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Name: Cheban Timofey

Aziza Mukhamedzhanova

Innovation Management in the Development of Renewable Energy Sources in the U.S. Fuel and Energy Complex

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Preface and acknowledgments

This thesis has been written as the final part of the master studies Master of Science in Global Management. Of the endless possibilities of research topics, we chose this because it is very relevant topic today. Currently, the world community pays more and more attention to the development of alternative energy, and not only developed, but also developing countries (such as China, India, Brazil) are now actively introducing renewable energy sources (RES).

The electricity industry in many countries around the world is currently undergoing significant changes aimed at ensuring universal access to affordable, reliable, sustainable, and modern energy for all.

Abstract

The purpose of this research is to provide data on the development of renewable energy in the United States. We analyze the use of renewable energy sources in the country, identifie the reasons for the expansion of alternative energy, and characterize the state of its industries. Due to the fact that there is no clear state strategy in this area in the United States, ways to support "clean" energy are outlined both at the federal and state levels.

The positive and negative consequences of increasing the production and consumption of "green" energy are considered and prospects are determined development of renewable energy. The United States remains one of the leaders in the production and use of green energy. The United States is a pioneer in the use of renewable energy sources. The expansion of the use of renewable energy sources became possible due to technical progress in this area, which made it possible, first of all, to significantly reduce the cost of electricity production by wind (WPP) and solar (SPP) power plants of various types.

In the scientific literature and global practice, there is the formation of a new direction, which assumes a significant contribution to the overall energy consumption of renewable energy sources and the displacement of traditional energy resources. A number of factors influencing the development of renewable energy are given. Prospects and growth potential of the renewable energy market are determined.

1 Introduction

1.1 Motivation and choice of problem statement

Background: Throughout the history of the global fuel and energy complex, companies in the industry have ensured the growth of their profits and the strengthening of their competitive position in the market through the development of innovations. At the same time, the inclusion of electric power industry (i.a. renewable energy) has become an important trend over the last two decades. This ensures not only the continuing trend toward the establishment of vertically integrated holding companies, but also the transformation of oil and gas companies into energy ones.

Problem topic: The relevance of investing in renewable energy in recent years has been constantly increasing against the background of the adoption of the course on decarbonization of many countries. This implies not only reducing and even abandoning the use of certain types of hydrocarbons (for example, coal), but also the active introduction of wind, solar and other renewable energy sources. In this regard, both the Russian Federation and the United States should work to eliminate the lag that has developed so far in the development of renewable energy sources. The leaders in this field are China and the EU members.

Availability of Power

One of the biggest concerns in the field of renewable energy is power generation depending on natural resources that are uncontrollable by humans. For example, solar powered electricity is generated only when sunshine is available and turns off at night; wind energy also depends on the availability of wind, so if the wind speed is very low, the turbine will not turn, and this result in zero power flow to the grid. On the other hand, too much wind can damage the generator and therefore a delicate balance needs to be maintained in order to keep a consistent generation of energy. The uncertainty in energy production in renewable energy technologies is making integration more complex.

Power Quality Issues

Consistently high-power quality is needed to ensure stability and high efficiency of the network. The quality of the power supply allows the system to work well with high reliability and lower costs. On the other hand, poor power quality can have major adverse effects on the power grid as well as industrial processes. It can lead to high costs and equipment failure. Power quality

problems include frequency disorder, voltage/current harmonics, low power factor, voltage variation and transmission lines transits.

Resource Location

Most renewable energy plants that share their energy with the grid require large areas of space. In most cases, renewable energy sources are dictated by location which can be off-putting to users. Firstly, some renewable energy sources are simply not available in different regions. Secondly, the distance between the renewable energy source and the grid is a major aspect in term of cost and efficiency. In addition to this, renewable energy sources depend on weather, climate and geographical location, therefore meaning that one type of energy generation is not appropriate for the region.

Information Barrier

While this area is improving, there is a lack of information and awareness about the benefits and need of renewable energy. Investment and capital allowances have been made available for the implementation of renewable energies. There is a clear need for government agencies to assist and advice applicants and potential recipients how to go about applying for renewable energy incentives.

Cost Issue

The high initial cost of installation is one of the major hurdles in the development of renewable energy. Although the development of a coal plant requires about $6 per megawatt, it is known that wind and solar power plants also required high investment. In addition to this, storage systems of the generated energy is expensive and represents a real challenge in terms of megawatt production.

The ongoing technological changes are accompanied by the creation of an institutional framework that determines the regulatory, technological, and economic rules for the reliable and efficient development and functioning of energy systems in new conditions.

In other words, the process of creating an integrated power management system corresponding to the new structure of energy systems is underway. Transformation of energy systems means an active process of creating the political, market, and regulatory conditions, as well as establishing practices for planning and operating energy systems that accelerate investment, innovation, and the use of smart, efficient, reliable, and environmentally friendly technologies.

Currently, the capacity of wind farms and solar photovoltaic power plants reaches hundreds and thousands of MW, and the energy sector is undergoing a fundamental shift towards a digitalized and decarbonized energy system. In this regard, an urgent task is to analyze the experience of large-scale development of renewable energy sources, its impact, including negative, on traditional generation, on the electricity market and network infrastructure, with the development of specific recommendations on how to solve specific problems and obstacles to increase investments in renewable energy in each of the CIS countries, as well as improve and optimize cross-border regional energy cooperation.

The rapid development of renewable energy sources today is due to several reasons. First, the disproportions between the growing demand for energy resources and the limited possibilities for using traditional energy capacities have increased recently.

The depletion and decline of fossil fuel reserves is a pressing problem. According to experts, in the near future, all hydrocarbon production can only be carried out in the sea, where there are great risks due to the great depth. Secondly, fossil fuel deposits are located very unevenly on the world map. Another reason is the aggravation of environmental problems, environmental pollution. It is the increase in emissions into the atmosphere and the deterioration of the environmental situation in the world that largely prompted the United States, as well as many other countries, to accelerate the introduction of renewable energy.

The United States is one of the driving forces in the development of clean energy. It is worth noting that all types of energy resources that do not emit carbon dioxide when used are classified as alternative energy sources in the United States. As a result, small hydropower, from the point of view of the classification adopted in the country, also belongs to alternative energy.

1.2 Methodological framework

Analysis, statistical data processing, logical methods (deduction, induction, synthesis, generalization, and abstraction), empirical methods (observation and expert evaluation). Theoretical basis was formed by the works of Russian and foreign authors: A. Dementieva, N. Kavkaeva, Viktor Kulkov, Mugammar Musin, M. Sokolova and others. Russian and foreign periodicals, annual reports, presentations, reports on the sustainable development of Russian and foreign companies of the fuel and energy complex were also used in the master's thesis.

1.3 Work structure

The paper is structured as follows. An introduction, the theoretical part, divided into three chapters, empirical research, results and findings and discussion, a conclusion and a list of references. The theoretical chapter examines the approaches to the definition of "fuel and energy complex", the current structure and key indicators of the global fuel and energy complex and assesses the current state of renewable energy development. The empirical research analyzes the energy balance of the United States and Russia, as well as approaches to the regulation of the energy industry and the development of renewable energy in this country, compares the development practices of the fuel and energy complex in general and renewable energy in particular in the United States and the Russian Federation, identifies the main problems and prospects for the growth of the use of renewable energy in the current geo-economic conditions. The results and findings reflect the current problems and prospects for the development of renewable energy in the United States and the Russian Federation.

1.4 The aim of theoretical discussion

To analyze Russian and foreign approaches to innovation management in the development of renewable energy sources. Achieving this goal is possible by solving the following tasks:

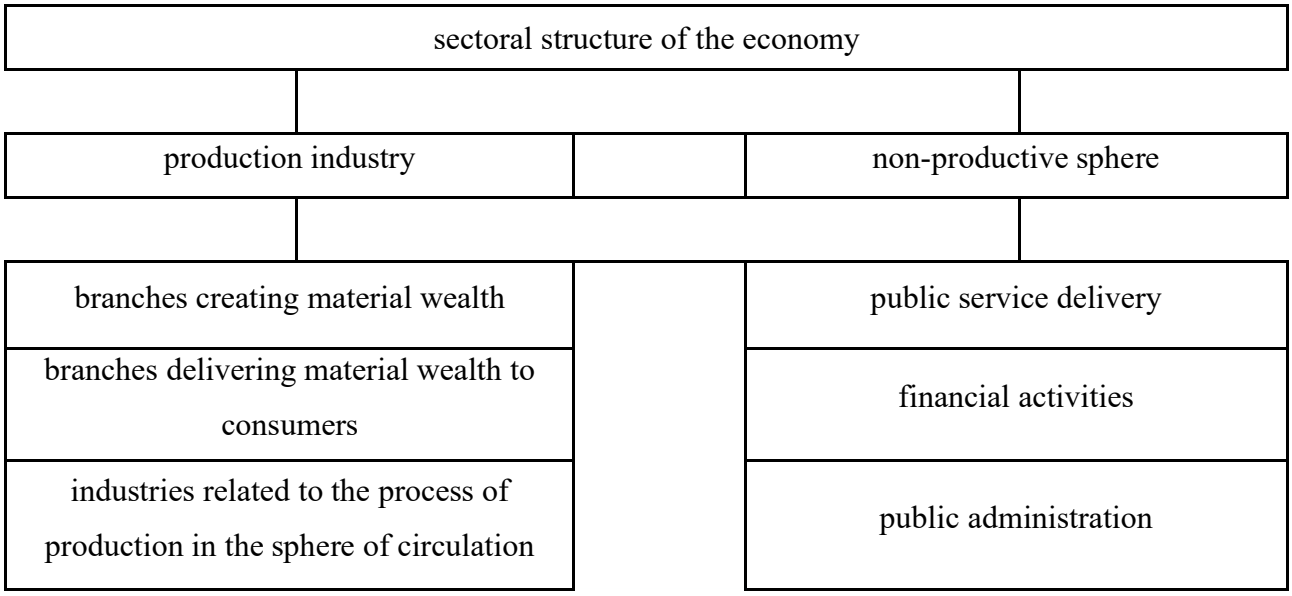
1. To study approaches to the definition of "fuel and energy complex", to analyze its structure and main indicators;
2. To determine the role of innovations in changing the cost of renewable energy generation;
3. To evaluate the current state of development of the renewable energy sector in the world, as well as in the United States and Russia in particular;
4. To explore U.S. approaches to energy industry regulation, practices, challenges, and prospects for the growth of the use of renewable energy;
5. To compare approaches to renewable energy development in Russia and the United States, identify common problems and potential solutions.

2 Theoretical background

2.1 The concept and structure of the fuel and energy complex. The main indicators of the world fuel and energy complex

Modern macroeconomic theory assumes consideration of the world economy and each national economy as a whole. This, however, does not exclude the study of individual aspects of the economy, financial, foreign economic, social and other problems. The subject of such analysis may be individual sectors of the economy, for example, their current state, global competitiveness, problems that require changes or adjustments. (Kulkov, 2022) The modern sectoral structure of the economy has a complex hierarchical structure (see Figure 1):

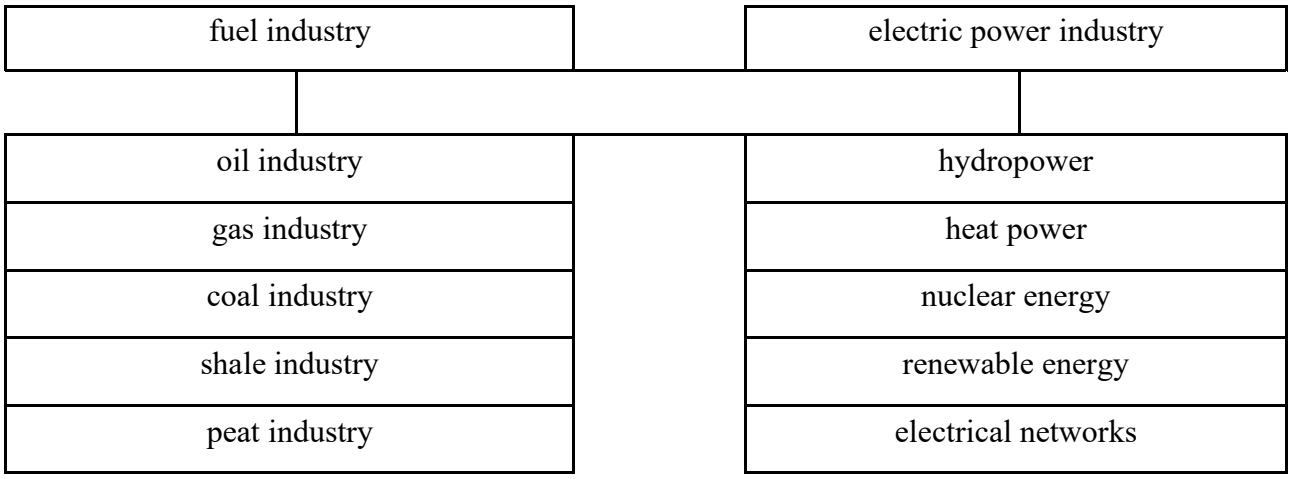
Figure 1. Sectoral structure of the national economy



Source: G. Rodina [et al]. (2022). Macroeconomics for managers. Edited by G. Rodina. 3-th ed., revised and extended. Moscow: Publishing house Yurait, P. 68.

Modern researchers refer more than 100 industries to the number of industries that create material goods, which in turn consist of more than 200 different industries or 11 complex industries. (Rodina, 2022) One of these is the fuel and energy complex, which is a complex inter-industry system, including the fuel industry and electric power industry (see Figure 2):

Figure 2. Structure of the fuel and energy complex



Source: Zhuravleva, G., Gromyko, V., Zabelina, M.et al. (2019). Economic Theory: Microeconomics-1, 2, Mesoeconomics: Textbook Plekhanov Russian University of Economics. *9th ed., Moscow: Publishing and Trading Corporation "Dashkov and K°"*, P. 780.

The main sources of fuel, heat and energy in the world economy are still such non-renewable sources as oil and natural gas (hydrocarbons), the level of availability of which still largely influences the growth rate of global industrial production and national economies. (Zhuravleva, 2019) Nonrenewable energy sources also include geothermal heat, nuclear fuel, and fusion fuel (hydrogen isotopes). (Mazlova 2018) Nevertheless, the development of renewable energy is becoming increasingly important in the structure of the global fuel and energy complex, since energy is not produced by fossil fuels, but by such replenishable or inexhaustible sources as the sun (solar radiation), wind (wind power) and water (tidal energy), as well as by plant biomass.

The structure of the fuel and energy complex can also be presented on the basis of the main industries included in it (see Table 1):

Table 1. Sectoral structure of the fuel and energy complex

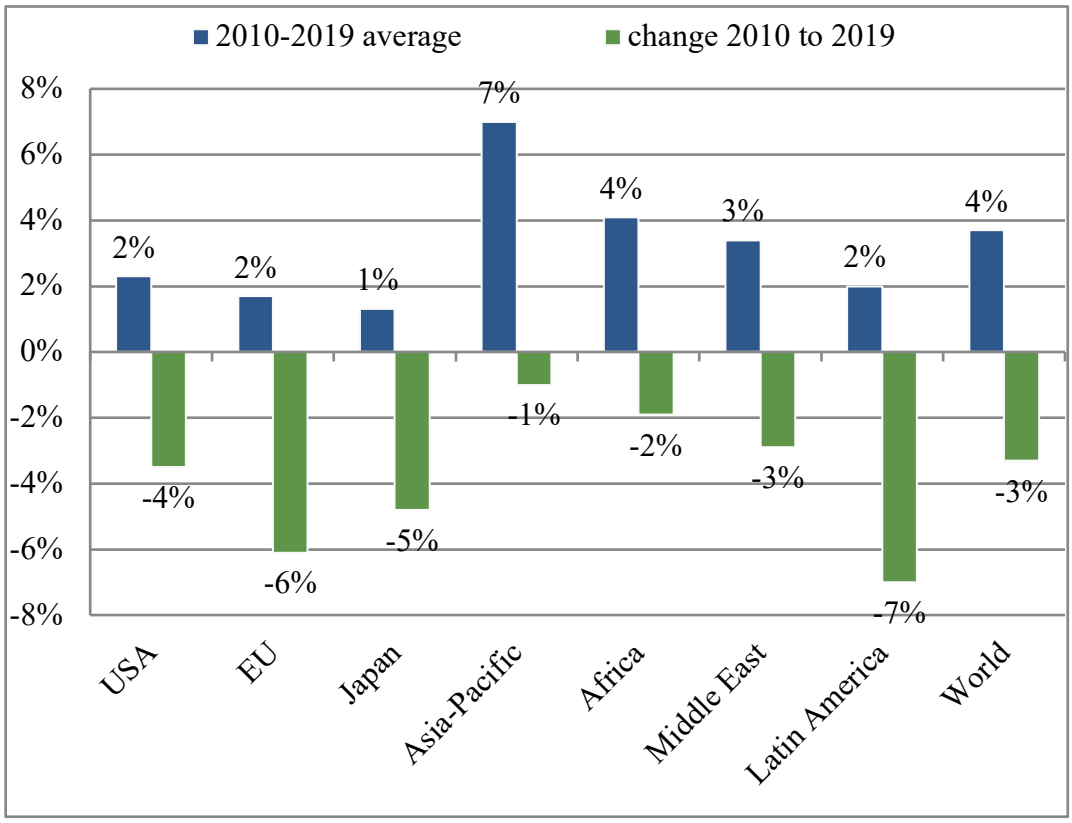
Key industries	Functions of key industries of the fuel and energy complex
Fuel	Exploration, extraction and processing of energy raw materials (oil, natural gas, coal, peat, etc.)
Manufacturing	Processing of energy raw materials (oil refining, gas processing, petrochemicals, etc.)
Transportation	Use of technological transport for transportation of energy carriers and products of their processing (including oil and gas pipelines and oil product pipelines)
Electric power	Energy production (electricity, steam, hot water)
Energy delivery and distribution	Power supply lines

Source: Kavkaeva, N.. (2018). Fundamentals of economics and technology of the most important industries. *Moscow-Berlin: D-Media*, P. 87.

According to the scenario of the roadmap 2050, the industry should increase the share of renewable energy in direct use and fuel to 48% by 2050. If renewable electricity is included, this share will increase to about 60%. Bioenergy sources will have the greatest contribution, mainly due to waste used for direct heating and combined heat and energy production (CHP). In percentage terms, the greatest growth will be due to solar thermal heat for low-temperature processes, as well as heat pumps for similar low-temperature heat needs. When switching to electricity, electricity should provide 41% of the energy needs of the industry by 2050.

It should be noted that the development of the global fuel and energy complex is influenced by recurrent economic crises, which entail a decrease in demand and the cost ofmajor energy resources. In particular, the global economic crisis of 2020 resulted in an unprecedented drop in global industrial production and GDP indicators (Figure 3):

Figure 3. Dynamics of GDP changes in individual countries and regions of the world in 2020 compared to 2019, %



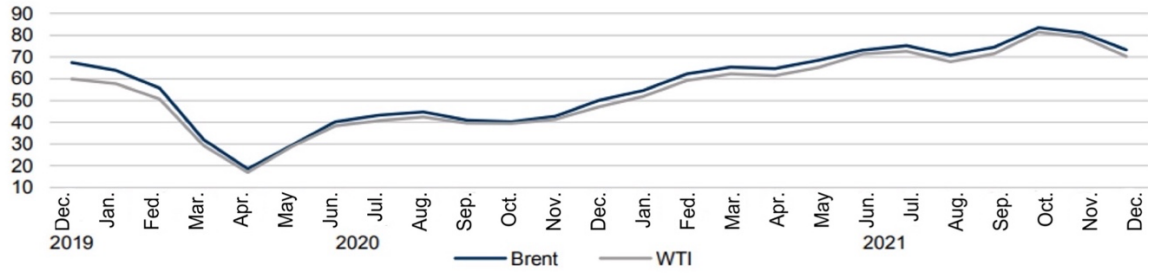
Source: Sechin, I. The World Energy Sector at a Crossroads. 2021 // Downloaded from: https://www.rosneft.ru/upload/site1/attach/0/14/02/SPIEF_slides_2021.pdf/

The decline in global GDP amounted to 3.3% in 2020, while this indicator demonstrated an annual growth of 3.7% during 2010-2019. At the same time, some countries and regions of the world suffered to different degrees: while the APR countries showed a drop in GDP of only 1%, the indicators of the Latin American region reached -7% of GDP. Significant declines in industrial production were also observed in such major economies as the United States (-3.5%), Japan (-4.8%) and the European Union (-6.1%).

Such a significant drop in global industrial production naturally led to a decrease in demand for energy resources, a reduction or temporary suspension of production of most types of petroleum products and fuels. For example, the most significant decline could be observed on the part of the transport industry. This was due to a reduction in the number of domestic and international flights and a decrease in passenger traffic by other modes of transport amid the introduction of coronavirus quarantine restrictions in many countries. The most significant drop in oil prices

as the main energy resource could be observed in April 2020, while the recovery of pre-crisis oil prices lasted more than a year (Figure 4):

Figure 4. Dynamics of Brent and WTI oil prices in 2019-2021, USD / bbl

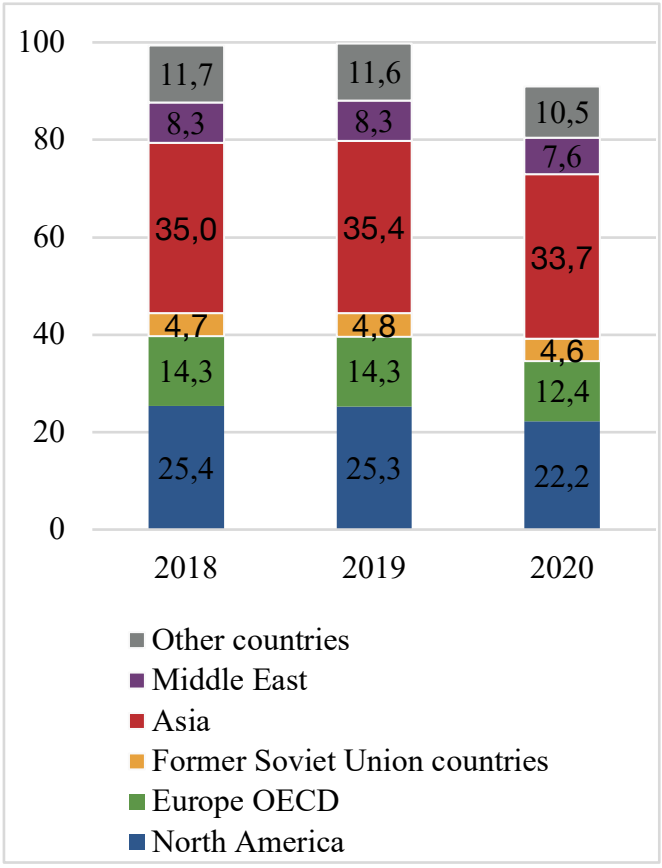


Source: Fuel Prices: Between Market and Regulation. Energy Bulletin No. 103 of the Analytical Center under the Government of the Russian Federation. December 2021. Downloaded from: https://ac.gov.ru/uploads/2-Publications/energo/2022/energo_103.pdf

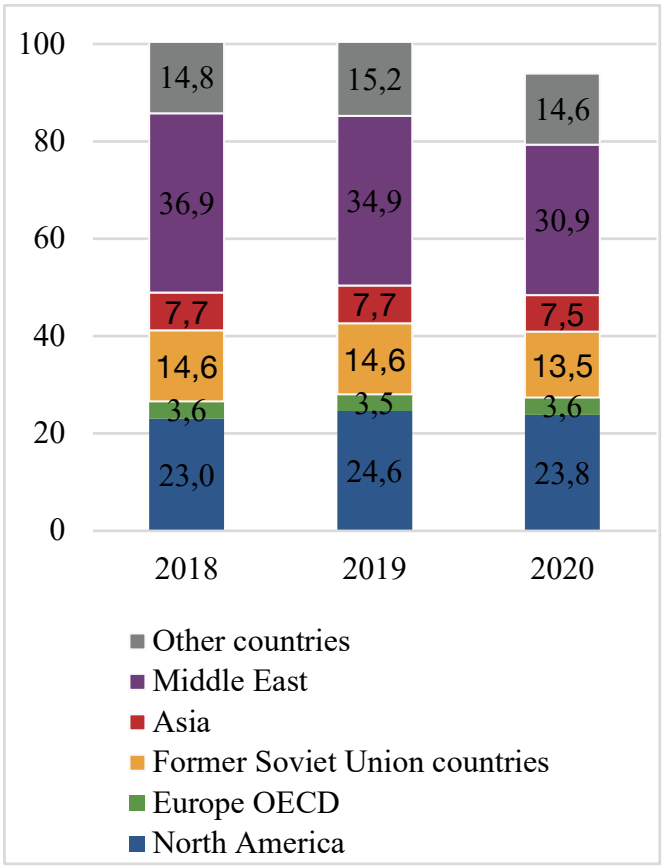
If we consider the crisis period, namely 2020, its results show that demand for oil fell by 8.7% (to 91 million bpd), while the volume of supply decreased by 6.5% (to 94 million bpd). However, the dynamics of demand for oil and other liquid hydrocarbons were uneven by region of the world. While North American countries, primarily the U.S., accounted for about 35% of the drop in demand from 2019 volumes, OECD countries - for 21%, and Asia-Pacific countries - for 20%. (PJSC, 2020)

The structure of oil demand and supply in 2020 is presented in more detail in Figure 5:

Figure 5. Structure of supply and demand for oil and other liquid hydrocarbons by regions of the world in 2020, mln bpd



World liquid hydrocarbon demand by region, mln bpd



World liquids production by region, mln bpd

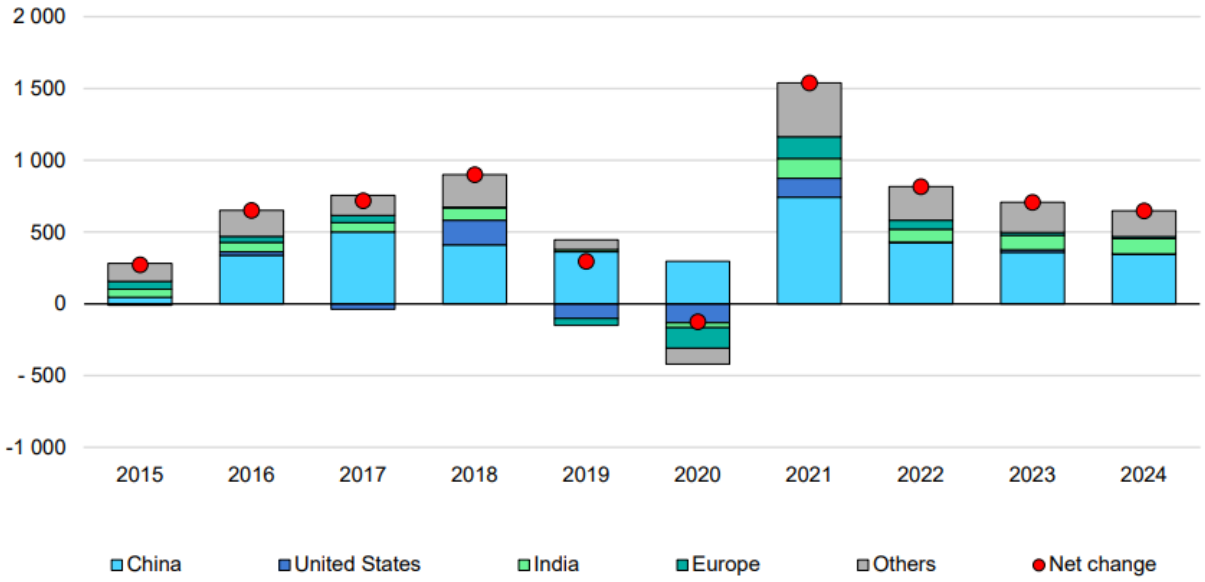
Source: PJSC Rosneft Annual Report 2020 // Downloaded from: https://www.rosneft.ru/upload/site1/document_file/a_report_2020.pdf

In turn, a faster-than-expected economic recovery led to a significant increase in electricity demand in 2021, which, combined with colder winters and warmer summers, resulted in the largest annual increase in electricity demand since 2010, more than 6 percent. (Electricity Market Report, 2022)

This led to an increase in demand for natural gas and coal and in wholesale and retail electricity prices. Despite significant progress in the renewable energy industry, gas and coal consumption reached record levels in 2021, which, among other things, led to a significant increase in carbon dioxide emissions in the global fuel and energy complex.

However, it is important to note that current market trends have overlapped with longer-term trends, namely changes in the energy map of the world. Growth in global electricity demand in 2021 has been concentrated predominantly in emerging economies, primarily China and other Asian countries. (Figure 6):

Figure 6. Actual and projected global change in electricity demand in 2015-2024, TWh



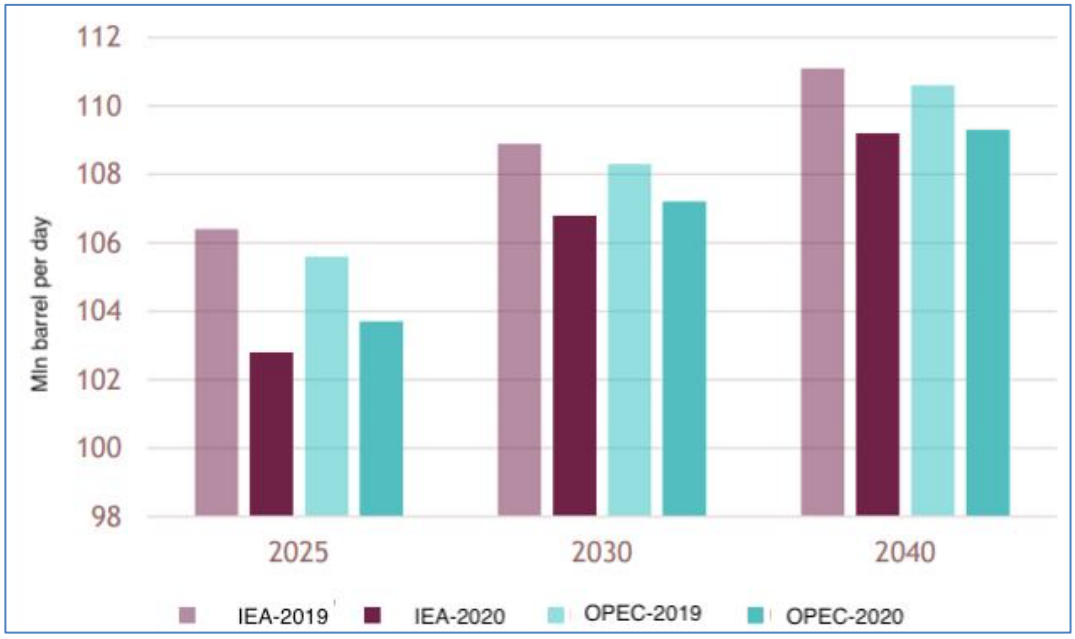
Source: Electricity Market Report - January 2022. Downloaded from: https://iea.blob.core.windows.net/assets/d75d928b-9448-4c9b-b13d-6a92145af5a3/ElectricityMarketReport_January2022.pdf

The prospects for further development of the global fuel and energy complex are related to the fact that by now there are billions of people on the planet who either do not use electricity at all or use it in minimal quantities. By 2050 it is the least developed and developing countries that will ensure population growth at the level of about 2/3 of the global indicator (about 2 billion people). As the example of China has shown, as their economies develop, the demand for energy and electricity in these countries will also increase intensively. By now, the global community has already seen attempts to reorient their demand toward renewable energy in order to reduce the possible harm to the environment, which in practice faces the lack of necessary technology in such important industries for growing economies as cement production, steel, freight transport, etc. (Electricity Market Report, 2022)

Nevertheless, the changes in the world energy market that took place during the acute phase of the current crisis were reflected in the adjustment of short-, medium- and long-term forecasts

of the IEA in the direction of reducing the demand for key energy resources (compared to pre-crisis forecasts), including oil (Figure 7):

Figure 7. Comparison of IEA and OPEC oil demand forecasts published in 2019 and 2020, mln bpd



Source: Energy forecasts against the backdrop of the crisis. Energy Bulletin No. 90 of the Analytical Center under the Government of the Russian Federation. November 2020 // [Electronic resource] - URL: https://ac.gov.ru/uploads/2-Publications/energo/energo_november_2020.pdf

The management of modern companies in the fuel and energy complex has to take into account many factors acting in different directions. This requires them to constantly change their own development strategies, from developing new fields to opening divisions to sell energy resources and refined products in the most promising regions of the world. In addition to geographical expansion, most international companies of the industry are now becoming vertically integrated and include not only production, transportation and sales of energy resources, but also their processing, as well as such areas as production of electricity, biofuels, equipment for carbon capture, charging stations for electric transport, etc.

It is this approach that allows modern fuel and energy companies to respond quickly to the constantly changing external environment, the emergence of new industries, innovative technologies and other factors. (Rugman, 2018) The ability of today's fuel and energy

companies to respond effectively to emerging challenges can be judged by their ability to maintain the profitability of their activities and the positive dynamics of key financial indicators and company capitalization.

If we consider the current structure of the FEC market from this point of view, its changes are assessed on a regular basis by the main international agencies that publish ratings of the leading companies in the industry based on their market capitalization, size of assets, net profit and other indicators. An example is the rating of the international consulting company S&P (Table 2):

Table 2. Top 10 of the 250 leading energy companies in the world at the end of 2020 in the S&P rating

1	Saudi Arabian Oil
2	Lukoil
3	Rosneft
4	Gazprom
5	Royal Dutch Shell
6	TOTAL SA
7	Exxon Mobil
8	CNOOC Ltd
9	ConocoPhillips
10	China Shenhua Energy Co Ltd

Source: Compiled by the author on the basis of the data of Top 250 Companies 2020 // Downloaded from: https://top250.platts.com/Top250Rankings

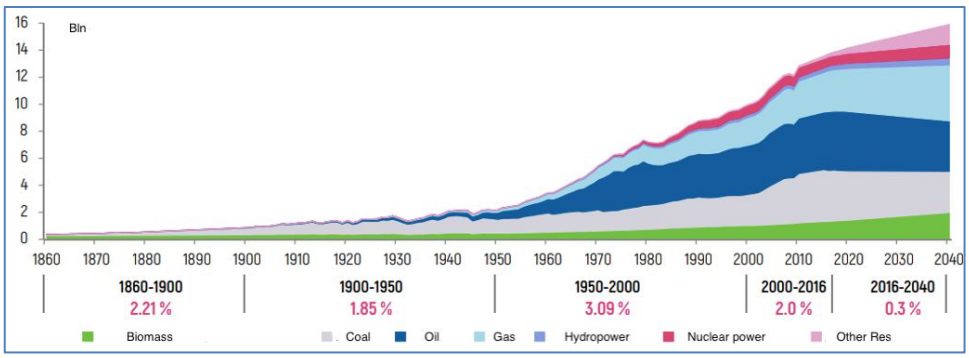
Saudi Arabian Oil tops the list of the world's leading energy companies in 2020. Russian companies in the global ranking are topped by Lukoil, Rosneft and Gazprom, which are ranked second through fourth, respectively.

Thus, the modern fuel and energy complex is a complex inter-industry system, including the fuel industry and electric power industry. Its current development is influenced by a multitude of multidirectional factors, from periodic economic crises to a significant increase in demand for energy resources from developing countries around the world. Despite the unprecedented drops in prices and demand for hydrocarbons in 2020, oil prices as the main energy resource have already recovered to pre-crisis levels in 2021, and the faster-than-expected global economic recovery has already led to a significant increase in demand for electricity, which creates additional opportunities for further development of the fuel and energy complex.

2.2 Innovations and development of renewable energy. Change in the cost of energy generation using renewable energy sources

Throughout the history of its development, the production volumes and structure of the fuel and energy complex have been directly related to the development of science and technology. Periodically occurring scientific and technological revolutions led to the emergence of new technologies for the extraction and use of energy resources, the emergence of new, often fundamentally different industries of production. In particular, the first stage of a sharp increase in global energy consumption was associated with the beginning of industrial use of oil and natural gas at the turn of the 19th and 20th centuries, and then with the development of hydropower and nuclear power. The current stage of development of the fuel and energy complex is associated with increased consumption of natural gas as one of the most environmentally friendly types of energy, as well as with the development of nuclear and renewable energy (Figure 8):

Figure 8. Actual and projected dynamics and growth rates of global energy consumption by type of energy use, 1890-2040, bln tons of oil equivalent, %



Source: World and Russian Energy Forecast. (2019). *Institute for Energy Research of the Russian Academy of Sciences, Center for Energy at Skolkovo Moscow School of Management, Moscow*, P. 210.

It is important to note that it was in the second half of the 20th century that energy consumption in the world grew at the fastest rate, namely 3.09% per year in 1950-2000, while one can observe a decline in energy consumption under the influence of the global trend towards resource and energy conservation at present, which in practice led to the development of appropriate saving technologies in all sectors of the economy.

Figure 9. The main types of competitive advantages (M. Porter)

competitive advantages	
low-order advantages	**high-order advantages**
cheap labor	unique product
cheap material resources	unique technology
cheap buildings and equipment	unique specialists
cheap financial resources	unique connections
favourable prices for the purchase of goods for resale	unique resources
	famous brand

Source: Lipsits, I., Ryazanova, O., Price Management in Retail: Targeted Marketing. - Moscow: Eksmo. - 2019. - 22 pp.

Over a long period of time, the main way to create competitive advantages for fuel and energy companies has been the use of fields with easily accessible oil and natural gas, cheap labor, access to cheap resources (credit, etc.), i.e. low-order advantages (Figure 9)

Over the past decades, however, higher-order advantages have become increasingly important in shaping the competitive advantages of fuel and energy companies. For example, a wide geographical representation, unique connections with consumers, development and offer to the market of more environmentally friendly fuels and lubricants, carbon capture technologies, floating wind farms that use the energy of coastal winds, etc. An important role is played by

increasing the image and value of the company's brand and brands of its products. This trend is inextricably linked with the development of technological innovation, which in modern companies is aimed both at reducing the cost of hydrocarbon production and at developing other areas of activity (refining, RES, biofuels, etc.).

Thus, the formation of the competitive advantages of companies in the industry now depends more and more on their participation in globalization processes, as well as on the development of technological innovation, which indicates a significant transformation of the structure of global competition. (Sokplova, 2018)

Among the key areas of innovative activities in the fuel and energy sector it is necessary to note both the ongoing work on reducing the cost of production of hydrocarbons and digitalization, which is aimed at reducing the impact of the human factor on key business processes, increasing the speed and quality of management decision-making, the level of intellectual work, etc. The most widespread in the industry is the introduction of such technologies as the use of cloud data storage and business intelligence (based on BigData and artificial intelligence), which allow the so-called "smart wells" and "smart fields" to function, i.e. divisions of fuel and energy companies, in which the process of hydrocarbon production is provided by continuous monitoring and maintenance by innovative intelligent systems. Similarly, digital technologies are being introduced in energy processing, as well as in all other business processes of fuel and energy companies, from logistics to service provision.

It is important to note that in the process of implementing digital technologies, fuel and energy companies not only receive many benefits in the form of reduced production costs, the number of errors and accidents, increased profits, etc., but also face serious problems, such as increasing cyber risks (Stefanov, 2018), as well as resistance to innovations by personnel and the need to constantly work on improving their skills. Researchers note that there is already a stable relationship between the level and quality of personnel management and the ability of modern companies to achieve their strategic objectives, improve their competitive position in the market and increase their market share. (Dementieva, 2018)

All this fully applies to the development of the alternative energy industry, which is based on the use of renewable energy sources (RES), permanently existing or periodically occurring in the environment energy flows (Table 3):

Table 3. Natural and technical conversion of RES

<table>
<tr><th>primary energy source</th><th>natural energy conversion</th><th>technical energy conversion</th><th>secondary energy consumption</th></tr>
<tr><td>Earth</td><td>Earth's geothermal heat</td><td>geothermal power plant</td><td rowspan="10">electricity</td></tr>
<tr><td rowspan="8">sun</td><td>evaporation of atmospheric precipitation</td><td>hydroelectric power plants</td></tr>
<tr><td>atmospheric air movement</td><td>wind turbines</td></tr>
<tr><td>sea currents</td><td>marine power plants</td></tr>
<tr><td>wave movements</td><td>wave power plants</td></tr>
<tr><td>ice melting</td><td>glacial power plants</td></tr>
<tr><td rowspan="2">photosynthesis</td><td>biomass power plants</td></tr>
<tr><td>photovoltaics</td></tr>
<tr><td>planets</td><td>tides</td><td>tidal power plants</td></tr>
</table>

Source: Turalina, A. (2021). Renewable Energy as an Innovative Factor in the Development of the World Economy. *Bulletin of Donetsk National University. Series B. Economics and Law*, 3, P. 309-316.

The use of the energy of flowing water and wind has been going on for thousands of years. In particular, these types of energy provided up to 6 GJ per person per year in agricultural civilizations from the Copper Age in the 3rd century BC to the end of the Roman Empire period in the 4th century AD, and up to 4.5 GJ for the rest of the world's population. (Markelov, 2015) The beginning of the search for alternative energy resources in its modern sense was laid more than two hundred years ago. A chronology of key moments in the development of alternative energy is given in Table 4:

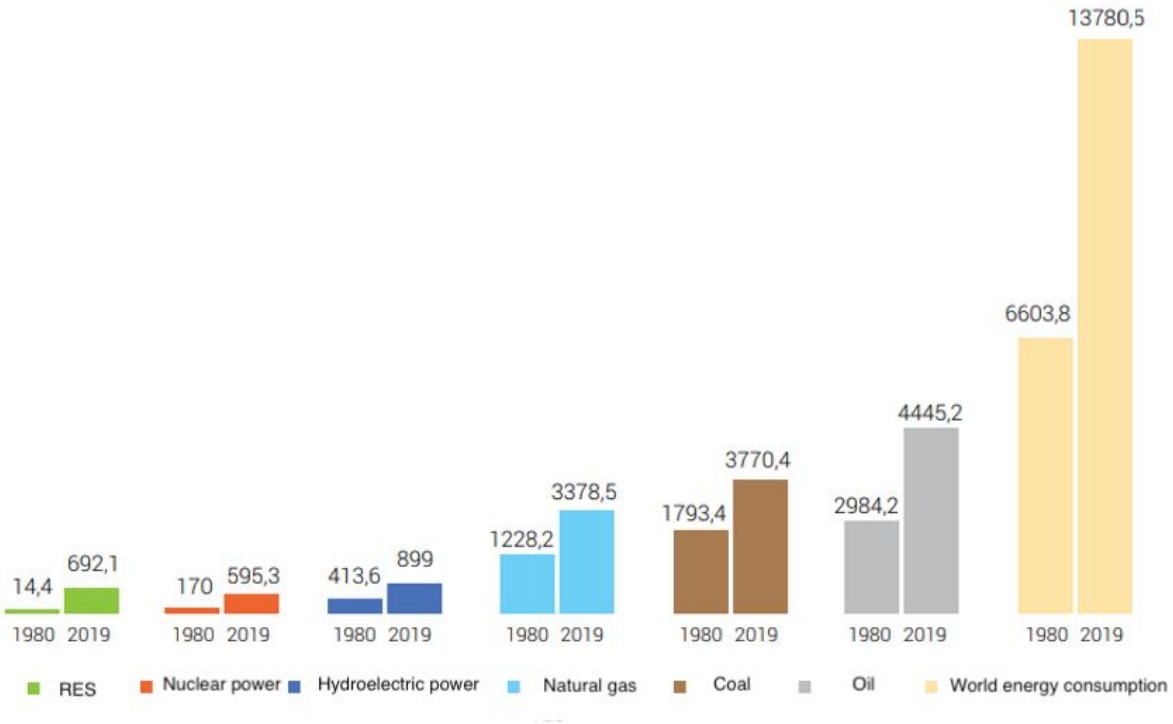
Table 4. History of alternative energy development

Year	Event
1774	French engineer de Belidor's "Architecture hydraulique" is published, outlining the key principles of hydraulic engineering
1839	French physicist Becquerel described the phenomenon of the photoelectric effect occurring in electrolyte
1846	Year of birth of La Coeur, who built the world's first wind turbine
1861	World's first patent on a plant for extracting electrical energy from sunlight
1881	The first hydroelectric power plant at Niagara Falls is put into operation, providing electricity for city street lighting
1913	Creation of the first ever geothermal power plant at Larderello by Count Conti of Italy
1925	Frenchman Darius invented the vertical rotor used in wind turbines
1931	The first commercial wind-powered D 30 power plant in the Crimea (designed by engineers of the Central Aero-Hydrodynamic Institute named after Professor Zhukovsky) was put into operation
1954	Employees at Bell Laboratories created the first silicon solar cell
1957	A 200 kW wind turbine is installed in the Netherlands, connected to the public power grid and marks the beginning of the modern phase of wind energy development
1958	Using the first solar panels on a U.S. space satellite
1966	Launch of a tidal wave power plant off the French coast near Brittany
1997	Signing in Japan of the Kyoto Protocol, a key instrument for regulating internationally the reduction of greenhouse gas emissions

Source: Lukmanov, A. (2021). Evolution of views on the development of alternative energy sources. *Exploitation of marine transport*, 3(100), P. 127-134.

Despite the increased attention to the development of alternative energy on the part of many developed and, in the last two decades, developing countries, the share of renewable energy without hydropower in the structure of energy resource use is still extremely low (Figure 10):

Figure 10. World energy consumption by energy group in 1980 and 2019, million tons of oil equivalent

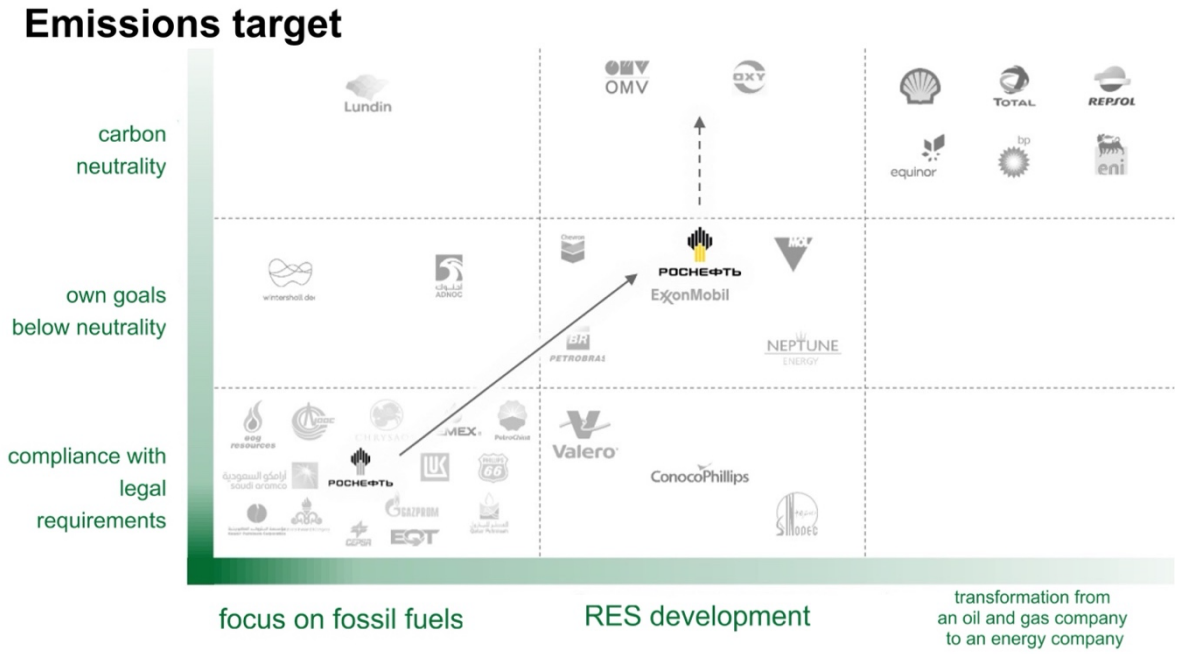


Source: Martynov V., Kucherov V., Bessel V., Lopatin A. (2022). Inorganic synthesis of oil as a factor of sustainable development of global energy. *Energy Policy*, 1(167), P. 20-29.

While global energy production increased 2.09 times, from 6.604 to 13.781 billion tons of oil equivalent from 1980 to the pre-crisis year of 2019, the growth of renewable energy use increased from 14.4 to 692.2 billion tons of oil equivalent. In terms of consumption volumes, alternative energy is second only to nuclear power.

Nevertheless, to date, the use of renewable energy sources is seen by society as an innovative direction that can have a positive impact on reducing the harm caused by human activity to the environment. Against this background, the largest fuel and energy companies are shifting their focus from fossil fuel extraction and use to the development of low-carbon and alternative energy sources (Figure 11):

Figure 11. Transformation of the oil and gas industry



Source: Sechin, I.. The World Energy Sector at a Crossroads. 2021 // Downloaded from: https://www.rosneft.ru/upload/site1/attach/0/14/02/SPIEF_slides_2021.pdf/

At the same time, some of the largest international companies even declare their transformation from oil and gas to energy companies and include in their own development strategies to achieve carbon neutrality by a certain year (2040, 2050). In particular, Equinor received its new name in 2018 (former name - Norwegian State Oil Company), when it announced a major revision of its own development strategy, namely the transition to the status of a diversified energy company (Roginskiy), and in 2021 published another change of development strategy, which announced the acceleration of its transition to a low-carbon future:

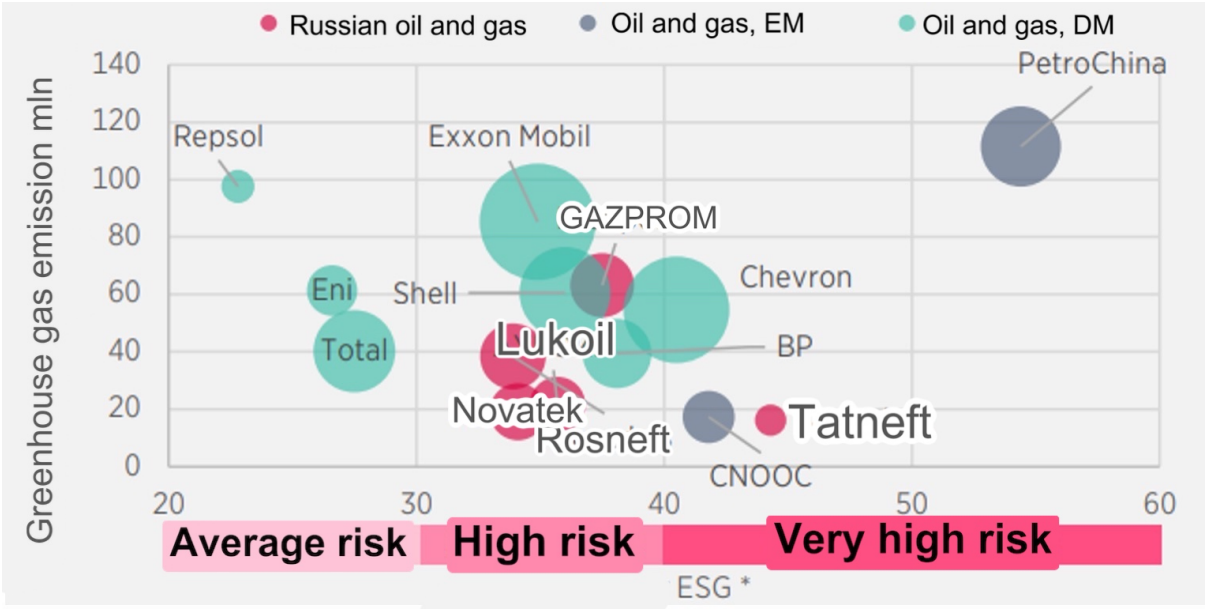
- A 40% reduction in carbon intensity by 2035;
- Achieving zero emissions by 2050 (Presenting strategy to accelerate Equinor's transition, 2021)

In a practical sense, the fulfillment of the company's stated aspirations can be seen in the fact that 67% of Equinor's total investment in pre-crisis 2019, totaling $59 million, was in renewable energy projects (Equinor: Sustainability report, 2019)

The trend of including alternative energy among the key areas of the world's leading energy companies is also reflected in the assessment of their positions by investors and society as a whole. The current analysis of their positions in the market is performed not only in terms of key financial indicators, including capitalization, but also in terms of compliance with ever-

tightening environmental requirements on the part of state authorities, dynamics in terms of reducing carbon dioxide emissions and development of alternative energy (Figure 12):

Figure 12. Comparative analysis of leading fuel and energy companies in terms of ESG ratings risk, carbon dioxide emissions (per million barrels of oil equivalent) and market capitalization, mln USD

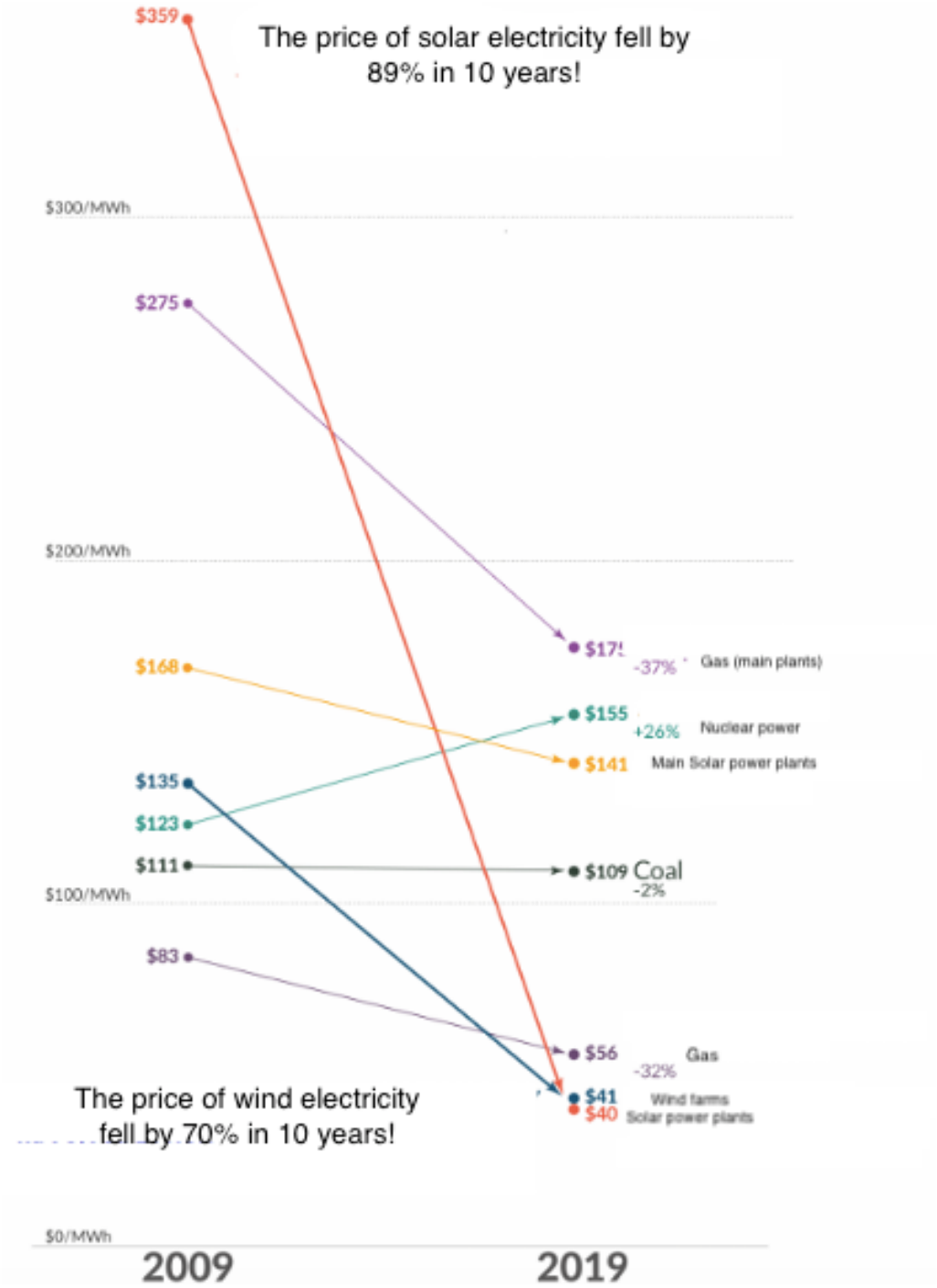


* ESG development of commercial activities on the principles of responsible attitude to the environment (E - environment), high social responsibility (S - social) and high quality of corporate governance (G - governance)

Source: Russian Oil and Gas Companies // https://investfunds.ru/analytics/251303/download/

It is important to note that the development of alternative energy by fuel and energy companies is based not only on stricter environmental requirements and changes in consumer attitudes, but also on economic factors. For example, over the past decade, scientific and technological advances have significantly reduced the cost of obtaining energy from renewable sources. In particular, in terms of LCOE (the average estimated cost of electricity generation over the full life cycle of the power plant) from 2009 to 2019. The cost of generating nuclear power increased by 26%, the cost of generating power using coal remained virtually unchanged (-2%), the cost of generating power from natural gas decreased by 37%, while the cost of generating power using wind turbines decreased by 70% and the cost of generating solar power decreased by 89% (Figure 13):

Figure 13. Cost of generation by plant type in 2009 and 2019, LCOE: USD/MWh



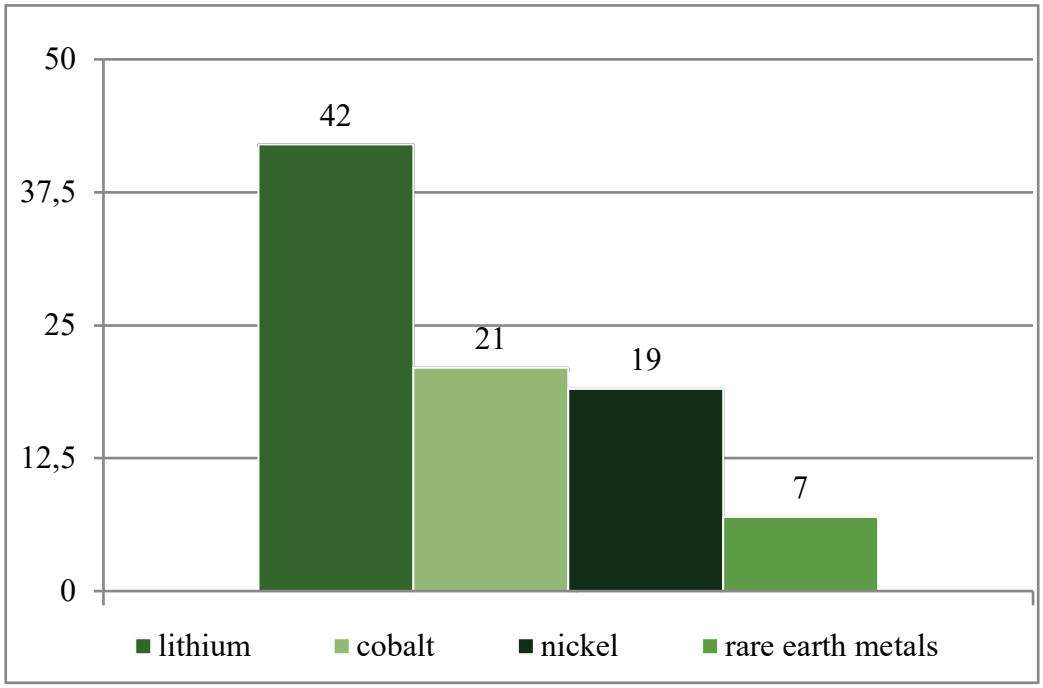
Source: Lazard Levelized Cost of Energy Analysis. Version 13.0// https://hsto.org/webt/vh/9e/tw/vh9etwwvmr9_g2e426pthkzn0vo.png/

Nevertheless, one could observe a global disruption of established supply chains and an increase in the cost of individual materials and components for the production of solar panels and wind turbines against the backdrop of the corona crisis of 2020, which led to an increase in

their cost in 2021 (according to Bloomberg estimates) by more than 50% and 13% respectively. (Manukov, 2022) According to experts, the situation with the shortage of minerals and metals required for the production of solar panels and wind turbines will only worsen in the near future, as demand for similar materials increases due to both the energy transition commitments made by countries and companies and the development of other economic sectors. For example, the production of batteries for electric cars, electronics, household appliances, etc.

Just to support the already announced energy transition plans between 2020 and 2040 will require a multiple increase in production of a range of metals (Figure 14):

Figure 14. Growth in demand for metals to meet energy transition plans 2020-2040, index, 2020 = 1



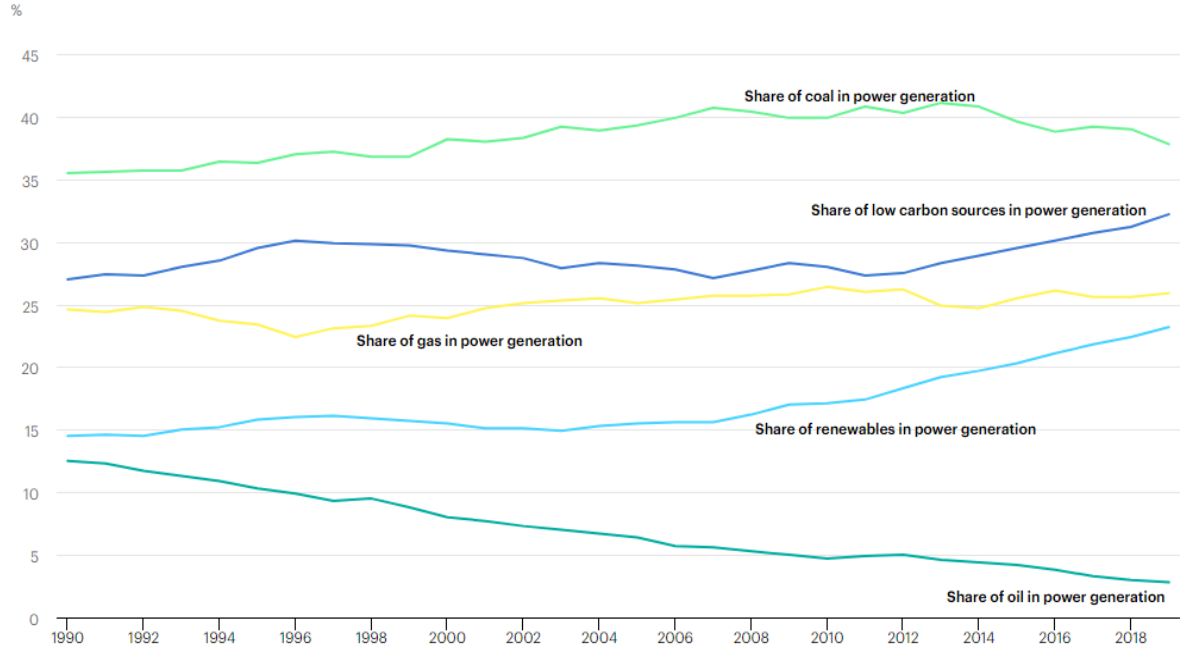
Source: Sechin, I.. The World Energy Sector at a Crossroads. 2021 // Downloaded from: https://www.rosneft.ru/upload/site1/attach/0/14/02/SPIEF_slides_2021.pdf/

Thus, the intensive reduction in the cost of generating energy from renewable sources observed during 2009-2019 has already been replaced by its growth in 2020-2021. This requires the introduction of innovative solutions aimed at reducing the consumption of used metals and materials, as well as restoring the normal functioning of supply chains and a comprehensive approach to the development of metal production necessary to ensure the energy transition.

2.3 Overview of the renewable energy sector in the world

As of pre-crisis 2019, renewable energy accounted for 23.2% of global electricity production, and its dynamics can be seen in the graph in Figure 15:

Figure 15. Change in the share of energy sources in global electricity production in 1990-2019, %



Source: Explore energy data by category, indicator, country or region // Downloaded from: https://www.iea.org/data-and-statistics/data-browser?country=WORLD&fuel=Energy%20transition%20indicators&indicator=ETISharesInPowerGen

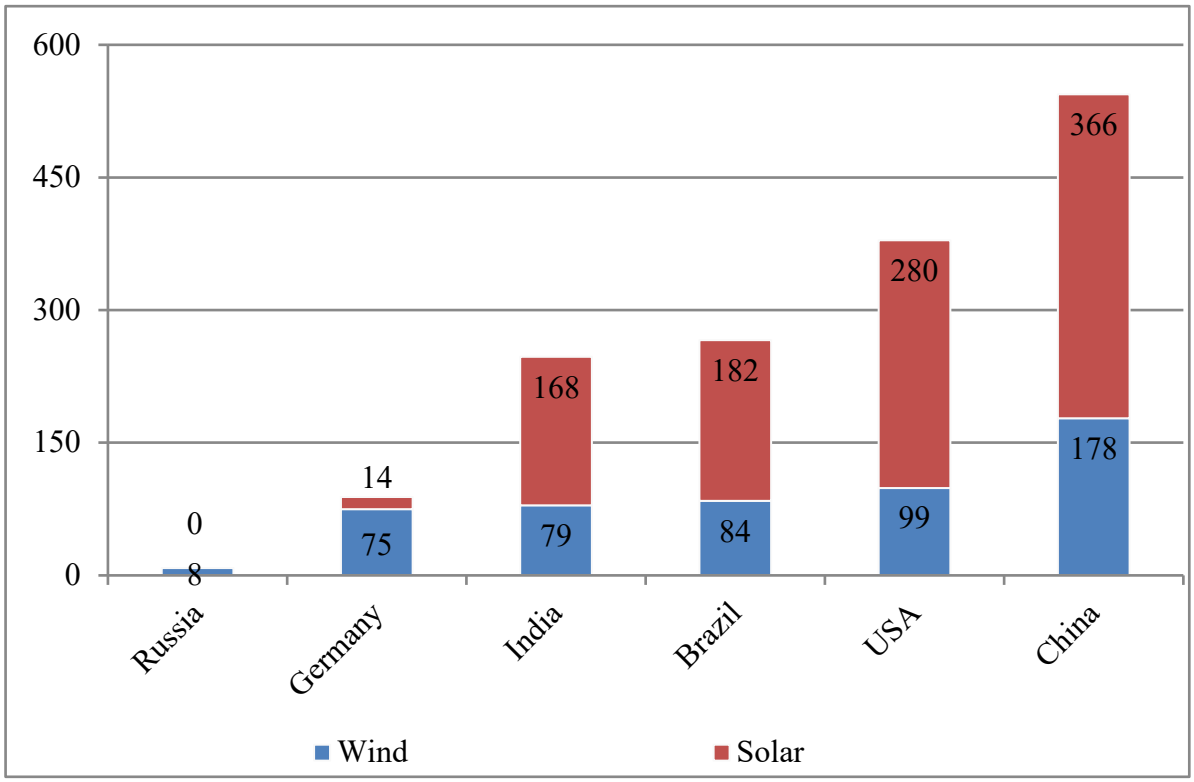
Analysis of the data presented leads to the conclusion that the use of oil for energy generation has significantly decreased over the past 30 years, while the use of natural gas and coal has remained relatively stable, the latter of which still maintains its leadership as the key resource in global energy production. At the same time, only the share of renewable energy sources has shown a positive trend in recent years, which also affects the overall growth of the share of low-carbon energy sources.

The first countries that began actively introducing alternative energy were the U.S. and the European Union. The EU adopted a program that provides for the contribution of renewable energy sources in the structure of the energy balance to 40% by 2040. Similarly, as of 2019

targets for RES development were set in most states of the USA, Japan, China, all in more than 70 countries around the world striving to reach the target of 10% to 30% RES contribution to the energy balance by 2025. (Energy: management, quality and efficiency of energy resources use, 2019)

Despite the fact that alternative energy has become increasingly popular in the developed world over a long period of time, the top countries for solar and wind generation were China, Brazil, and India as of pre-crisis 2019 (Figure 16):

Figure 16. Volumes of electricity generation from renewable energy sources in the leading countries in 2019, billion kWh



Source: Turalina, A. (2021). Renewable Energy as an Innovative Factor in the Development of the World Economy. Bulletin of Donetsk National University. Series B. Economics and Law, 3, P. 309-316.

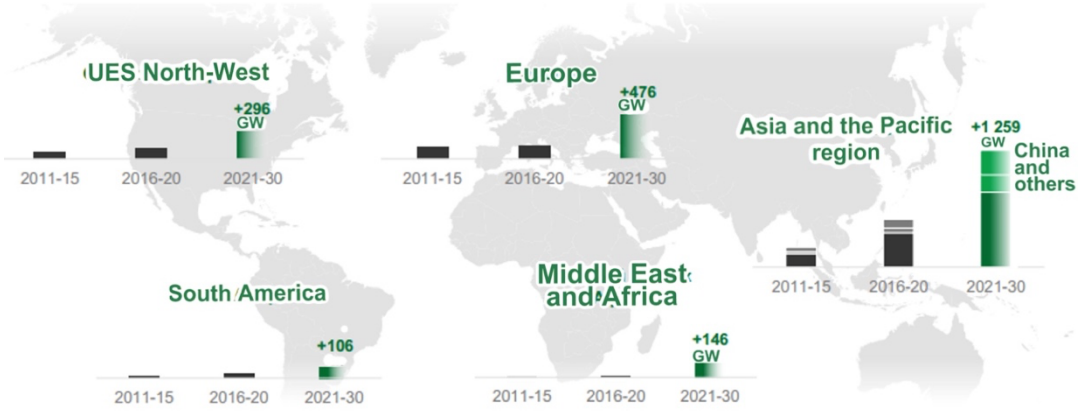
At the end of the crisis year of 2020, power generation from RES, despite the crisis trends in the fuel and energy complex, increased by another 7%. This was primarily due to the growing use of solar and wind technologies, which accounted for almost 60% of the total increase in the use of RES. As a result, the share of renewables in global power generation reached an all-time

high of 28.6% amid a general slowdown in economic activity and falling demand for electric power. (Renewable Power, 2021)

The preliminary results of alternative energy development in 2021 also show an acceleration of the growth of global power generation capacity using solar panels, wind turbines and other RES, which will provide a new record for the indicator of commissioning new RES capacities at the level of up to 290 GW. At the same time, forecasts for 2022 suggest another year of record increases in renewable capacity. According to the forecast of the international consulting company PwC, their growth could reach 295 GW. (Prime, 2022)

As for the distribution of this growth among countries and regions of the world, both the IEA's forecasts and estimates of representatives of Russian energy companies agree that the main growth of alternative energy will be concentrated in China and other countries of the Asia-Pacific region (Figure 17):

Figure 17. Actual and projected net growth of RES capacity in 2011-2030, GW



Source: Sechin, I. The World Energy Sector at a Crossroads. 2021 // Downloaded from: https://www.rosneft.ru/upload/site1/attach/0/14/02/SPIEF_slides_2021.pdf/

Such high expectations for the growth of the renewable energy sector worldwide are due to the setting of ambitious goals by many countries and regions of the world in terms of energy transition. This will entail an increase in the volume of government support and implementation of measures aimed at stimulating investment by the private sector. At the same time, experts consider the increase in prices for materials for the production of wind turbines and solar panels,

their production and transportation, as well as the possible aggravation of the current global economic crisis with a worsening epidemiological situation in the countries-leaders in energy production from renewable sources as the key obstacles to the development of alternative energy.

The analysis of the history of the development of the fuel and energy complex and its current state allows us to conclude that, in the modern sense, the global fuel and energy complex is a complex intersectoral system, the generalized structure of which includes the fuel industry and the electric power industry. As factors positively influencing the development of the fuel and energy complex, one can designate the continued growth of the world's population and the growth in the well-being of citizens of the developing countries of the world, as well as the rapid development of innovative technologies in the sector, while periodically occurring global economic crises have a negative impact on the fuel and energy complex, since the fall in world industrial production is natural leads to a decrease in demand and prices for energy resources.

The distinctive features of the current economic crisis are, on the one hand, an unprecedented drop in demand and prices for oil as the main energy resource, and, on the other hand, a faster (compared to expectations) recovery of world industrial production, which led to an increase in demand and prices for energy resources already in second half of 2021.

At the same time, the renewable energy sector was the only one in 2020 that showed growth, despite all the crisis phenomena in the industry - its share in global electricity generation increased from 23.2% to 28.6% compared to 2019, which was a record indicator throughout history.

The leading countries in terms of renewable energy generation include such countries as China, the USA, Brazil, India and Germany, and experts' forecasts for the near term agree that the development of alternative energy will continue, despite the existing problems with logistics and an increase in the cost of raw materials and materials for the production of wind turbines and solar panels, and the countries of the Asia-Pacific region (primarily China and India) will be the leaders in terms of further growth in renewable energy capacities.

The analysis of the US experience in terms of applying innovations in the country's fuel and energy complex allows us to conclude that innovative development in this area has been effectively used throughout the entire history of the fuel and energy complex: from the launch of the world's first oil rig in 1859, which served as the start of industrial oil production to

effective implementation of hydraulic fracturing technology for the extraction of shale oil and natural gas over the past two decades, which allowed the United States to become a leader not only in consumption, but also in the production of oil and other liquid hydrocarbons, as well as to move from importing to exporting oil and natural gas.

In terms of the development of renewable energy, the United States is currently behind China and the European Union, ranking third in the world both in terms of the volume of generated solar energy and wind energy, and in terms of the growth rate of these types of generation. The development of this area is significantly influenced by the energy policy of state authorities, which over the past decade has been changing to almost diametrically opposite when the president and the ruling party change in the country. In addition to this factor, the growth in the use of renewable energy is stimulated by significant climate change, which entails direct damage to the population and businesses, as well as an increase in internal climate migration, as well as the use of the climate factor in building US foreign policy.

Negative factors negatively affecting the development of renewable energy include the disruption of supply chains during the current economic crisis and the rising cost of materials and components for the production of solar panels and wind turbines, as well as growing environmental concerns about the harm caused by wind and hydroelectric power plants. bird and fish populations.

3 Empirical research

This part will make sense of the philosophy utilized for this examination project. It incorporates research plan, information assortment, as well as legitimacy and unwavering quality.

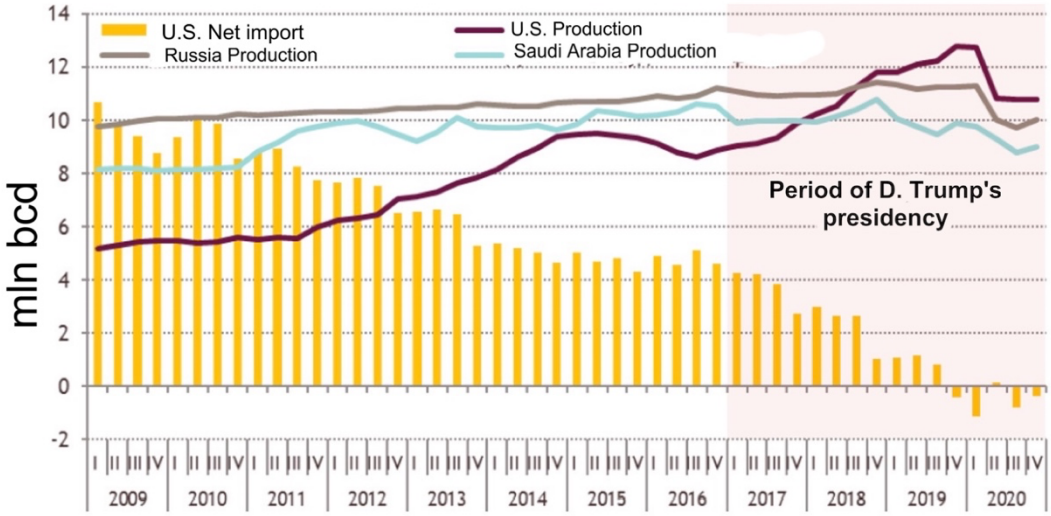
3.1 Methodology. Approaches to regulation of the energy industry and new vectors in the energy policy of the United States.

The main goal of the U.S. energy industry regulation policy during the pre-crisis decade was to achieve independence of the country from external energy supplies. As previously mentioned, the U.S. not only did not impose restrictions on shale oil and gas production in order to achieve this goal, but also pursued a policy of stimulating this segment of the industry. This consisted in different methods from providing tax incentives to shale companies to increasing the availability of credit through hedging instruments, reinsurance, financial derivatives and futures.

In addition, the very introduction of innovative technologies in the field of shale oil and natural gas production has largely become possible due to the use of long-term government funding of R&D, which has been carried out for more than 30 years. (Konoplyanik. 2014) Additional incentives for the development of the U.S. oil and gas industry include the U.S. monetary policy, which promotes the provision of cheap and affordable loans and the general development of investment activity in the country.

The first positive results in the development of the U.S. oil industry were achieved during the presidency of Barack Obama, but they became most impressive during the presidency of Donald Trump. It was during his presidency that the U.S. became the world's number one oil producer, overtaking Russia and Saudi Arabia, and also became a net exporter of oil and petroleum products (Figure 18):

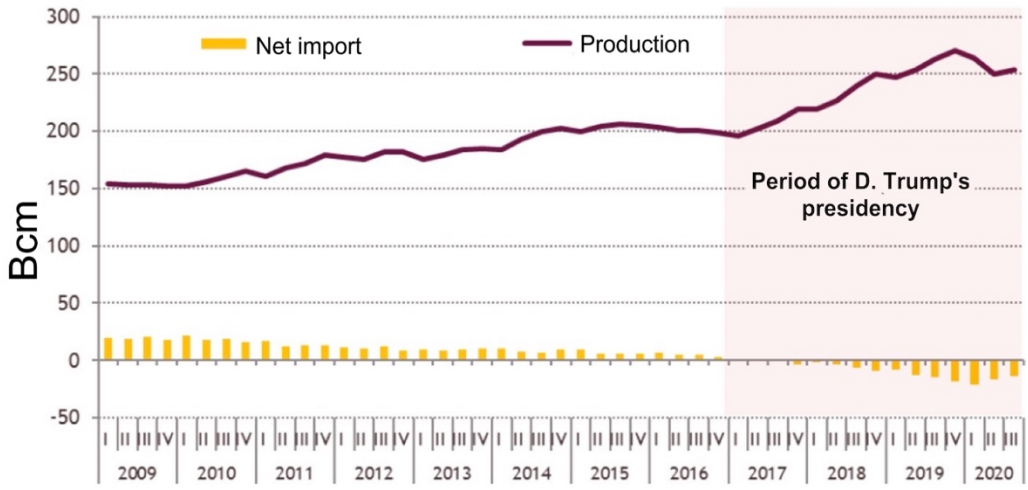
Figure 18. U.S. oil production vs. Russia and Saudi Arabia, and U.S. net imports of oil and petroleum products in 2009-2020, mln bpd



Source: New Vectors in U.S. Energy Policy / Energy Bulletin No. 92 of the Analytical Center under the Government of the Russian Federation // Downloaded from: https://ac.gov.ru/uploads/2-Publications/energo/energo1_jan2021.pdf

The situation developed similarly in terms of production and import/export of natural gas. After reducing federal income taxes for US corporations under the Tax Cuts and Jobs Act (part of the 2017 Tax Reform), the US managed to become a net exporter of natural gas by the end of this year and achieve record levels of its production by the end of 2019 (Figure 19):

Figure 19. The volume of natural gas production in the United States and its net imports in 2009-2020, billion cubic meters m



Source: New Vectors in U.S. Energy Policy / Energy Bulletin No. 92 of the Analytical Center under the Government of the Russian Federation // Downloaded from: https://ac.gov.ru/uploads/2-Publications/energo/energo1_jan2021.pdf

During the acute phase of the economic crisis in 2020, the U.S. experienced a significant decline in the number of active natural gas drilling rigs, namely from 198 at the beginning of 2019 to 120 at the end of 2020, i.e. by 40%. (RIA, 2022) Nevertheless, the decrease in the number of operating rigs was compensated for by improvements in the efficiency of natural gas production technologies in shale deposits, as well as the production of associated gas in shale oil production, which ultimately helped to maintain the U.S. position as a net exporter of natural gas.

Given the ever-increasing number of bankruptcy proceedings initiated by shale oil and natural gas producers in 2020, which included industry pioneer Chesapeake Energy, as well as such major producers as Whiting Petroleum and California Resources (RIA, 2020), the Trump administration decided to provide large-scale assistance to the country's oil and gas sector, which amounted to billions of dollars. At the same time, for the first time in its history, the U.S. Federal Reserve began buying the debts of oil and gas and energy companies, having bought the bonds of 19 energy companies in six months beginning from March 2020, which contradicted not only the Federal Reserve Statute, but was also considered by many experts as a direct interference in the financial markets. (Expert, 2020)

In the pre-crisis development of alternative energy in the U.S., wind power accounted for the highest renewable electricity generation in 2019 at 62%, while solar power generation was only 22% (Table 5):

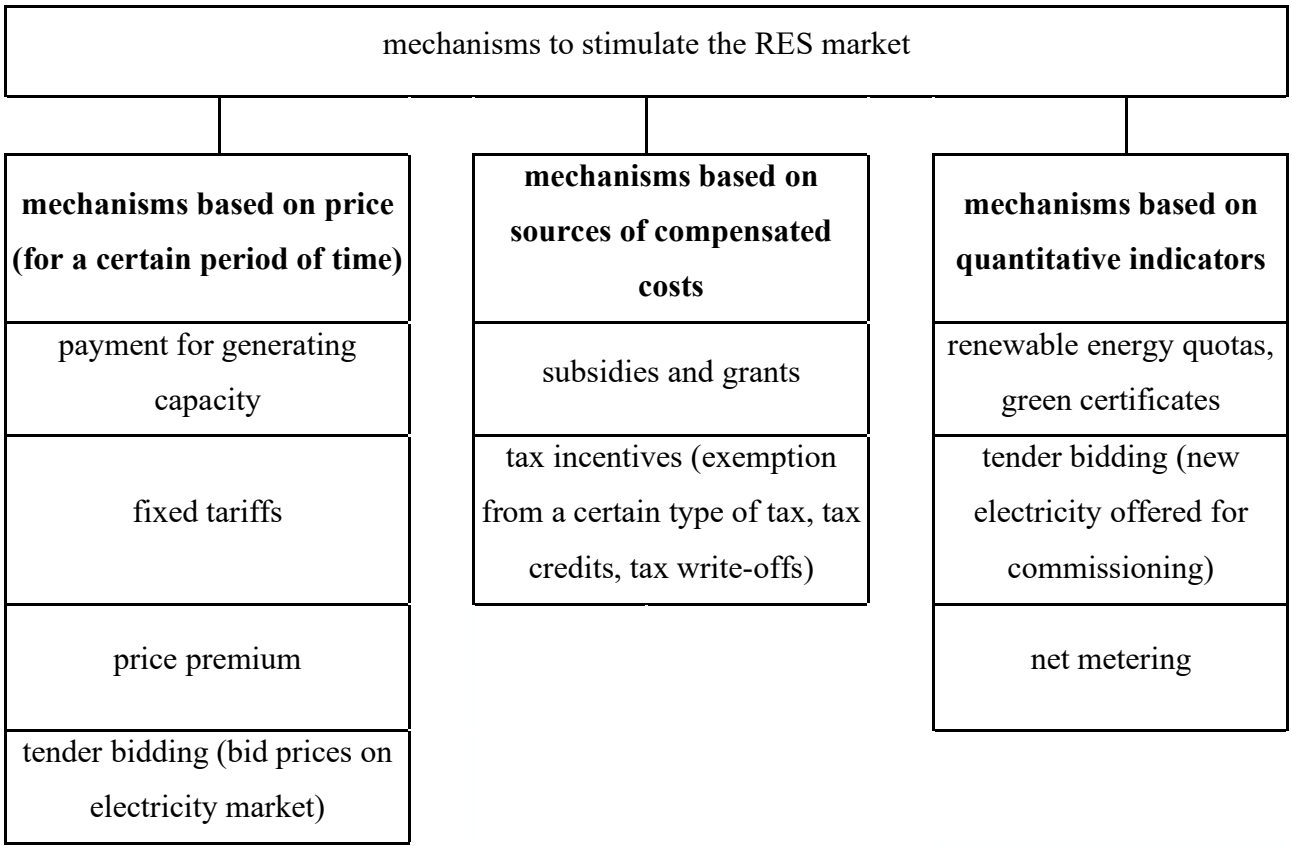
Table 5. Energy production from RES in the leading countries and regions in 2019, TWh

countries / type of RES	wind	sun	other RES	total RES
USA	303,1	108,4	78,3	489,8
China	405,7	223,8	102,8	723,3
EU	430,7	138,4	199,1	768,2

Source: Matveev, V. (2021). The fight against climate change - a new arena of confrontation between China and the United States. *China in world and regional politics. History and Modernit*y, Vol. 26, 26, P. 337-351.

Energy regulation in terms of the development of renewable energy is inextricably linked to the achievement of the goals of the Paris Agreement. Each country chooses its own methods and directions for achieving climate neutrality. In addition to prohibitions and restrictions, these methods include a wide range of tools to stimulate the development of the renewable energy market (Figure 20):

Figure 20. Classification of the main instruments for stimulating RES development

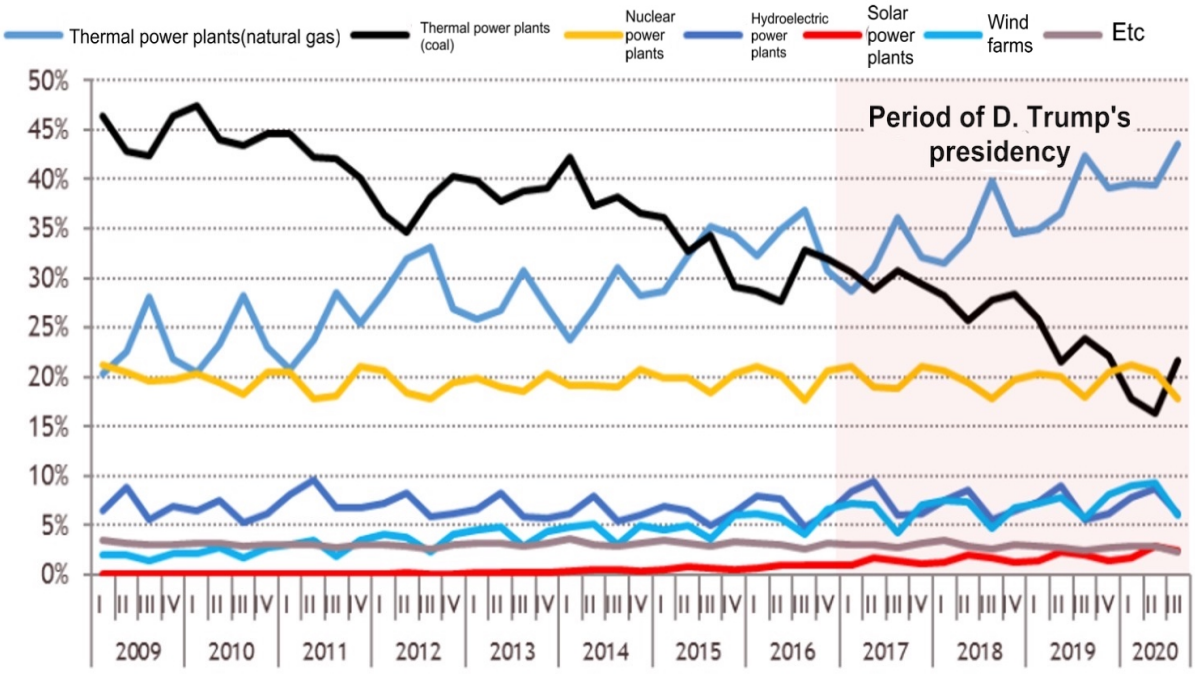


Source: Komar, S. (2021). Regulation and stimulation of renewable energy development in Russia and in the world. *Innovations. Science. Education*, 37, P. 249-256.

The peculiarity of the use of these measures in the U.S. is their implementation mainly at the state level, while in most other countries of the world they are introduced at the state level.

Donald Trump's policy was aimed at the maximum elimination of barriers to the development of the oil and gas industry in the country, the construction of pipelines and increasing demand for fossil fuels, while easing environmental legislation and the U.S. withdrawal from the Paris Agreement on Climate Change. Nevertheless, measures launched before he came to power did reduce coal-fired power generation, giving way to gas-fired power plants, and solar and wind generation continued to grow, despite the lack of new stimulus measures by the federal government (Figure 21):

Figure 21. Structure of power generation in the USA by plant type in 2009-2020, %



Source: New Vectors in U.S. Energy Policy / Energy Bulletin No. 92 of the Analytical Center under the Government of the Russian Federation // Downloaded from: https://ac.gov.ru/uploads/2-Publications/energo/energo1_jan2021.pdf

However, the change of president in the United States and the actual control of both houses of Congress by the Democratic Party led to a radical change in the energy policy of the country, namely to its green agenda with the priority of RES development, electric vehicles, infrastructure modernization, improving energy efficiency and environmental protection. Joe Biden formulated the following 9 key areas of the "Clean Energy Revolution Plan":

1. Tightening restrictions on methane emissions from oil and gas companies, implementing stricter fuel economy standards for transportation, protecting federal water and land ecosystems, including banning new leases for oil and natural gas production.

2. Initiating a process to develop a legislative framework that sets a course toward zero U.S. greenhouse gas emissions by 2050

3. Returning the U.S. to the Paris Climate Agreement, initiating more ambitious national commitments from all other participants.

4. Increasing public investment in clean energy innovation and development to $400 billion over 10 years.

5. Accelerating the introduction of "clean" technologies in the national economy through deep modernization of industries, including electrification, energy efficiency, and clean energy production.

6. Making "environmental justice" a priority for all federal agencies in the country.

7. Tougher penalties for pollution violations.

8. Creating 10 million well-paying jobs for the middle class employed in this plan.

9. Ensuring that all social obligations to fossil fuel employees are met.

In addition to enacting new regulations, Biden's executive order initiated a review of all regulations enacted during the Trump administration related to energy development and potential environmental damage. In particular, permission was withdrawn for the construction of the Keystone XL oil pipeline, and restrictions were imposed on the development of oil fields in the Arctic National Wildlife Refuge. (New Vectors in U.S. Energy Policy, 2021)

One of the most radical measures taken by Biden was a temporary moratorium on issuing new licenses to oil and gas companies to produce hydrocarbons on U.S. federal lands. Federal lands in the U.S. account for about 22% of the total proven oil reserves and 12% of the country's natural gas reserves. However, most hydrocarbon production is concentrated on state lands, which have their own licensing authority. (API, 2020)

Thus, the current U.S. energy policy does not actively support the oil, gas and coal industry, which can only count on the further preservation of favorable market conditions, while conditions for the development of renewable energy are being actively created.

3.2 Data collection. Problems and prospects for the growth of renewable energy in the US.

The United States has set its own course toward achieving zero net greenhouse gas emissions no later than 2050 in its policy documents, including:

- Executive Order on Tackling the Climate Crisis at Home and Abroad; (The White House, 2021)

- Plan for Climate Change and Environmental Justice. (Biden-Harris Democrats, 2020)

It is renewable energy that occupies one of the key places in achieving the goals in the U.S., which by 2030 will bypass natural gas as the main source for generating electricity, according to the EIA (U.S. Energy Information Administration) forecast. The share of renewable energy is expected to rise to 42% by 2050, up from 21% in 2020. This projection also assumes that more than 2/3 of the total increase in power generation through 2024 will come from wind power technologies, with solar power generation (photovoltaic and other thermal technologies) taking the lead through 2040. (Eenergy, 2021)

Nevertheless, the Biden administration is attempting to accelerate this transition - for example, in April 2021, the president submitted his industrial and infrastructure renewal plan for discussion (Biden-Harris Democrats, 2020), which includes:

- A clean energy transition by 2035;
- Establishment of a special Advanced Research Projects Agency (ARPA-C, Advanced Research Projects Agency), which will focus on small modular nuclear reactors, air conditioning and cooling systems using refrigerants, zero net energy building design, hydrogen production from renewable energy sources, carbon-free heat for steel, chemicals and concrete, carbon dioxide capture and storage systems, etc.
- Development of electric transport;
- Improving the energy efficiency of buildings;
- Improving agricultural practices in terms of low-carbon technologies, etc.

Biden's plans have been criticized on all sides, both by the powerful oil and gas lobby, which provides a significant amount of energy and jobs, and by supporters of the energy transition. The latter criticize the U.S.'s over-reliance on nuclear power, which, combined with renewable energy, accounts for about 38 percent of the country's total energy generation (Lanisha, 2021). The existing U.S. energy transition plans do not envisage abandoning nuclear power until 2050, which, according to environmentalists, entails huge risks of accidents at nuclear power plants, problems with radioactive waste storage, etc.

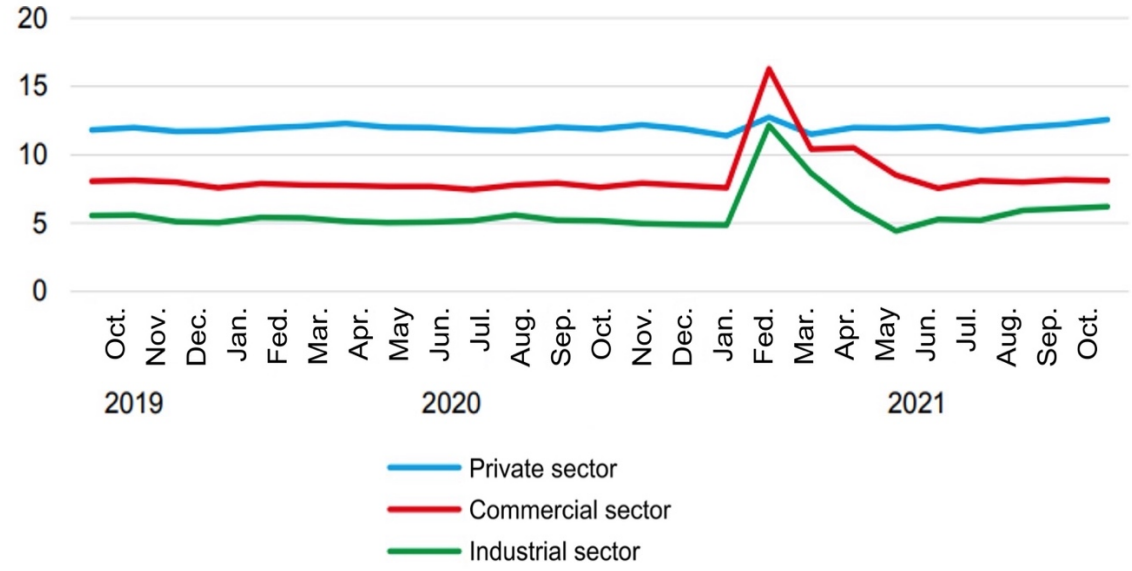
Another problem is the growing volume of renewable energy products and materials that must be disposed of, as many previously installed renewable energy facilities are coming to the end of their lives.

In particular, about 1 million tons of waste and about 80,000 tons of materials requiring recycling may be generated in the U.S. by 2030. This will happen as a result of decommissioning of used solar panel modules. Given that the technology for recycling such plants is still in the early stages of development, the U.S. policy in this area should be significantly strengthened in the near future. (Sklyarov, 2022)

The current renewable energy strategy in the U.S. has also been criticized by those who are concerned about energy security and the stability of the country's energy system. The renewable energy sector was severely tested in February 2021, when wind turbines, which in 2020 accounted for about 19.5% of the state's total energy generation, stopped working amid a severe cold snap in Texas. At the same time, gas and oil pipelines stopped pumping due to severe frosts, as well as equipment at thermal power plants and other power grid failures were observed.

The greatest reduction in power generation in February was precisely because wind and coal generation decreased by 20.1% and 14.4%, respectively, which rightly raised questions about the overall level of flexibility and stability of such energy systems, where renewables occupy such a significant share. As a result, this emergency situation led to a sharp spike in electricity costs for both the private and, especially, the industrial and commercial sectors (Figure 22):

Figure 22. Electricity costs in Texas, USA in 2019-2021, cents/kWh



Source: Development of renewable energy against the backdrop of energy crises / Analytical Center under the Government of the Russian Federation. Energy Trends. № 104. January 2022.

Thus, further increase in the use of RES in the U.S. requires a review of ways to reduce the risks of falling power generation and requires an overall increase in the sustainability of the power system. One option for solving this problem is the development of energy storage systems, as well as the combination of RES with other generating capacities, i.e. the creation of interchangeable generation facilities within one system.

Nevertheless, it is important to note that U.S. authorities are announcing a continuation of the transition to clean energy and increased investment in this area to ensure less energy vulnerability in the United States even in the current worsening geopolitical situation and a significant increase in gasoline prices in the United States, including due to the ban on imports of Russian energy carriers. (RIA, 2022)

An extremely important challenge to the further development of renewable energy in most of the world, including the U.S., is the disruption of established supply chains, which began back in 2019 due to trade disagreements between the U.S. and China, continued in 2020-2021 amid corona restrictions, and is now exacerbated by the West's confrontation with Russia over the special military operation in Ukraine.

In particular, the U.S. had a shortage of raw materials and components for the production of wind farms, solar panels, and energy storage systems in 2021. This forced many manufacturers to search for alternative sources of supply, as well as to switch to partial import substitution. For example, steps have been taken to increase national production of wind turbine components due to unethical labor use issues, increasing the number of production sites in the sector to more than 500 and their geographic representation to 40 states. (Sklyarov, 2022) Nevertheless, the U.S. still has a high level of dependence on foreign supplies for energy in general, and for renewable energy.

As already discussed in the first chapter of this paper, global energy transition in 2020-2040 requires a multiple increase in production of a number of metals: lithium 42-fold, cobalt 21-fold, nickel 19-fold, and other rare-earth metals 7-fold or more. Given the fact that the U.S. buys most of the above metals from China, which has controlled these markets for more than 30 years, the U.S. authorities are taking measures to increase these reserves and to reduce their dependence on foreign supplies for the long term.

Currently, there is only one lithium mine in the U.S., which is clearly not enough to meet the needs both in terms of growth in the production of batteries for electric vehicles and to meet the needs of the renewable energy sector. In terms of rare earth metals, the situation is even more complicated, and they are used not only in the renewable energy segment, but also in many other sectors of the U.S. economy, including weapons, jet aircraft, electronics, etc. (Tass, 2022)

In an effort to reduce U.S. dependence on foreign supplies of rare earth metals, the Pentagon announced a $35 million investment in MP Materials, a U.S. company that manufactures and processes rare earth metals in California. Among other things, the company is engaged in the production of permanent magnets needed to make wind turbines. China currently controls about 87% of the permanent magnet market. MP Materials estimates its total investment in import substitution in this area for the period up to 2024 at about $700 million. Another import substitution project is being implemented by Berkshire Hathaway Energy Renewables, which gets lithium from geothermal brines in California. Its cost is estimated at several billion dollars (Filatov, 2022).

As for the current geopolitical conflict with Russia, it has already led to a significant increase in the prices of certain metals. In particular, between the beginning of 2022 and March 10, 2022, palladium rose in price by 61%, and nickel by 130%. Russia occupies about 45% of the global palladium market, having the largest proven reserve of this metal, as well as provides about 3% of global consumption of nickel (Fores, 2022), which is essential for the development of renewable energy.

At the same time, as one of the world's leading producers of nickel, copper and platinoids, Norilsk Nickel accounted for more than 53% of its 2021 revenues from metal supplies to Europe and another 15% to the USA and South America. At the time of writing this chapter, the U.S. and other countries have not imposed sanctions on this company and, according to experts, do not plan to do so, considering the consequences for their economies. However, as the geopolitical situation worsens, such decisions may still be taken either by the United States or by Russia as retaliatory sanctions, which will become an even greater negative factor for the development of American renewable energy than the current increase in prices for these metals.

Thus, the analysis of practices and problems of growth in the use of renewable energy in the U.S. showed that now the use of renewable energy is the main bet in ensuring energy security

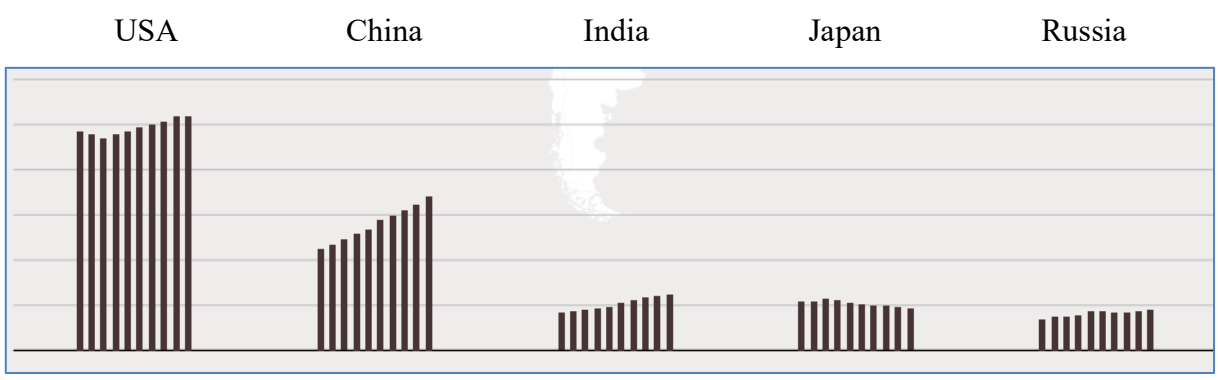
of the United States, except for a slight decrease in the attention of the authorities to this sector during the Trump administration. This direction is seen as a key element of the implementation of plans to achieve carbon neutrality by 2050, and possibly by 2035, if the relevant proposals of President Biden's plan will be adopted. At the same time intensive development of renewable energy in the country is opposed by the lobby of the oil and gas sector, as well as representatives of various environmental organizations, raising questions of instability of energy production from renewable energy, the growth of waste during the decommissioning of wind and solar power plants and other related problems. In addition, the dependence of this sector on supplies of materials from China and Russia poses significant risks to the implementation of plans for the development of renewable energy in the United States.

3.3 Data analysis. US Energy Balance Analysis.

The accumulation of experience in the application of innovations in the fuel and energy complex of the United States dates back to the very beginning of its formation. It was in Pennsylvania in 1859, the first oil rig in the world was built with a production capacity of about 25 barrels per day, which researchers attribute to the start of the first stage of industrial oil production (Profile, 2019). This was followed by a long period of participation in the development of the industry by such entrepreneurs as Rockefeller, whose activities were marked by the introduction of many innovations not only in oil production, but also in the field of oil refining and transportation.

During the pre-crisis decade 2010-2019, the U.S. continued to be the world's leading consumer of oil and petroleum products, second only to China in terms of consumption growth (Figure 23):

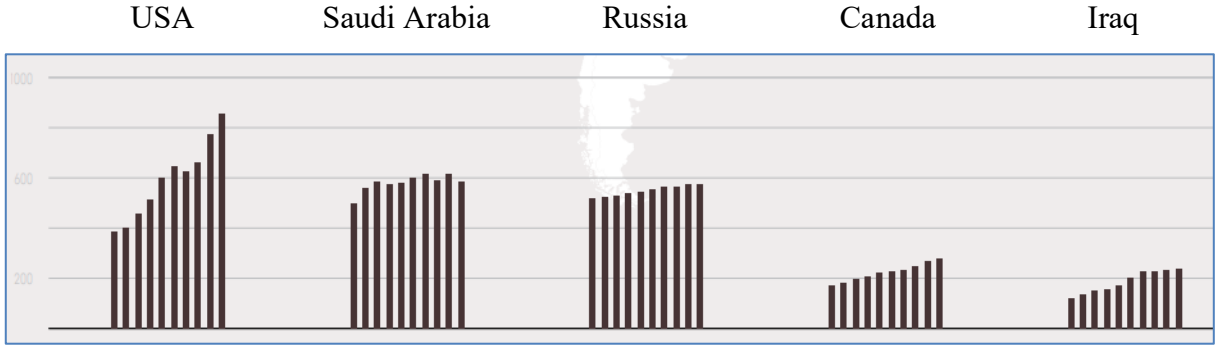
Figure 23. Oil and petroleum products consumption in the top 5 countries in 2010-2019, million tons



Source: Fuel and Energy Complex of Russia-2019. Statistical collection // Analytical Center under the Government of the Russian Federation. - June 2020. - P. 22.

Over the period under review, the United States also moved from third place to first place in terms of oil production, demonstrating the highest growth rate on this indicator (Figure 24):

Figure 24. Dynamics of oil and other liquid hydrocarbons production in the top 5 countries of the world in 2010-2019, million tons



Source: Fuel and Energy Complex of Russia-2019. Statistical collection // Analytical Center under the Government of the Russian Federation. - June 2020. - P. 18.

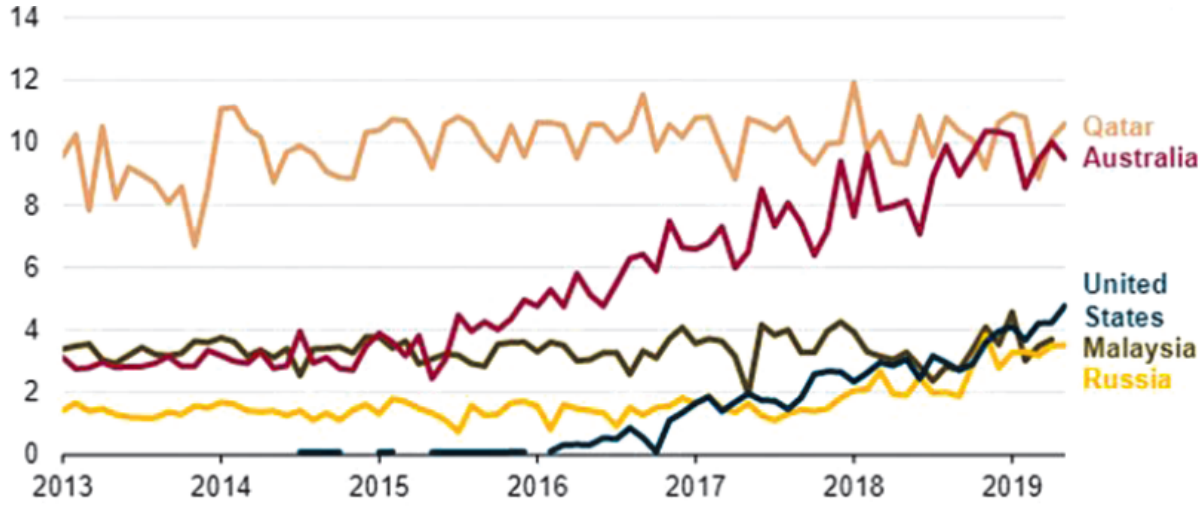
This allowed the U.S. to move from being a major importer to the position of one of the leading exporters of oil and natural gas. It was the introduction of such innovative technology as hydraulic fracturing that largely made it possible to achieve these results. Such technology is used to extract oil and natural gas from oil shale deposits - a type of sedimentary rock that contains from 20% to 70% of sapropelic or humus-sapropelic materials (evenly distributed organic matter), from which natural gas and shale oil - a substance similar to oil in most of its parameters and element content - are produced (Musin, 2019).

Despite the fact that oil shale deposits can be found almost everywhere in the world, most European and other governments have decided to ban the use of hydraulic fracturing because of the significant environmental damage caused by its use. In the U.S., however, no such ban has been enacted. To date, oil and gas reservoirs have been discovered in 23 states, and the largest shale basins include Barnett, Fayetteville, Haynesville, Permian, Marcellus, Woodford and Three Forks Shale (Neftegaz, 2020)

It is important to note that shale gas and oil production is a more complicated method compared to their production from conventional fields. Therefore, U.S. shale companies had to spend a considerable amount of time to reach zero profitability and then to make a profit. The export-oriented transport and logistics infrastructure (Ivanov, 2019), as well as the use of another innovative technology, liquefied natural gas (LNG), which makes it possible to transport produced natural gas to such premium markets as the EU and later the Asia-Pacific region, have also contributed to increasing profitability in this area.

The analysis of global LNG trade allows us to conclude about the growth of trade volumes in this segment in 2020. Despite the crisis phenomena in the global economy, global LNG trade increased by 0.4% in 2020 as compared with 2019 and reached the level of 356.1 million tons. First of all, this dynamics was due to the growth of demand from Asian countries; the leading positions in terms of growth of supply volumes were taken by the USA and Australia, which in 2020 took the second and third places in the world, giving way only to Qatar (Figure 25):

Figure 25. Dynamics of global LNG exports in 2013-2020 by leading exporting countries, bcma/d



Source: Koening, T. (2021). Global energy transition: challenges and opportunities - a perspective from North America. *Georesources*, Vol. 23, 3, P. 53-58.

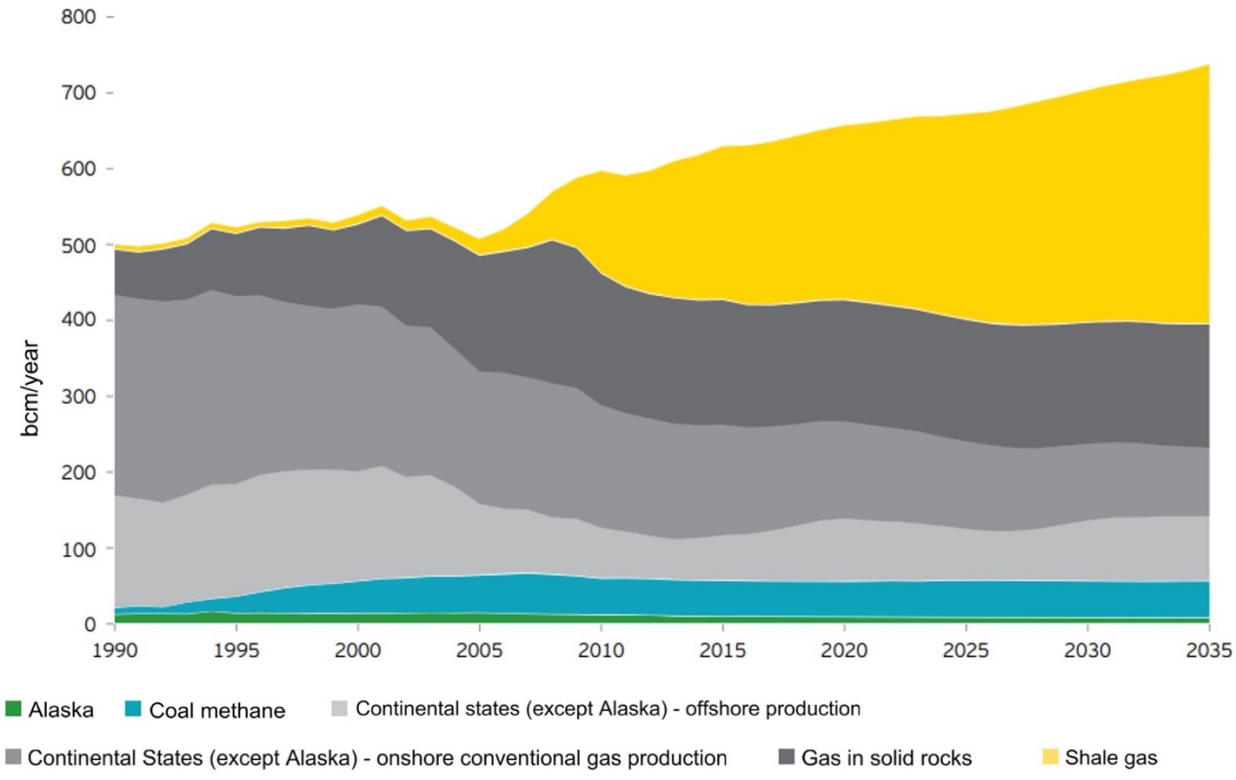
At the same time, the development of shale oil and gas production in the United States was facilitated not only by the development of innovative technologies in this area, but also by a set of other factors, the key ones of which can be identified as follows:

- High level of exploration of the country's territory from a geological point of view;
- Relatively shallow depth of oil and gas bearing strata;

- The presence of an extensive infrastructure of existing main gas and oil pipelines, to which almost any production company that starts drilling has an opportunity to connect;
- Favorable conditions in terms of the development of a flexible economic mechanism: from the availability of affordable credit resources to the rapid formation of industry legislation;
- Opportunity to use special tax regimes;
- Free sales market.

Pre-crisis forecasts of the U.S. Energy Information Administration assumed a significant increase in the use of hydraulic fracturing technology, which would allow to reach the level of shale gas production of about 342 billion cubic meters per year by 2035, while reducing its production by all other methods (Figure 26):

Figure 26. US EIA natural gas production forecast to 2035, bcm/year

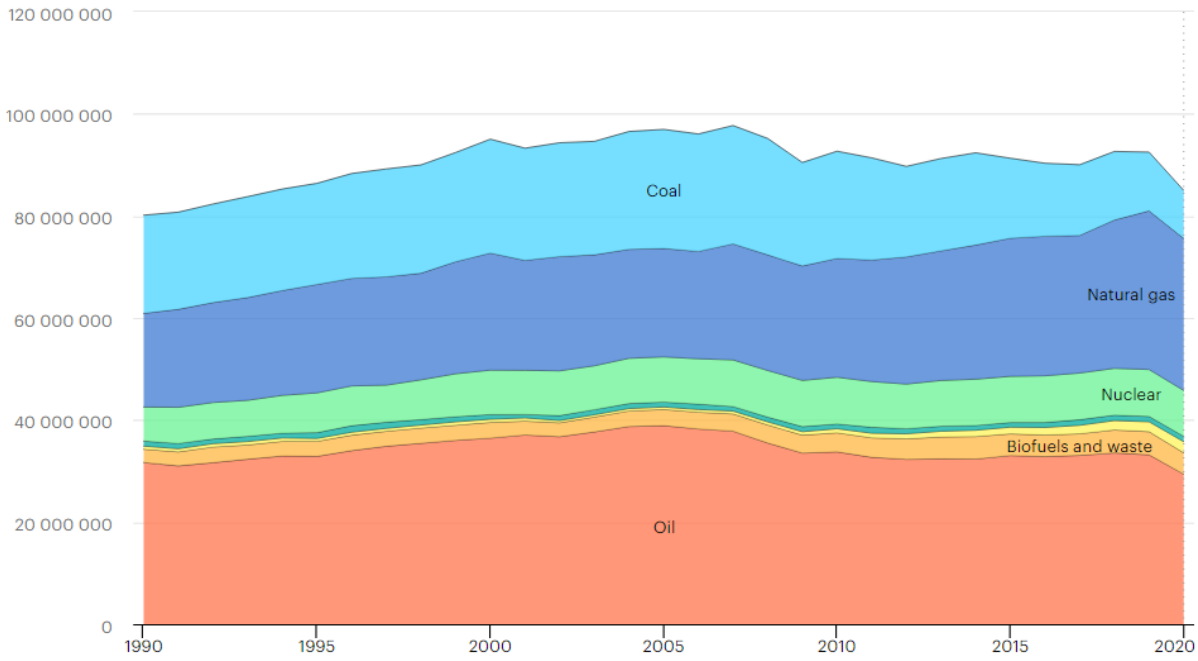


Source: Shale Gas in Europe: Revolution or Evolution? // Downloaded from: https://www.hse.ru/data/2014/01/25/1326320349/Сланцевый%20газ.pdf

Due to the development of natural gas production in the U.S. shale deposits, it was possible not only to increase its export volumes, but also to significantly change the structure of electricity

generation in the country. Over the period from 1990 to 2020, the share of coal as an energy resource used for power generation in the U.S. has significantly decreased, and the share of oil and oil products has decreased, while the share of natural gas has significantly increased (Figure 27):

Figure 27. Structure of power generation in the United States by energy resource during 1990-2020, TJ



Source: United States // Downloaded from: https://www.iea.org/countries/united-states/

Thus, it was the use of such innovative technologies as shale oil and natural gas production by hydraulic fracturing, as well as transportation of liquefied natural gas that allowed the United States to become a leader in oil and other liquid hydrocarbon production during the last pre-crisis decade, as well as significantly increase the volume of energy resources exports.

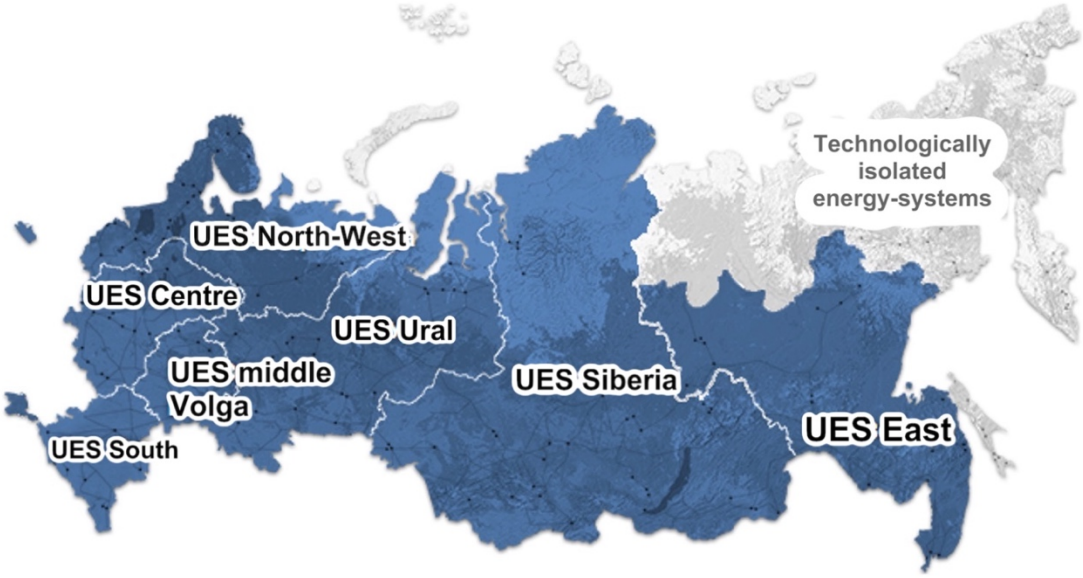
3.4 Development of renewable energy in the Russian Federation

Over the past decades, this area has developed quite poorly in Russia, despite the fact that the USSR acted as one of the world leaders in renewable energy, including hydro and wind power. The reason for this was both general problems in the country's economy throughout the 1990s and early 2000s, and overestimation of the impact of hydropower on the environment in terms of its negative impact on flooding of territories, landscape changes and destruction of natural ecosystems.

Active work on the development of renewable energy resumed only in the 2010s, when certain measures of state support began to be implemented in different sectors, including the development of the wholesale and retail electricity market, as well as microgeneration. It is important to note that modern wind and solar power plants began to be built in Russia only after 2015, and their number currently reaches only a few dozen units (Lanisha, 2021)

Today's electric power industry in Russia is developing on the basis laid down during the Soviet period, which entails both advantages and disadvantages in terms of the efficiency of its functioning. Currently, the Unified Energy System (UES) of Russia consists of 911 power plants with capacity over 5 MW, 71 regional power systems, included in 7 united energy systems, presented in Figure 28:

Figure 28. Geographic structure of UES of Russia

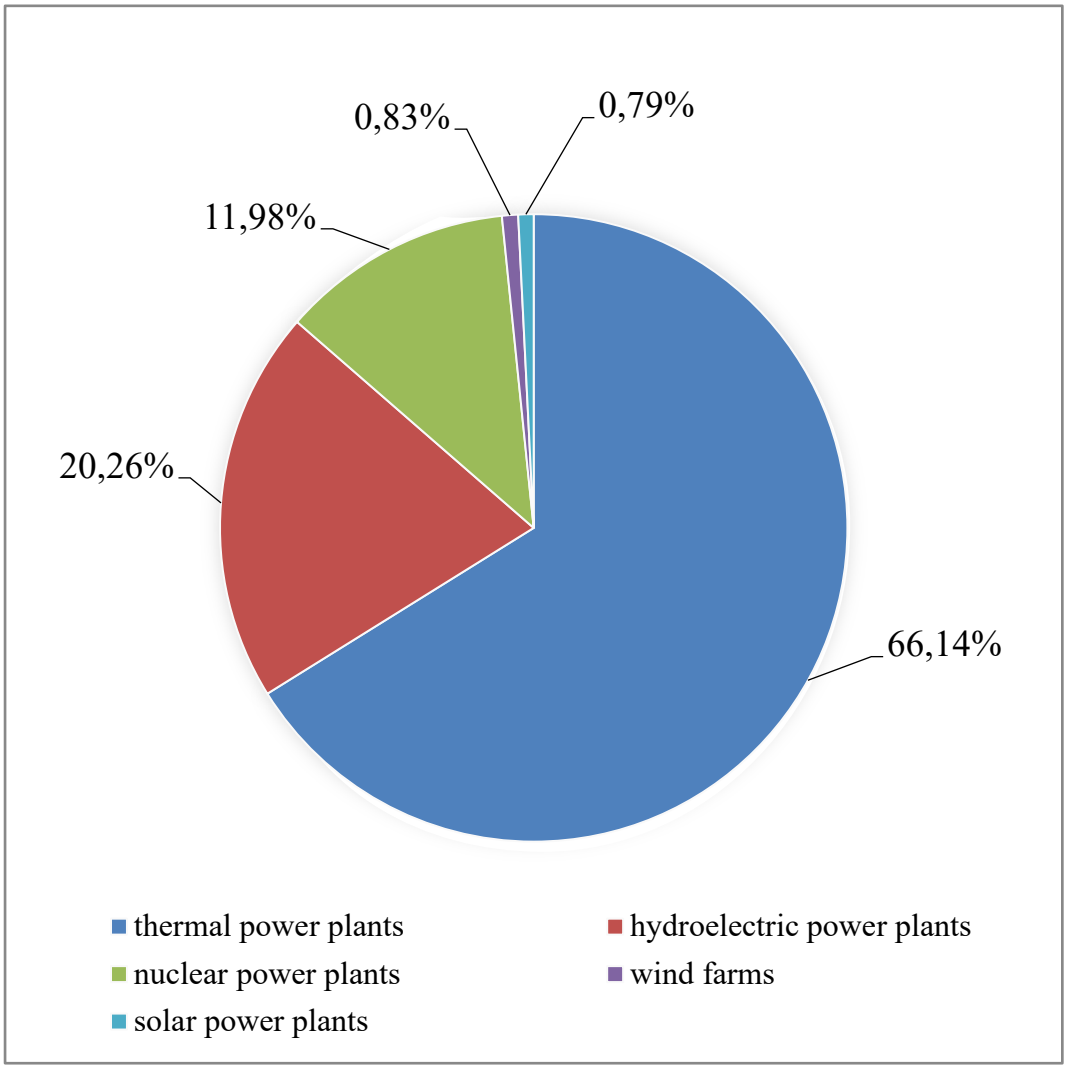


Source: Unified Energy System of Russia. Downloaded from: https://www.so-ups.ru/functioning/ees/ups2022/

As of the beginning of 2022, the total capacity of UES of Russia was 246,590.9 MW. At the same time, power generation for 2021 reached 1,114.55 billion kWh. Due to the fact that domestic consumption in 2021 was 1,090.44 billion kWh, UES exported electricity to China, Georgia, Belarus, Kazakhstan, Norway, Finland, Ukraine and a number of other countries as in previous years (directly or indirectly - for example, through the energy system of Kazakhstan to Kyrgyzstan and Uzbekistan) (RPSO, 2022)

By now, Russia's electric power industry includes such major sub-branches as thermal, hydropower, nuclear, and renewable energy, where thermal, hydro, and nuclear power plants account for most of the power plant capacity (Figure 29):

Figure 29. Structure of the installed capacity of UES of Russia by types of power plants



as of 01.01.2022, %

Source: Unified Energy System of Russia. Downloaded from: https://www.so-ups.ru/functioning/ees/ups2022/

As can be seen from the presented graph, thermal power plants account for more than 66% of the total capacity of all power plants in the Russian Federation, and second place in this structure is occupied by hydroelectric power plants with a share of more than 20%, while wind and solar power plants occupy less than one percent.

If we consider the position of renewable energy in Russia in terms of actual power generation, it is generation from renewable sources that showed the highest growth rate of 73.5%, with overall production growth of 6.4% in 2021, nevertheless accounting for a small share in the structure of power generation (Table 6):

Table 6. Electricity balance of UES of Russia in 2021, billion kWh, %

	December 2021	% to December 2020	January - December 2021	% to January-December 2020
consumption	107,6	4,2	1090,4	5,5
production, incl.	110,0	4,9	1114,5	6,4
thermal power plants	65,5	8,2	609,2	9,9
hydraulic power plants	16,7	-2,6	209,5	1,0
nuclear power plants	21,0	1,2	22262	3,1
industrial plants	6,3	1,2	67,7	1,9
RES	0,5	150,0	5,9	73,5

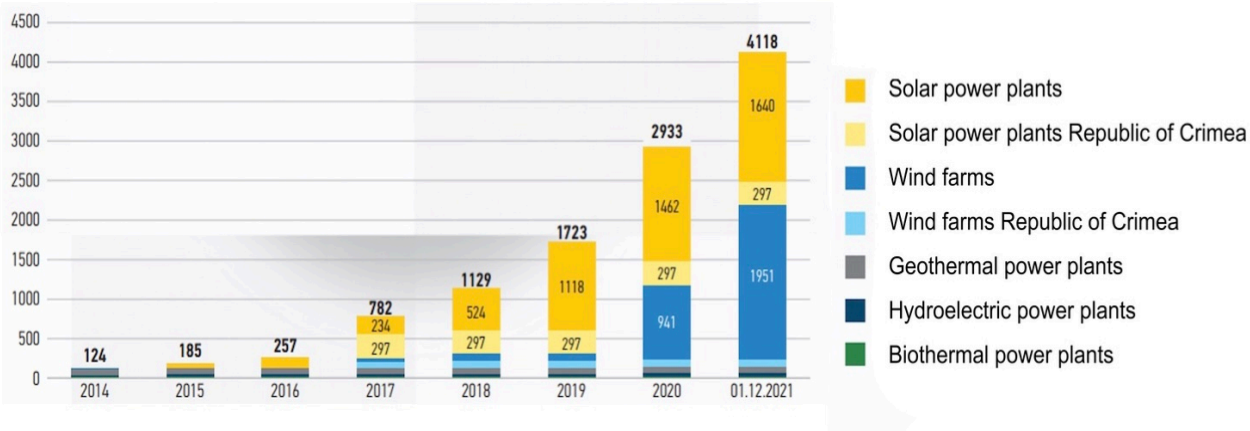
Source: Development of renewable energy against the backdrop of energy crises / Analytical Center under the Government of the Russian Federation. Energy Trends. № 104. January 2022. Downloaded from: https://ac.gov.ru/uploads/2-Publications/energo/2022/energo_104.pdf

In 2019, the Russian Federation reaffirmed its commitment to its obligations under the Paris Agreement on Climate Change by adopting the relevant government resolution (Garant, 2019), after which the country significantly intensified its work on combating climate change in general, as well as on the development of affordable and environmentally friendly energy sources. It is important to note that many experts saw these changes as infringing on the interests of energy-producing countries, while deliberately ignoring such parameters of sustainable development as providing access to reliable and cheap energy supply, the development of clean hydrocarbon technologies, etc. (Mastepanov, 2022)

This led to their reflection as risks to Russia's energy security in the corresponding Doctrine of Energy Security, which was also approved in 2019 by Presidential Decree (Garant, 2019), as well as in the Energy Strategy of the Russian Federation until 2035, which was approved by the Russian Government in 2020 (Consultant, 2020). This was followed by a series of other normative legal acts aimed at clarifying plans and measures to achieve the goals and objectives set forth in the above documents.

As discussed above, 2021 was one of the most landmark years in the history of renewable energy development in Russia, both in terms of the adoption of important regulations and the development of new support programs, and in terms of commissioning new generation facilities, the structure of which is shown in Figure 30:

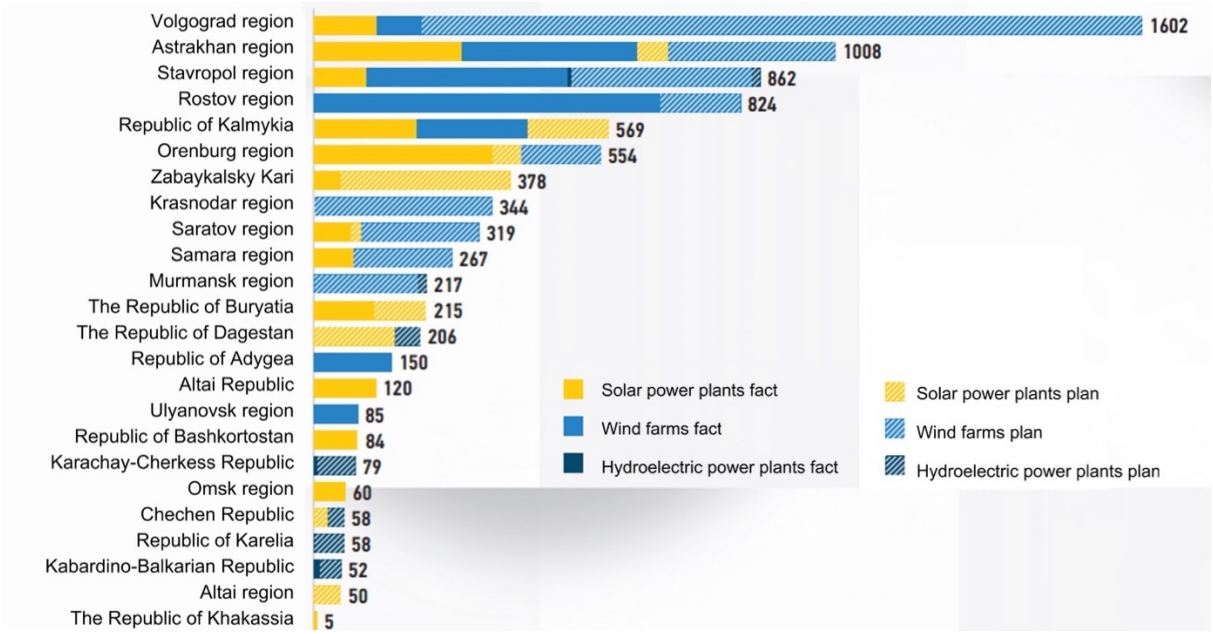
Figure 30. Installed capacity structure of RES-based power plants in Russia by power plant type in 2014-2021, MW



Source: The future of renewable energy in Russia / Renewable Energy Development Association. 2021. Downloaded from: https://rreda.ru/information-booklet-december-2021/

In terms of regional distribution of existing solar power plants, Astrakhan and Orenburg regions are the leaders in Russia. In the near future, Zabaykalsky Krai and the Republic of Kalmykia will join the group of leaders. Rostov, Astrakhan and Stavropol regions are leading in terms of wind generation development, and the Volgograd region will join them soon (Figure 31):

Figure 31. Actual and planned structure of the regional distribution of renewable energy projects in Russia in 2021, MW



Source: The future of renewable energy in Russia / Renewable Energy Development Association. 2021. Downloaded from: https://rreda.ru/information-booklet-december-2021/

As can be seen from the presented graph, wind and solar generation are actively developing in those regions where there is correspondingly high solar and wind activity, while hydroelectric power plants are being prepared for commissioning in such regions as the Kabardino-Balkar Republic, the Republic of Karelia, etc.

If we consider plans for the further development of renewable energy in the Russian Federation, the Renewable Energy Development Program, designed until 2024, is still under revision (Table 7):

Table 7. Current targets for commissioning of installed capacity of generating facilities based on renewables, MW

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	total
WPP	-	51	50	200	400	500	500	500	500	500	214,7	3415,7
SPP	35,2	140	199	250	270	270	270	162,6	162,6	240	238,6	2238
mini-HPP	-	-	-	20,7	-	49,8	16	24,9	33	23,8	41,8	210
total	35,2	191	249	470,7	670	819,8	786	687,5	695,6	763,8	495,1	5863,7

Source: Ministry of Energy of the Russian Federation / Renewable Energy Sources. Downloaded from: https://minenergo.gov.ru/node/489/ //.

If the current objectives in this area provide for the commissioning of the installed capacity of generating facilities based on renewable energy in 2014-2024 at 5.9 GW, the plans under discussion involve a significant increase in the number of renewable energy facilities scheduled for commissioning between 2023-2035, and their total capacity in 2023-2035 should be more than 6.7 GW (Minenergo, 2022).

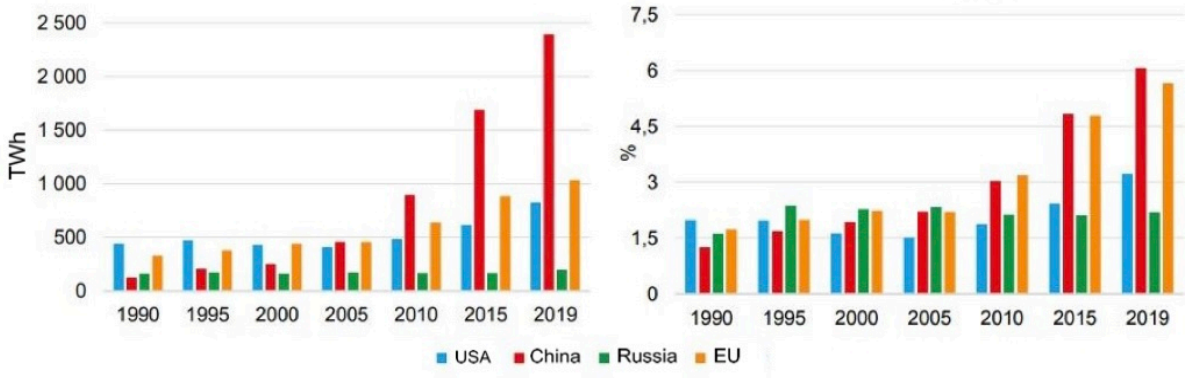
Thus, the development of renewable energy in the USSR and Russia over a long period of time was focused on increasing the volume of generation at hydroelectric power plants. At the same time, wind and solar generation received support and new impetus for development only since 2014-2015. By now, solar and wind generation accounts for less than 1 percent in the total capacity structure of Russia's unified power system, while hydro generation accounts for more than 20 percent. A more detailed comparison of renewable energy development in Russia and the U.S. will be discussed in the next paragraph of this chapter.

4 Results and Findings.

Comparison of renewable energy development in the Russian Federation and the USA

As discussed in previous chapters and paragraphs of this paper, the mainstreaming of the climate agenda has led to an energy transition trend in many developed and developing countries, including Russia and the United States. Both of these countries are lagging behind the leaders, China and the European Union, in both absolute and relative terms (Figure 32), in reducing their use of fossil fuels and introducing renewable energy:

Figure 32. Renewable energy production dynamics and the share of renewable energy in primary energy production in some countries of the world, 1990-2019, TWh, %



Source: Development of renewable energy against the backdrop of energy crises / Analytical Center under the Government of the Russian Federation. Energy Trends. № 104. January 2022. Downloaded from: https://ac.gov.ru/uploads/2-Publications/energo/2022/energo_104.pdf

As of the pre-crisis year of 2019, the U.S. was ahead of Russia both in terms of renewable energy production and the share of this type of generation in the overall structure of primary energy production. Between 2010 and 2019, the share of renewable energy generation in the U.S. increased by 71.3%. At the same time, experts point out that this growth could have been much higher if the Trump administration had not changed the government's course towards supporting the development of the coal and oil industries.

One of the key differences between the development of renewable energy in Russia and the U.S., of course, is the general period of development of these technologies and the implementation of state support measures. Thus, if they began to actively develop only in the last 5-10 years in Russia, in the United States the total period of development of these technologies has exceeded three decades, and according to some researchers even four decades, given that the first mechanisms to support and attract investment to the sector began to be

applied with the adoption of Energy Policy and Conservation Act, 1975. The Act for the first time provided incentives for wind power generation, and in 1978 the country adopted the Public Utility Regulatory Act, in which the state undertook to purchase energy from renewable sources and introduced 10% tax incentives for investment in renewable energy (Malikova, 2019)

It is important to note that U.S. policy now provides for various forms of RES support, which exist at both the local and federal levels. But many of them are coming to an end. For example, the U.S. government has already repeatedly extended the validity of regulations aimed at subsidizing investments in green energy, including the Investment Tax Credit and Renewable Energy Production Tax Credit, introduced back in 1992. These acts have been repeatedly amended, extended and expanded, but will soon be terminated. President Joseph Biden's plan calls for new tax credits and incentives that will not only continue the development of renewable energy infrastructure, but also create more than 600,000 new jobs. Nevertheless, this project could become a significant burden on the U.S. budget, and lead to an investment crisis in the industry if it is not adopted (Investing, 2021)

Russia also has a system of tax and non-tax incentives for renewable energy development. However, their quantity and quality are clearly insufficient to achieve the ambitious plans under consideration, which requires bringing the RES support system in line with these plans when considering a new Renewable Energy Development Program. The U.S. experience in stimulating the industry may be of some interest to the Russian authorities, as well as the experience of the EU countries and China.

It is because of the lack of significant public policy measures aimed at accelerating the introduction of renewable energy technologies and energy transition, Russia lags behind China, EU countries and the United States in the development of the industry, while the leading countries are actively using a set of mechanisms such as tax incentives, special investment programs, subsidies, carbon trading mechanisms, etc. For example, while the EU in 2021 has already approved the first cross-border system of carbon regulation, Russia only discusses such tools in the formation of strategies for long-term development.

It is important to note that Russia and India are only two exceptions among the top 10 countries in terms of GDP at PPP, which have not yet established their own plans and timetable for the transition to carbon neutrality (Table 8):

Table 8. National plans for achieving carbon neutrality in the world's top 10 economies

country	GDP at PPP 2020, trillion USD	deadline for transition to carbon neutrality	law enshrining carbon neutrality goal	plan or program for transition to carbon neutrality
China	24,27	2060	-	-
USA	20,94	2050	-	Biden Plan for a Clean Energy Revolution & Environmental Justice
India	8,91	-	-	-
Japan	5,33	2050	Law Concerning the Promotion of the Measures to Cope with Global Warming	Green Growth Strategy Through Achieving Carbon Neutrality in 2050
Germany	4,47	2045	Climate Protection Act 2019	Climate Action Plan 2050
Russia	4,13	-	-	-
Indonesia	3,30	2060	-	-
Brazil	3,15	2060	-	-
France	3,12	2050	Law on Climate and Energy 2019	National Low-Carbon Strategy
UK	3,02	2050	Climate Change Act	Ten Point Plan for a Green Industrial Revolution
EU	19,69	2050	European Climate Law 2021	EU Green Deal 2019

Source: Lanshina, T. (2021). The transition of the world's largest economies to carbon neutrality: areas of potential cooperation with Russia. *Bulletin of international organizations: education, science, new economy*, Vol. 16, 4, P. 98-125.

The United States, unlike Russia, has designated 2050 as the deadline for its transition to carbon neutrality, while the development of renewable energy and other types of carbon-neutral energy is currently under way in accordance with the President's plan.

In addition to differences in the timing of renewable energy development, diversity, and amount of government support, significant differences can also be observed in the structure of energy generation in Russia and the United States:

- Wind and solar power plants in the U.S. account for about 70% of total renewable energy generation;
- Hydropower plants in Russia account for 98.6% of total generation, with a minimal share of wind and solar plants (ac.gov, 2022)

These differences are due both to the peculiarities of the territories and weather and climate specifics, and to government policies, including those related to limiting the development of hydropower due to the indirect negative impact of hydropower construction on the biosphere.

According to the generalized data of such authoritative international agencies as the IEA, the International Nuclear Association (INA) and the International Renewable Energy Agency (IREA), solar and wind power plants have the lowest average life cycle estimates among all types of power plants, about 25 years, while the life cycle of nuclear power plants can reach 60 years, and hydroelectric power plants - up to 80 (Table 9).

At the same time, wind and solar power plants have some of the lowest payback rates, which makes them attractive for business. And, as a result, they will continue to increase the amount of waste to be disposed of, combined with a short life cycle.

Table 9. Average estimates of the key indicators of power plants by type of energy source

	coal plant	gas plant	nuclear power plant	solar power plant	windmill	hydroelectric power plant

life cycle, years	40	30	60	25	25	80
lifecycle emissions, grams CO2 / kWh	751-1095	403-513	5,1-6,4	8-83	7,8-23	6-147
present value of electricity, cents / kWh	80-90	60-70	50-60	60-120	50-130	50-70
adjusted present value of electricity, cents / kWh	62	39	50	81	55-85	55
payback period, years	1-2	2,5	6,5	1-4	0,5-1,4	6

Source: Development of renewable energy against the backdrop of energy crises / Analytical Center under the Government of the Russian Federation. Energy Trends. № 104. January 2022. Downloaded from: https://ac.gov.ru/uploads/2-Publications/energo/2022/energo_104.pdf/

Thus, the longer life cycle of hydropower plants provides the Russian Federation with an advantage in terms of the long-term use of available renewable energy capacity, while the United States considers the shorter payback period of solar and wind power plants as a key advantage.

In terms of the implementation of U.S. approaches to assessing the benefits of certain types of generation based on renewable energy, we can identify the Russian transition from using the principle of minimizing the declared costs of the investor when considering projects in the field of renewable energy to the principle of maximizing the comprehensive performance indicators of these projects. In addition, import substitution is an important direction of change in approaches to the development of renewable energy in Russia, as well as in the U.S. At the same time, in addition to reducing Moscow's dependence on supplies of rare earth metals from the United States, the country is changing its requirements for the localization of components of power equipment. Table 10. presents targets in this area until 2024:

Table 10. Targets for the degree of localization of RES-based generation facilities in Russia by 2024

types of generating facilities	year of commissioning	target index of localization, %

generating facilities based on photovoltaic conversion of wind energy	2020-2024	65
generating facilities based on photovoltaic conversion of solar energy	2020-2024	70
generating facilities with installed capacity of less than 25 MW based on water energy	2020-2024	65

Source: Ministry of Energy of the Russian Federation / Renewable Energy Sources. Downloaded from: https://minenergo.gov.ru/node/489/

Although the active development of solar and wind power generation in Russia can be observed only in the last few years, and about 55% of the total resources used in the country for power generation are natural gas, another 25% is produced by hydroelectric and nuclear power plants, this allows us to maintain a fairly low level of specific CO2 emissions. To date, Russia's level is about 250 grams CO2/kWh, which is comparable with EU averages (230 g CO2/kWh) and well below the global average (440 g CO2/kWh), China (540 g CO2/kWh) and the United States (400 g CO2/kWh) (Veselov, 2021)

To summarize, despite the relatively short development of wind and solar generation, the key difference and advantage of using renewable energy sources in Russia is the widespread use of hydroelectric generation. Hydropower plants have a long-life cycle and do not require significant investments in recycling, which are required for the disposal of waste wind and solar plants. The development of hydropower has also allowed Russia to provide a much lower level of specific CO2 emissions compared to the United States. Nevertheless, the further development of renewable energy in Russia is inextricably linked with the introduction of modern solar and wind power plants, which requires a higher level of import substitution, as well as the introduction of a comprehensive system to support the industry. The experience of tax and non-tax incentives for renewable energy in the United States can be used for this purpose.

5 Discussion and Conclusion

The analysis of the current state and key trends in the development of the global fuel and energy complex as a complex inter-industry system, which includes the fuel industry and electric

power industry, allows us to highlight the continuing growth of the global population with increasing prosperity in most developing countries, as well as accelerating innovation processes that allow enhancing productivity in this sector as key positive factors for the activities of fuel and energy companies. At the same time, the main negative factor that affects the activities and financial performance of companies of the fuel and energy complex is the global economic crisis, which sometimes entails a decrease in demand and prices for energy resources. In particular, one could observe a sharp drop in demand and prices for oil during the first phase of the corona crisis during 2020-2021, with a faster recovery of global industrial production in the 2nd half of 2021. This led to an increase in demand and prices for energy resources and their shortages in some regions of the world.

Despite the crisis phenomena in the global economy, the renewable energy sector was the only one in the industry in 2020 that showed growth compared to pre-crisis 2019, and its share in global energy generation rose from 23.2% to an all-time high of 28.6%. China, the U.S. and Brazil are leaders in the development of renewable energy in the world. According to experts, it is China and other countries of the Asia-Pacific region, including India, that will act as leaders in terms of further introduction of renewable energy facilities in the near future.

The study of the experience of American innovative development in the field of fuel and energy complex allows us to state a high level of efficiency, starting from the launch of the first oil rig in the USA in 1859 to the transition of the country from a major importer of oil and natural gas to an exporter over the past two decades. This was largely due to the introduction and development of hydraulic fracturing technology, growth of shale gas and oil production, and the production and sale of LNG.

The U.S. is behind China and the EU countries in the level of renewable energy development, ranking third in the world in terms of volume and growth of energy generation from renewable energy sources. The determining factor for the development of this sector is the energy policy of the authorities, which has undergone radical changes over the past decade due to changes in the ruling party and president in the country. In addition, important factors affecting the development of renewable energy include significant climate change, the growth of domestic climate migration, climate business risks, as well as the use of the climate factor in the construction of U.S. foreign policy, including confrontation with China. The development of the sector is also negatively affected by the disruption of supply chains and the rising cost of components and materials required to produce wind turbines and solar panels. These problems

were clearly manifested during the 2020-2021 crisis and have now become even more pronounced due to the current geopolitical situation.

The analysis of practices and challenges of renewable energy development in the U.S. has shown that to date, this area is considered by the authorities as the key to ensure the implementation of plans to achieve zero net greenhouse gas emissions in the period no later than 2050. If all the targets are met, renewable energy in the U.S. will surpass natural gas as the main source of electricity generation by 2030, and its share will increase from 21% in 2020 to 42% by 2050. However, these plans are subject to constant revision, as well as criticism from both the oil and gas sector and various environmental organizations, which raise questions about the instability of energy production from renewables, the growth of waste when decommissioning wind and solar power plants, and other related problems. The dependence of this sector on supplies of materials from China and Russia also poses objective risks to the implementation of the plans for the development of generation based on renewables in the United States.

Analysis of the development of renewable energy in Russia showed that historically, since Soviet times, it has been focused on the construction and operation of hydroelectric power plants, whose share in the total capacity structure of the unified energy system of Russia in 2021 was more than 20%. At the same time, wind and solar generation account for less than 1%, which is due to the relatively short period of development in this area, the active phase of which began in 2014-2015.

The high level of dependence on supplies of rare-earth metals from China is one of the common problems for Moscow and Washington in the development of renewable energy. At the same time, the U.S. is also dependent on supplies of certain metals from Russia, while the Russian energy industry as a whole depends on foreign innovative technologies in the field of renewable energy. This forces the authorities to take measures aimed at import substitution. The risks of disruption of existing supply chains have increased significantly in the current geopolitical conditions, which may negatively affect the plans already adopted and under development to develop the use of RES in both Russia and the United States.

6 References

6.1 Regulatory documents

1. Resolution of the Government of the Russian Federation of September, 21 2019 № 1228 "On the Adoption of the Paris Agreement". Downloaded from: https://www.garant.ru/products/ipo/prime/doc/72661694/

2. Decree of the Government of the Russian Federation of June, 6 2020 N 1523-r "On Approval of Energy Strategy of the Russian Federation until 2035". Downloaded from: http://www.consultant.ru/document/cons_doc_LAW_354840/feb387ba6cb412e94e5c4fd72de0228c1a68af25/

3. Decree of the President of Russia of May, 13 2019 N 216 "On Approval of the Doctrine of Energy Security of the Russian Federation". Downloaded from: https://base.garant.ru/72240884/

4. Biden-Harris Democrats (2020). The Biden Plan for a Clean Energy Revolution and Environmental Justice // Downloaded from: https://joebiden.com/climate-plan/

5. Biden-Harris Democrats (2021). The Biden Plan to Build a Modern, Sustainable Infrastructure and an Equitable Clean Energy Future // Downloaded from: https://joebiden.com/clean-energy

6. The White House (2021). Executive Order on Tackling the Climate Crisis at Home and Abroad. Presidential Act, 27 January // Downloaded from: https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/ executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/

6.2 Academic literature and monographs

7. Dementieva A., Sokolova M. (2018). Strategic Management of Global Business: Textbook. *Moscow: Magister, INFRA-M*, 608 pp.

8. Dementieva, A. (2018). Personnel Management: Textbook. *Moscow: Magister*, 352 pp.

9. Energy: management, quality and efficiency of energy resources use: Proceedings of the IX International Scientific and Technical Conference. (2019). *Blagoveshchensk: Amur State University*, 576 pp.

10. Evolution of world energy markets and its consequences for Russia. (2015). Ed. by A. Makarov, L. Grigoriev, T. Mitrova. *Moscow: Institute of Energy Research RAS-AC under the Government of the Russian Federation*, 400 pp.

11. Kavkaeva, N.. (2018). Fundamentals of economics and technology of the most important industries. *Moscow-Berlin: D-Media*, 236 pp.

12. Kulkov, V. (2022). Macroeconomics. 2nd ed. revised and extended. *Moscow: Publishing house Yurait*, 294 pp.

13. G. Rodina [et al]. (2022). Macroeconomics for managers. Edited by G. Rodina. 3-th ed., revised and extended. *Moscow: Publishing house Yurait*, 471 pp.

14. Musin M. (2019). Development of oil fields: a training manual. Ed. by A. Lipaev. - 2nd edition, revised and extended. *Moscow; Vologda: Infra-Engineering*, 329 pp.

15. Rugman, A. M. and Collinson, S. (2018). International Business (6th ed). *Harlow: Pearson*, 800 p.

16. The Shale Revolution and the Global Energy Transition. (2019). Ed. by N. Ivanov. *Moscow; St. Petersburg: Nestor-History*, 540 pp.

17. Zhuravleva, G., Gromyko, V., Zabelina, M.et al. (2019). Economic Theory: Microeconomics-1, 2, Mesoeconomics: Textbook Plekhanov Russian University of Economics. *9th ed., Moscow: Publishing and Trading Corporation "Dashkov and K°"*, 934 pp.

6.3 Journal articles

18. Koening, T. (2021). Global energy transition: challenges and opportunities - a perspective from North America. *Georesources*, Vol. 23, 3, P. 53-58.

19. Komar, S. (2021). Regulation and stimulation of renewable energy development in Russia and in the world. *Innovations. Science. Education*, 37, P. 249-256.

20. Lanshina, T. (2021). The transition of the world's largest economies to carbon neutrality: areas of potential cooperation with Russia. *Bulletin of international organizations: education, science, new economy*, Vol. 16, 4, P. 98-125.

21. Lukmanov, A. (2021). Evolution of views on the development of alternative energy sources. *Exploitation of marine transport*, 3(100), P. 127-134.

22. Lustgarten A. (2020). How climate migration will reshape America. *The New York Times Magazine*.

23. Lyzhin, D. (2021). Climate Policy of the USA: Problems and Prospects of Global Leadership. *Problems of National Strategy*, 3(66), P. 221-245.

24. Malikova O., Zlatnikova M. (2019). State policy in the development of renewable energy. *Public administration. Electronic Bulletin*, 72, P. 5-30.

25. Martynov V., Kucherov V., Bessel V., Lopatin A. (2022). Inorganic synthesis of oil as a factor of sustainable development of global energy. *Energy Policy*, 1(167), P. 20-29.

26. Mastepanov, A. (2022). Russia on the way to carbon neutrality. *Energy Policy*, 1(167), P. 94-108.

27. Matveev, V. (2021). The fight against climate change - a new arena of confrontation between China and the United States. *China in world and regional politics. History and Modernit*y, Vol. 26, 26, P. 337-351.

28. Mazlova, E., Smirnova, T., Bogdanov, O. (2018). Analysis of terminological component in the normative-legal base of FEC. *Competence*, 8(159). P. 6-12.

29. Stefanov R. (2018). Cybersecurity of Oil and Gas Assets. *Control Engineering Russia: Journal*, 4(76), P.72-76.

30. Turalina, A. (2021). Renewable Energy as an Innovative Factor in the Development of the World Economy. *Bulletin of Donetsk National University. Series B. Economics and Law*, 3, P. 309-316.

31. Veselov F., Solyanik. A., Urvantseva, L. (2021). Low-carbon restructuring of electric power industry in Russia until 2035: potential of reducing CO2 emissions and its "price" for the consumer. *Energy Policy*, 11(165). - P. 30-43.

32. World and Russian Energy Forecast. (2019). *Institute for Energy Research of the Russian Academy of Sciences, Center for Energy at Skolkovo Moscow School of Management, Moscow*, P. 210.

6.4 Internet publications

33. The future of renewable energy in Russia / Renewable Energy Development Association. 2021. Downloaded from: https://rreda.ru/information-booklet-december-2021/

34. The head of the U.S. Department of Energy told what would make the country "less vulnerable. Head of the U.S. Department of Energy Granholm: the country needs a transition from conventional fuels to clean energy. Downloaded from: https://ria.ru/20220401/energiya-1781190989.html

35. PJSC Rosneft Annual Report 2020 // Downloaded from: https://www.rosneft.ru/upload/site1/document_file/a_report_2020.pdf

36. Unified Energy System of Russia. Downloaded from: https://www.so-ups.ru/functioning/ees/ups2022/

37. If Biden's new plan is not accepted, a crisis awaits green energy // [Electronic resource]. – URL: https://ru.investing.com/analysis/article-200287901

38. Konoplyanik, A. American shale revolution: the consequences are irreversible // [Electronic resource] - URL: http://www.konoplyanik.ru/ru/publications/111Konoplyanik2014_05.pdf/

39. What the renewable energy sector is preparing for in 2022 // Downloaded from: https://www.eg-online.ru/news/449337/

40. Ministry of Energy of the Russian Federation / Renewable Energy Sources. Downloaded from: https://minenergo.gov.ru/node/489/ //.
41. New Vectors in U.S. Energy Policy / Energy Bulletin No. 92 of the Analytical Center under the Government of the Russian Federation // Downloaded from: https://ac.gov.ru/uploads/2-Publications/energo/energo1_jan2021.pdf
42. Nornickel has developed a contingency plan in case of tougher sanctions // Downloaded from: https://www.rbc.ru/business/12/03/2022/622c59459a794733d1f4a3fa/
43. Pentagon plans to increase reserves of lithium, cobalt, and rare earth metals // Downloaded from: https://tass.ru/ekonomika/13763979
44. The First Driller of the United States // Downloaded from: https://profile.ru/culture/item/116488-pervyj-burilshchik-ssha
45. Development of renewable energy against the backdrop of energy crises / Analytical Center under the Government of the Russian Federation. Energy Trends. № 104. January 2022. Downloaded from: https://ac.gov.ru/uploads/2-Publications/energo/2022/energo_104.pdf
46. Roginsky S. Equinor Energy Transition// Downloaded from: https://oilcapital.ru/article/general/25-12-2018/energeticheskiy-perehod-equinor/
47. Russian oil and gas Ccmpanies // https://investfunds.ru/analytics/251303/download/
48. Sechin, I. The World Energy Sector at a Crossroads. 2021 // Downloaded from: https://www.rosneft.ru/upload/site1/attach/0/14/02/SPIEF_slides_2021.pdf/
49. The shale revolution in the U.S. has come to an end // Downloaded from: https://expert.ru/2020/10/15/neft-ssha/
50. Shale Gas in Europe: Revolution or Evolution? // Downloaded from: https://www.hse.ru/data/2014/01/25/1326320349/Сланцевый%20газ.pdf
51. Shale gas: myths and reality // Downloaded from: https://magazine.neftegaz.ru/articles/aktualno/525992-slantsevyy-gaz-mify-i-realnost/ Date of reference:
52. Shale collapse: the U.S. will be the record-breaker in oil production decline // [Electronic resource]/: - URL: https://ria.ru/20200618/1573088126.html
53. U.S. announces plan to reduce dependence on Chinese exports of lithium and rare earth elements // Downloaded from: https://d-russia.ru/ssha-obnarodovali-plan-snizhenija-zavisimosti-ot-kitajskogo-jeksporta-litija-i-redkozemelnyh-jelementov.html
54. In 10 years RES will become the main source of electricity for the U.S. // Downloaded from: https://eenergy.media/2021/02/10/uzhe-cherez-10-let-vie-stanut-dlya-ssha-glavnym-istochnikom-elektrichestva/

55. The shale gas revolution is running out of cheap gas // Downloaded from: https://ria.ru/20200123/1563740979.html/
56. Fuel prices: between the market and regulation. Energy Bulletin No. 103 of the Analytical Center under the Government of the Russian Federation. December 2021. Downloaded from: https://ac.gov.ru/uploads/2-Publications/energo/2022/energo_103.pdf/
57. What threatens the export of Russian non-ferrous metals // Downloaded from: https://www.forbes.ru/mneniya/458511-cto-grozit-eksportu-rossijskih-cvetnyh-metallov/
58. Experts expect another record growth of RES capacity in the world // Downloaded from: https://1prime.ru/energy/20220127/835898837.html
59. Energy forecasts against the backdrop of the crisis. Energy Bulletin No. 90 of the Analytical Center under the Government of the Russian Federation. November 2020 // [Electronic resource] - URL: https://ac.gov.ru/uploads/2-Publications/energo/energo_november_2020.pdf
60. The era of cheap renewable energy sources has come to an end // Downloaded from: https://expert.ru/2022/01/26/era-vie/
61. CDP Scores // Carbon Disclosure Project. 2020 // Downloaded from: https://www.cdp.net/en/ scores/
62. Equinor: Sustainability report 2019 // Downloaded from: https://www.equinor.com/en/how-and-why/sustainability.html
63. Electricity Market Report - January 2022. Downloaded from: https://iea.blob.core.windows.net/assets/d75d928b-9448-4c9b-b13d-6a92145af5a3/ElectricityMarketReport_January2022.pdf
64. Explore energy data by category, indicator, country or region // Downloaded from: https://www.iea.org/data-and-statistics/data-browser?country=WORLD&fuel=Energy%20transition%20indicators&indicator=ETISharesInPowerGen
65. Hurricane Harvey Information and Resources // Morgan Stanley. 2020 // Downloaded from: https:// www.morganstanley.com/content/dam/msdotcom/en/assets/pdfs/hurricane-harvey-docs/ W1LA-Hurricane_Harvey_Information_and_Resources.pdf/
66. Lazard Levelized Cost of Energy Analysis. Version 13.0 // Downloaded from: https://hsto.org/webt/vh/9e/tw/vh9etwwvmr9_g2e426pthkzn0vo.png/
67. Presenting strategy to accelerate Equinor's transition // Downloaded from: https://www.equinor.com/news/archive/20210615-cmd-2021

68. Renewables 2021. Analysis and forecast to 2026 // Downloaded from: https://iea.blob.core.windows.net/assets/5ae32253-7409-4f9a-a91d-1493ffb9777a/Renewables2021-Analysisandforecastto2026.pdf/
69. Renewable Power // Downloaded from: https://www.iea.org/reports/renewable-power/
70. The Consequences of a Leasing and Development Ban on Federal Lands and Waters // American Petroleum Institute. 2020. September // Downloaded from: https://www.api.org/~/media/Files/News/2020/09/Consequences_of_a_Leasing_and_Development_Ban_on_Federal_Lands_and_Waters.pdf?utm_source=API_InformzEmail&utm_medium=Email&utm_campaign=Test/
71. Third National Climate Assessment Downloads & Materials // U.S. Global Change Research Program. 2017. Fourth National Climate Assessment // Ibid. 2018. // Downloaded from: https://www.globalchange.gov/nca3-downloads-materials; Fourth National Climate Assessment; : https://nca2018.globalchange.gov/
72. Top 250 Companies 2020 // Downloaded from: https://top250.platts.com/Top250Rankings
73. United States // Downloaded from: https://www.iea.org/countries/united-states/