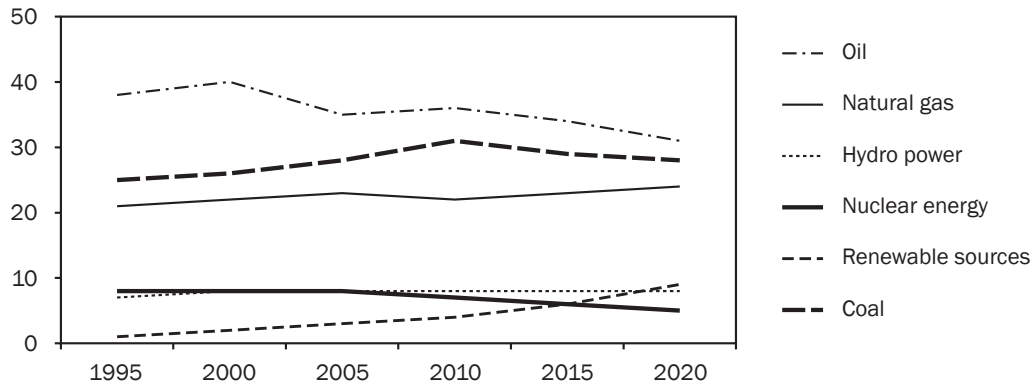
The largest numbers of reactors are in the USA, France, China, Russia, Japan, Korea, and India. Leaders in the share of nuclear power in national electricity generation are France, Slovenia, Ukraine, Hungary, and Bulgaria. Nuclear energy is present in 13 countries of the European Union.

The top ten countries in terms of power generation using the nuclear sector is different. The leader in the volumes of such energy is the USA (789 GW). China ranks 2nd with 344 GW. France ranks 3rd with 338 GW, Russia ranks 4th with 201 GW, Germany ranks 8th with 60 GW, and Spain ranks 9th with 55 GW [Doufene et al., 2019; Gomez-Calvet et al., 2019]. Belarus ranks lowest with 0.34 GW[7].

The globally growing construction of NPPs should be noted. However, the existing structure of nuclear energy has no serious impact on the transformation of the global energy balance [Nigmatulin, 2019]. For several decades, the balance of various energy sources has tended to increase the share of the "green" sector [Khan et al., 2021]. Along with that, the share of hydropower, nuclear, solar-wind, geothermal, tidal and biomass energy in the overall share of primary energy in 2020 was about 17%[8] (Fig. 1).

Figure 1

Share of energy sources in primary energy in 1995–2020 (%)



Source: compiled by the authors on the basis of data from bp. (2021), Statistical Review of World Energy 2021 (https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-primary-energy.pdf).

Oil still has the highest share in the energy balance (31.2%). Coal is the second most used type of fuel in 2020 with a share of 27.2% of total primary energy consumption, slightly higher

[5] *World Nuclear Industry Status Report (2021). Available at: https://www.worldnuclearreport.org/.*

[6] *International Atomic Energy Agency (2021). Nuclear Power Capacity Trend. Available at: https://pris.iaea.org/PRIS/WorldStatistics/WorldTrendNuclearPowerCapacity.aspx.*

[7] *International Atomic Energy Agency (2021). Nuclear Share of Electricity Generation in 2020. Available at: https://pris.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx.*

[8] *bp (2021). Statistical Review of World Energy 2021. Available at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-primary-energy.pdf.*

than the 27.1% of the previous year. The share of natural gas and renewable sources jumped to the record-high level of 24.7% and 5.7%, respectively[9].

Renewable sources overtook nuclear sources that account for 4.3% of the energy balance. The share of hydropower increased by 0.4% in 2020 to 6.9%, which happened for the first time since 2014[10].

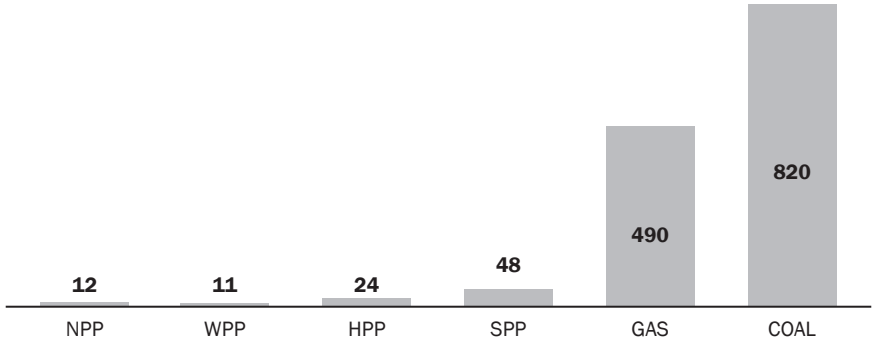
This is mainly because the fossil fuel industry is growing much faster than the clean energy industry. Some emerging economies use timber, manure and coal as their primary fuels.

The previous years saw an active development of the renewable energy sector while NPPs tended to shut down. Solar-wind generation is distinctive for its instability (10–30% of the time when there is enough sun and wind) [Petrenko, 2021b; Petrenko, 2022]. The need for affordable and uninterrupted energy resources scales up research into nuclear energy, as the NPPs uptime is about 92%.

The need to comply with the Paris Agreement in terms of reducing atmospheric emissions leads to new approaches in ensuring carbon neutrality in 2030–2060, namely in the development of nuclear energy. According to experts, NPP operation on a global scale helps save greenhouse gas emissions at the level of 2 billion tons of CO_2 equivalent per year and is equal to the absorption capacity of global woodlands[11] (Fig. 2).

Figure 2

Greenhouse gas emissions by type of power generation (tons of CO_2-equivalent per GWh)



Source: compiled by the authors on the basis of data from Intergovernmental Panel on Climate Change (IPCC), 2021 (https://www.ipcc.ch/).

Compliance with the sustainability requirements implies both minimization of greenhouse gas emissions and absence of risk of negative impact on the environment, life and health of the population. According to experts[12], nuclear energy is competitive with renewable energy sources in terms of negative environmental effect, and the specifics of NPP operation are superior to those of other types of power generation. Initiatives (in France, Poland, Hungary, Romania, Czech Republic, Slovakia, and Slovenia) to include nuclear power in the list of approved measures to achieve carbon neutrality are extensive but have not yet had the desired effect[13] [Khorishko, 2021].

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[9] *bp (2021). Statistical Review of World Energy 2021. Available at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-primary-energy.pdf.*

[10] *Ibidem.*

[11] *Intergovernmental Panel on Climate Change (IPCC), 2021. Available at: https://www.ipcc.ch/.*

[12] *Joint Research Center (2021). Available at: https://ec.europa.eu/info/departments/joint-research-centre_en.*

[13] *Ten EU Countries Appealed to Include Nuclear Energy into Green Classification (2021). Available at: https://www.atomic-energy.ru/news/2021/10/11/118314*

Along with that, according to the VEB-RF classification[14] of "green" projects, nuclear energy belongs to the "green" types. Moreover, nuclear energy is considered as a source of low-carbon green power in some of Russia's strategic policy documents[15].

The global trend away from the peaceful atom (Germany, etc.) may not only lead to negative socio-economic consequences [Solarin, Bello, 2021], but will also result in additional CO_2 emissions of $4 billion by 2040 and an increase in costs of $500 billion in the EU countries[16].

Thus, today nuclear energy acts as an efficient low-carbon source of energy. It is affordable, and highly productive[1718], but the number of countries may reduce its scope of application.

NUCLEAR ENERGY IN RUSSIA AND THE EU COUNTRIES: DISTINCTIVE FEATURES

Nuclear energy is now the largest source of low-carbon power in Russia and the EU. The distribution of operating reactors by countries, net power capacity and the share of nuclear energy in national electricity generation is represented in Table 1.

Table 1

Russia and the EU countries by the number of operating reactors in 2020

Country	Number of operating reactors	Net power capacity, MW	Share of nuclear energy in electricity generation, %
Russia	39	29.503	20.6
EU countries	109	107.012	26.7
Including:			
France	58	63.130	70.6
Belgium	7	5942	39.1
Sweden	7	7763	29.8
Spain	7	7121	22.2
Czech Republic	6	3934	37.3
Germany	6	8113	11.3
Slovakia	4	1837	53.1
Hungary	4	1902	48.0
Finland	4	2794	33.9
Bulgaria	2	2006	40.8
Romania	2	1300	19.9
Slovenia	1	688	37.8
Netherlands	1	482	3.2

Source: compiled by the authors on the basis of data from International Atomic Energy Agency (2021), Nuclear Share of Electricity Generation in 2020 (https://pris.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx).

The specifics of nuclear energy development in Russia show that 216 billion kWh was generated in 2020, which exceeded all previous levels including the 1988 record in the USSR. Along with that, large-scale foreign processes are underway, involving the construction of 35 nuclear power units in 12 countries. Twenty-four units are under construction in 9 countries (more than 70% of the global nuclear construction volume).

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[14] *Green Finances and Role of VEB-RF (2021). Available at: https://veb.ru/ustojchivoe-razvitie/zeljonoe-finansirovanie/zelenye-finansy-i-rol-veb-rf/.*

[15] *Strategy of Social and Economic Development of the Russian Federation with Low Level of Greenhouse Gas Emissions until 2050 (2021). Available at: http://static.government.ru/media/files/ADKkCzp3fWO32e2yA0BhtIpyzWfHaiUa.pdf.*

[16] *International Energy Agency (2021). Available from: https://www.iea.org/.*

[17] *Intergovernmental Panel on Climate Change (IPCC) (2021). Available at: https://www.ipcc.ch/.*

[18] *International Energy Agency (2021), Net Zero by 2050. Available at: https://iea.blob.core.windows.net/assets/ad0d4830-bd7e-47b6-838c-40d115733c13/NetZeroby2050-ARoadmapfortheGlobalEnergySector.pdf.*

The EU countries with over 107 GW of nuclear capacity and 109 reactors are showing a decline in activity in this energy sector. The lack of initiatives for further lifetime extensions and construction of new nuclear plants may not only result in additional emissions of 4 billion tons of CO_2 but also seriously affect the quality of life and the smooth functioning of many systems.

Moreover, the current condition of nuclear energy capacities indicates that most of them is approaching the end of their design life cycle. Given their age, NPPs are being shut down and about 25% of existing nuclear capacities in developed countries are expected to be shut down by 2025 [Invernizzi et al., 2017].

It must be noted that the specifics of the Russian nuclear power industry characterize the highest modernization rates in this sector. However, extending the life cycle of a reactor is cheaper than constructing a new one, but comparable, in terms of attracted financial resources, with clean energy alternatives (solar-wind).

However, challenging market conditions pose an obstacle to the life cycle extension. The long period of falling prices in the solar-wind generation sector in most developed countries has greatly reduced or even eliminated margins for many technologies, putting nuclear energy at risk of premature shutdown. Thus, the practicability of lifetime extensions mainly depends on domestic market conditions.

NUCLEAR ENERGY: ASPECTS OF FINANCING

The role of nuclear energy under this transition cannot be overestimated. Therefore, the need to develop and implement appropriate economic measures at national levels involves the need to design energy markets taking into account clean energy and attributes of energy security of low-carbon technologies, including nuclear energy.

In the world practice there are several models of financial support of nuclear power functioning, depending on the set of used forms and methods of state control.

According to the first model, the nuclear power industry is completely under state control and financial support. This model has taken shape in Russia, China, India and France. South Korea is among the countries that have developed a system of softer government participation, which allows non-state shareholders to participate in the capital of nuclear power companies.

The second model of nuclear power financing implies that countries with a state monopoly within existing nuclear power companies have an opportunity to attract other (non-state and foreign) investment resources in the contour of building new capacities (Bulgaria), transferring them to the long-term disposal of the non-state sector (Canada).

The third model assumes a high degree of importance of non-state resources in the development of the industry. At the same time, the system of financing provides for the investment of public funds in a number of priority directions (the USA, Great Britain, Germany, Spain, Sweden, Switzerland, Finland, etc.). In a number of countries there is a possibility of participation of foreign shareholders in the capital of companies of the industry (Great Britain, Spain, Sweden).

It's important to note that the EU countries have a very active investor base in the nuclear energy sector. One of the leaders in terms of investment activity in the industry is France. Major projects include the development of fast neutron reactors and the design of the 600 MW ASTRID fast sodium reactor, in which more than €1 billion of budget funds were invested in 2010[19].

[19] *Nuclear powers shared plans for the development of fast reactors at the IAEA conference (2022). Available at: https://strana-rosatom.ru/2022/05/23/yadernye-derzhavy-podelilis-planami-p/.*

According to the Nuclear Industry Strategy and the UK Nuclear R&D Support Program, about £250 million has been allocated to the industry. In the 2020s, it is planned to spend £500 million on the introduction of small reactors[20].

At the same time, it should be noted that in most countries public funding dominates — in the R&D sector, which provides innovative development of the industry, as well as when it comes to nuclear waste disposal.

At the level of nuclear power companies, changes have occurred in recent decades (deregulation of markets and unbundling of companies), which have not only increased competition between them and increased the risks of their activities, but have also had a serious impact on the model of financing projects in this sector. In this context, the role of state participation has increased in many countries through the expansion of partial investments and state credit guarantees.

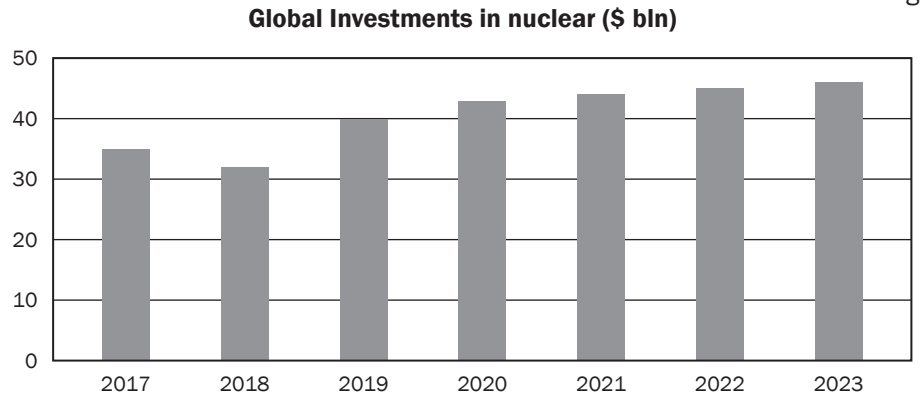
In addition, the globalization of financial markets has led to increased competition for investment resources, which has resulted in the emergence of new financial instruments (staged financing to reduce risk at different stages of the project: from construction to the addition of new power units).

The efficiency of investments in the construction of new nuclear plants is largely predetermined by the high share of capital costs (about 60%) in the total structure of electricity costs, the burden of servicing debt capital, and the long construction period. After completion of construction production and commissioning of NPPs, the costs of power generation have more stable and lower values.

The emergence of economic risks is predetermined by the influence of the following factors: regulation of electricity markets, which creates unequal opportunities for different modes of electricity generation; ensuring nuclear safety; performance of plant construction; operational characteristics; political risk; and, in the absence of opportunities for their regulation by participants, the expanding influence of dominant state companies.

Experts estimate[21] that about $91 billion will be invested in the nuclear power sector during 2022–2023. At the same time, the largest volume of investments will be observed in the countries implementing nuclear capacity expansion programs (including Russia) (Fig. 3).

Figure 3



Source: compiled by the authors on the basis of data from RystadEnergy (2022) (https://www.rystadenergy.com/newsevents/news/press-releases/Nuclear-investments-on-the-rise-More-than-90-billion-to-be-spent-in-next-two-years-with-more-coming-as-52-reactors-in-the-works/).

[20] *Nuclear energy 2.0 (2022). Available at: https://www.atomic-energy.ru/UK.*

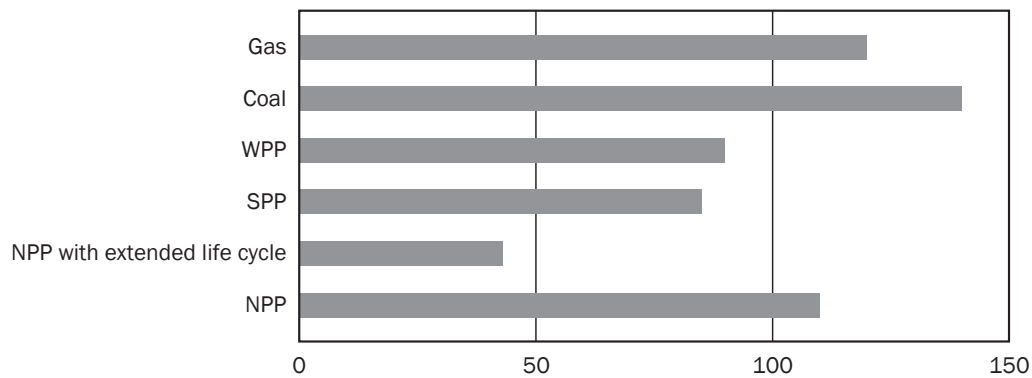
[21] *RystadEnergy (2022). Available at: https://www.rystadenergy.com/newsevents/news/press-releases/Nuclear-investments-on-the-rise-More-than-90-billion-to-be-spent-in-next-two-years-with-more-coming-as-52-reactors-in-the-works/.*

The expansion of investment activity in the nuclear energy sector implies active participation of states in the implementation of long-term contracts, price guarantees and direct state investment in the segment of advanced nuclear technologies — small modular reactors. At the same time, the use of public funding mechanisms for research and development in this sector, public-private partnerships in terms of venture financing, as well as grant support for early deployment, should be supported by the expansion of opportunities for standardization of reactor designs.

Along with the need to implement national programs to expand nuclear power capacities, there is a problem of their obsolescence. While in a number of countries the reduction of the scale of nuclear energy is due to the peculiarities of national policy in this area (Germany), the states stimulating the development of this sector (France, Great Britain, etc.) are largely limited by the influence of a number of economic factors. Thus, according to the forecasts of the International Energy Agency, by 2040 the cost of electricity generated by NPPs with extended service life will be minimal compared to other types of power generation (Fig. 4). Extension of service life of 1 GW of nuclear power for at least 10 years is estimated to cost up to $ 1 billion and is comparable with the cost of construction of new solar-wind power generation facilities.

Figure 4

Expected power cost in the EU countries in 2040 (USD/MW-h)



Source: compiled by the authors on the basis of data from International Energy Agency (2019), Nuclear Power in a Clean Energy System (https://www.iea.org/data-and-statistics/charts/wind-and-solar-pv-generation-by-scenario-2019-2040).

Intensification of the processes of obsolescence and decommissioning of nuclear power facilities in the absence of large investments will reduce the share of this sector in the energy structure of the EU countries to 4% (fig. 5).

The development and implementation of national policies in countries aimed at expanding the scale of nuclear energy involves the creation of equal competitive development conditions for all energy sectors, including nuclear power. Financial support for extending the life of nuclear power plants can be implemented through the creation of risk management and financing mechanisms that can help to mobilize capital for new and existing power plants at an acceptable cost, taking into account the risk profile and long-term prospects of nuclear projects.

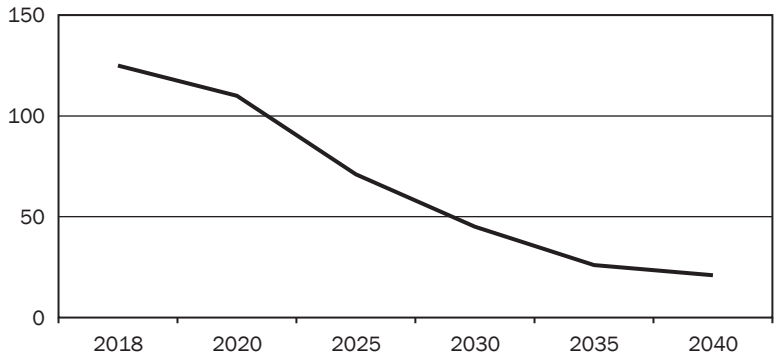
The intensified decarbonization of national economies of the world requires a transition to clean energy using a range of technologies, including nuclear power [Bello, 2021; Thapar et al., 2019].

Renewable sources are still expected to be ahead, while nuclear energy can also play an important role along with fossil fuel using capture, disposal and storage of carbon [Zheng,

Wang, 2019]. However, to achieve respective sustainability goals, including international climatic objectives, the expansion of clean energy production must triple and reach 85% of clean sources by 2040. Along with large-scale investments in efficiency improvement and renewable sources, meeting these goals will require increasing global nuclear energy production by 80% by 2040.

Figure 5

Dynamics of nuclear power capacities in the EU countries in case of NPP shutdown in 2018–2040 (GW)



Source: compiled by the authors on the basis of data from International Energy Agency (2019), Nuclear Power in a Clean Energy System (https://www.iea.org/data-and-statistics/charts/wind-and-solar-pv-generation-by-scenario-2019-2040).

CONCLUSIONS

It is important to note a number of specific features in the operation of nuclear power[22].

The advantages of NNPs (the availability factor of 393 GW is 0.7–0.95) as compared to wind power plants (WPPs) and solar power plants (SPPs) include a high level of independence from natural climatic changes. Moreover, comparison of degradation of lands used for SPPs, WPPs and NPPs construction show advantages in terms of compactness of nuclear facilities: NPP — 26 ha/GW; WPP — 25,000 ha/GW; SPP — 3400 ha/GW[23]. A comparison of the need for primary energetic materials also speaks in favor of NPPs (metal, concrete, glass)[24]. According to research, the degree of impact of accidents at NPPs on people's lives and the environment is much lower than in the case of other man-made disasters related to the operation of other energy facilities.

Along with that, there is also the problem of nuclear waste disposal, since the volumes of wastes will grow over the next two decades and will reach more than 500 million tons by 2040 (about 250 million tons by 2020)[25]. In addition, the competitive ability must be also addressed in terms of ensuring the required level of economic efficiency of nuclear power concerning LCOE as compared to renewable energy facilities and conventional gas generation. Nuclear energy development based on an open nuclear fuel cycle results in limitations for the inclusion of nuclear technologies into the "green" pool even with no carbon footprint [Gao et al., 2021].

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[22] *Joint Research Center (2021). Available at: https://ec.europa.eu/info/departments/joint-research-centre_en.*

[23] *Russian Power System Operator (2019), Analysis of Electricity and Capacity Balances in the Unified Energy System of Russia. Available at: https://www.so-ups.ru/fileadmin/files/company/reports/ups-review/2020/ups_balance_analysis_2019q4.*

[24] *Ibidem.*

[25] *International Energy Agency (2019), Nuclear Power in a Clean Energy System. Available at: https://www.iea.org/data-and-statistics/charts/wind-and-solar-pv-generation-by-scenario-2019-2040.*

Perspectives of global energy development are mainly related to expanded research into two-component nuclear energy with a closed fuel cycle[26] [Temiz, Dincer, 2021] and mass commercial production of low-capacity nuclear plants to supply power to remote regions[27] [Tolstoukhov et al., 2021].

According to experts, new technologies will be scaled up in Russia and globally and will support the transition of nuclear energy to the pool of green and renewable sources of energy as early as in the first half of the 21st century.

The growing global need to achieve the Sustainable Development Goals necessitates the creation of an effective structure of the global energy sector by expanding its "clean" segment. Nuclear energy supports sustainable global development, is linked to the UN Sustainable Development Goals and can be used to address energy poverty by providing clean energy worldwide, supporting high living standards, good health, a clean environment and a sustainable economy.

The peculiarities of the current period of nuclear power development are characterized by the scaling of the processes of obsolescence of production capacities in this sector. At the same time, in the conditions of decarbonization, there is an urgent need to develop this method of electric generation.

The models of financial support of nuclear power functioning that have developed in the world and are determined by the degree of involvement of state financial resources in this process at various stages, are formed under the influence of the peculiarities of national energy policies in this area.

The predominance of state financial participation is observed in most countries in the R&D segment and in nuclear waste disposal issues. There is a growing inflow of budgetary resources into the energy sector under consideration within the framework of partial investment and government loan guarantees.

The prospects for increased investment of the non-state sector are influenced by the globalization of financial markets and increased competition for investment resources, and are also supported by the need for nuclear capacity expansion programs in a number of countries.

Achieving the Sustainable Development Goals implies the need to develop and implement appropriate financial and economic measures at national levels in the design of energy markets.

Thus, nuclear energy, having a powerful innovative potential, can be considered as one of the cleanest sectors of the green economy, which, subject to the expansion of economic mechanisms of state participation, is able to ensure the implementation of national socio-ecological and economic objectives in the field of sustainable development.

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Перспективы атомной энергетики в рамках реализации концепции устойчивого развития

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Аннотация

Необходимость создания эффективной структуры глобальной энергетики, отвечающей современным вызовам в области устойчивого развития и нарастающим потребностям в электроэнергии, предполагает расширение использования потенциала атомной энергетики и обусловливает необходимость более детального исследования перспектив ее развития, с учетом экономической эффективности, высокой технологичности, экологичности и безопасности этого способа электрогенерации.

Цель работы состоит в выявлении особенностей и определении возможностей для глобального развития атомной энергетики в условиях усиления влияния концепции устойчивого развития.

В рамках работы выявлены особенности развития глобальной атомной энергетики, характеризующиеся как интенсификацией процессов устаревания мощностей, так и высокой степенью их значимости в общей энергоструктуре в условиях декарбонизации.

Обоснована потребность в разработке и реализации финансово-экономических мер на уровне национальных экономик в контуре проектирования энергетических рынков с учетом чистой энергии и энергетической безопасности низкоуглеродных технологий, включая ядерную энергетику, подкрепленных расширением прямого и косвенного государственного участия.

Рассматриваемые вопросы имеют практическое значение для общества с учетом необходимости решения стоящих перед ним социо-эколого-экономических задач.

***Ключевые слова:** глобальная энергетика, атомная энергетика, устойчивое развитие, зеленая энергетика, декарбонизация, финансирование, государственная финансовая поддержка, инвестиционные ресурсы*

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