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The Transition of the World's Largest Economies to Carbon Neutrality: Areas of Potential Cooperation With Russia[1, 2]

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Abstract

In 2020, despite the global economic crisis caused by the COVID-19 pandemic, it became clear that decarbonization and energy transition had become strategic goals rather than market trends. Moreover, they have become part of the broader and more ambitious plans of the world's largest economies to move toward carbon neutrality by the middle of the 21st century. These economies include the European Union, the U.S., China, Japan and Korea.

In Russia, these trends are typically viewed through the prism of risk: carbon neutrality implies a dramatic decrease in demand for fossil fuels, the production and export of which still play a key role in the Russian economy. However, apart from the risk to traditional sources of income, the global transition to carbon neutrality creates new opportunities for the development and diversification of the Russian economy, as well as for international cooperation in new areas. This article is devoted to the general identification of such opportunities.

Key words: sustainable development goals (SDGs), Agenda 2030, renewable energy sources (RES), carbon neutrality, net zero emissions

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Introduction

Carbon neutrality has recently attracted considerable attention from the research community. According to the special Intergovernmental Panel on Climate Change (IPCC) report, Global Warming of 1.5°C, human activities have caused an increase in global temperature of 1.0°C compared to pre-industrial levels. To minimize climate-related risks, it is necessary limit this to no more than 1.5°C. To achieve this goal, greenhouse gas emissions should peak as quickly as possible, net global anthropogenic emissions should be reduced by 45% from 2010 levels by 2030, and a net-zero value should be reached by around 2050. Achieving and maintaining net-zero global anthropogenic emissions can stop anthropogenic global warming [IPCC, 2019].

Carbon neutrality, or net-zero anthropogenic emissions, is usually understood as a situation in which anthropogenic greenhouse gas emissions are balanced by their absorption [Chen, 2021]. Carbon neutrality can be achieved through a combination of two strategies: first, reducing emissions by a transition from fossil fuels to renewable energy sources (RES), improving energy efficiency, and changing production processes and consumer habits; second, absorbing greenhouse gases from the atmosphere, for example, through the protection and planting of forests and soil carbon sequestration. A drastic reduction in emissions is necessary since the current volume of global greenhouse gas emissions is almost four times higher than the volume of their absorption by natural sinks [C2ES, n. d.; Neier, Neyer, Radunksy, 2018].

After numerous pledges and commitments by the world's largest economies to transition to carbon neutrality by the middle of the century, researchers are trying to formulate the measures necessary to achieve this goal [Iqbal, 2021; Li et al., 2021; Safi et al., 2021; Wan et al., 2021]. The transition to net-zero anthropogenic emissions opens up significant opportunities for economic growth. These opportunities extend far beyond the so-called "low-carbon sector." In fact, in the coming decades, the entire global economy will transform. At the same time, demand for greener products will grow rapidly, and countries that take action to develop cleaner technologies, products and processes will be able to create new markets and enjoy significant economic benefits earlier than others [Stern, Valero, 2021].

Russia is not yet among the leaders of the global transition to climate neutrality. Moreover, it is one of the few large economies in the world that has not yet set a goal of achieving zero net emissions by the middle of the century and has not yet developed appropriate strategic documents. Considering that the decisions on the transition to climate neutrality have already been made or are about to be made by most countries of the world, including both developed and developing economies, Russia faces the threat of losing its export markets and, consequently, confronts the possibility of a large-scale economic crisis. To identify industries that will grow the most in the world's largest economies as they transition to carbon neutrality, the purpose of this article is, first, to analyze the strategic documents of the respective countries and then formulate their low-carbon sectoral priorities. This is followed by an examination of the level of development of the relevant economic sectors in Russia. Finally, recommendations for transforming the Russian economy are developed and areas that are promising for propelling international economic cooperation are identified, taking into account the emerging global changes.

Plans of the World's Largest Economies to Achieve Climate Neutrality

An increasing number of countries have declared their intention to achieve net-zero emissions by the middle of the century. As of June 2021, 132 countries and the European Union (EU) have discussed or adopted a climate neutrality goal; of these 90 were in the discussion stage,

26 had included a carbon neutrality goal in their strategic documents, four were considering the possibility of adopting laws that would make the achievement of net-zero emissions mandatory, 10 more and the EU had already adopted such laws, and two countries (Suriname and Bhutan) had achieved climate neutrality [Energy & Climate Intelligence Unit, 2021a]. As of March 2021, countries that had made or were discussing a commitment to net-zero emissions accounted for 61% of global greenhouse gas emissions, 68% of gross domestic product (GDP), and 56% of the world's population [Black et al., 2021].

Among the countries in the top 10 in terms of GDP calculated at purchasing power parity (PPP), only two countries – India and Russia – have not yet set a timeline for the transition to carbon neutrality (Table 1). Four out of the 10 largest economies and the EU have set a legally binding goal of carbon neutrality. Five out of the 10 largest economies and the EU have already started to develop plans or programmes for such a transition. The absence of a goal for achieving carbon neutrality and a corresponding strategy in Russia creates risks of a worsening economic situation and a decline in living standards in the country in the coming decades.

Table 1. National Plans to Achieve Carbon Neutrality in the Top 10 Economies of the World and the EU

Country	GDP by PPP in 2020, $ Trillions	Timeline for the Transition to Carbon Neutrality	Carbon Neutrality in the Law	Plan or Strategy for the Carbon Neutrality Transition
China	24.27	2060	–	–
United States	20.94	2050	–	The Biden plan for a clean energy revolution and environmental justice
India	8.91	–	–	–
Japan	5.33	2050	The Act on Promotion of Global Warming Countermeasures	The Green Growth Strategy Through Achieving Carbon Neutrality by 2050
Germany	4.47	2045	The Climate Change Act	The Climate Action Programme 2030
Russian Federation	4.13	–	–	–
Indonesia	3.30	2060	–	–
Brazil	3.15	2060	–	–
France	3.12	2050	The Energy and Climate Law (2019)	The National Low-Carbon Strategy
United Kingdom	3.02	2050	The Climate Change Act	The Ten Point Plan for a Green Industrial Revolution
EU	19.69	2050	The European Climate Law (2021)	The European Green Deal (2019)

Source: Compiled by the authors based on ECIU [2021], WB [2021], and other open sources.

The European Union

The European Green Deal, adopted by the European Commission in 2019, set the EU's goal of transition to climate neutrality by 2050. At the end of 2020, the European Council approved a mandatory EU target for a net domestic reduction in greenhouse gas emissions of at least 55% by 2030 compared to 1990 [European Council, 2020]. Previously, it was planned that emissions would be reduced by 40% by 2030. On 24 June 2021, the European Climate Law was adopted, which legislated the goal of achieving carbon neutrality by 2050 and established the European Scientific Advisory Council on Climate Change, which will provide independent scientific advisory support and publish reports on the realization of the European Climate Law and the implementation of the EU's international obligations under the Paris Agreement [European Council, 2021].

For a fair transition to a green economy, the European Commission developed a set of measures related to energy, industry, consumption, infrastructure, transport, and agriculture, as well as taxation and provision of benefits. Improving energy efficiency, developing renewable energy sources and phasing out fossil fuels will play a critical role in the implementation of the European Green Deal. Reducing greenhouse gas emissions in the energy system will be of prior importance since the production and use of energy in various sectors accounts for more than 75% of all greenhouse gas emissions in the EU [Eurostat, 2021]. In 2020, solar and wind energy alone produced 19.6% of the EU's electricity. The share of coal in electricity generation in the EU fell from 25% in 2015 to 13% in 2020 [Ember, 2021]. In the future, RES will become the basis of the entire EU energy sector. An important part of the European Green Deal is the energy transition in the transport sector, as well as in the heating/cooling sector, in which progress is still significantly slower than in the electricity sector. To achieve the goal of the European Green Deal, it is necessary to reduce greenhouse gas emissions in the transport sector by 90% through the modernization of road, rail, water, and air transport. A significant proportion of road freight transport (75%) should be transferred to rail and inland waterways [EC, 2019]. Large-scale electrification of road transport is planned. By 2035, the EU will ban the sale of cars with internal combustion engines (ICE) [EC, 2021]. Buildings account for about 40% of energy consumption in EU countries [EC, 2019]. To reduce greenhouse gas emissions from buildings, a large-scale renovation is planned. Energy efficiency renovations will primarily affect the poorest households, schools, and hospitals.

The EU's industrial sector accounts for about 20% of all greenhouse gas emissions. European industrial companies have already begun to shift toward a circular economy, but so far only 12% of raw materials in the EU are recycled materials [EC, 2019]. In May 2021, the European industrial sector received an updated strategy that has three main priorities: environmental friendliness, digitalization, and competitiveness. The most energy-intensive industries, such as steel, chemicals, and cement production, will modernize first. The strategy provides for a transition to a new business model with the introduction of technologies for the reuse of materials for production, increasing responsibility of producers, sharing of goods and services, and expanding opportunities and participation of consumers. In addition to energy-intensive industries, priority will be given to resource-intensive industries such as construction, electronics, textiles, and plastics production. The environmental policy in the field of production will also touch upon the problems of waste generation and disposal, which will require legislative approval of new targets and measures, including the expansion of the market for secondary raw materials and the use of environmentally friendly primary raw materials. Digital technologies will play an important role in this transition, allowing for optimal use of energy resources, as well as innovative technologies in key industries.

In addition, the European Green Deal contains plans to solve the problems of ecosystems and biodiversity as well as air pollution. For example, concerning biodiversity, the proposals relate to extending the coverage of protected areas on land and at sea and for restoring damaged ecosystems, including carbon-rich ecosystems [EC, 2019].

Germany

Germany's path to carbon neutrality is enshrined in the 2019 Climate Protection Act [Federal Office of Justice of the FRG, 2019]. Germany is one of the few EU countries that have legislated the transition to a carbon neutral economy. In April 2021, Germany's Federal Constitutional Court made a historic decision that, because the country's key climate law does not detail the goals of reducing greenhouse gas emissions after 2030, it is insufficient to rapidly reduce emissions [Federal Constitutional Court, 2021]. Subsequently, an updated version of the Climate Protection Act was developed and approved by the German government in May 2021. According to the updated version, by 2030, greenhouse gas emissions should be reduced, not by 55% as previously planned, but by 65%; moreover, they should be reduced by 88% compared to the 1990 level by 2040. Climate neutrality must be achieved by 2045. The German federal parliament adopted these amendments on 24 June 2021 [Federal Government of the FRG, 2021].

To fulfil the objectives of the Climate Protection Act, in 2019 the Climate Action Programme 2030 was developed [Federal Government of the FRG, 2019]. A key element of this programme was the introduction of a carbon price for the transport and heating sectors from 2021, in addition to the EU emissions trading scheme. The proceeds from this mechanism will be directed to the green sectors of the German economy. The programme provides tax incentives to improve energy efficiency in buildings and replace old fossil-fuelled central heating systems with new, more environmentally friendly ones, or those running on RES. By 2030, RES will provide 65% of the country's electricity needs. In 2020, 50.5% of all German electricity was produced using RES, including 10.5% using solar photovoltaic (PV) energy and 27.0% using wind energy [Fraunhofer ISE, 2021]. All coal-fired power plants in Germany will be closed by 2038. In the transport sector, electrification, the use of railways, and public transport will be encouraged. By 2030, the German network of electric charging stations will reach 1 million units. There are also plans to introduce RES in industrial processes, develop hydrogen energy, and produce energy storage devices and technologies for storing and using CO_2. In the agricultural and forestry sectors, priority will be given to organic farming, waste reduction, and sustainable forest management. Following the amendments to the Climate Protection Act, another programme was adopted aimed at achieving Germany's climate neutrality by 2045, the Immediate Action Programme for 2022 [Federal Ministry of Finance of the FRG, 2021]. The programme prioritizes the reduction of greenhouse gas emissions in the industrial sector (using hydrogen in the steel industry for green steel production and stimulating investment in the chemical industry), energy (energy transition in thermal energy and green hydrogen production), and buildings.

France

On 8 November 2019, France adopted the Energy and Climate Law, which requires a transition to carbon neutrality by 2050 [Law No 2019-1147, 2019]. According to the law, climate neutrality will be achieved through more than sixfold reductions in greenhouse gas emissions. The law envisages the closure of the last coal mines by 2022, a 40% reduction in fossil fuel consumption by 2030 compared to 2012, a reduction in the share of nuclear energy in the electricity

sector to 50% (currently 70%), stimulation of the development of offshore wind energy, covering with solar panels at least 30% of the roof surfaces of new warehouses, supermarkets, and parking lot canopies. Much attention is paid to improving the energy efficiency of buildings, in particular, through mandatory energy audits for residential premises leased or offered for sale and a ban on rent increases for non-energy efficient residential premises.

In 2020, to make France carbon neutral, the National Low-Carbon Strategy, first adopted in 2015, was revised [Ministry of Ecological Transition, 2020]. According to the strategy, by 2050, the French energy sector will be completely carbon-free. Due to the developed nuclear energy sector, the share of fossil fuels in the French electric power sector is already low – 9% in 2019 [IEA, 2021a]. The transport sector, excluding domestic air transport, will be completely decarbonized by 2050 through electrification and a switch to hydrogen fuel, traffic management, and the promotion of public transport. Significant increases in the energy efficiency of buildings, including through the renovation of 500 thousand houses per year, is also planned. Emissions from the industrial sector will be reduced by 81% by 2050 due to the introduction of renewable energy technologies and energy efficiency, the management of raw materials flows, the introduction of elements of a circular economy, and research and development (R&D) in the field of low-carbon production processes. Measures are also planned for agriculture and forestry (development of agroecology and agroforestry, minimizing the use of nitrogen fertilizers, carbon sequestration in agricultural soils, and sustainable forestry) and the waste management sector (waste reduction, reuse, and recycling).

United Kingdom

In 2019, the UK passed a law mandating net-zero emissions by 2050 through amendments to the 2008 Climate Change Act [The Climate Change Act, 2019]. Originally, the law provided for an 80% reduction in greenhouse gas emissions by 2050 compared to 1990.

In November 2020, British prime minister Boris Johnson presented the Ten Point Plan for a Green Industrial Revolution [Gov.UK, 2021]. The plan aims to rebuild the economy after the pandemic, create 250,000 green jobs by 2030, and accelerate the transition to net-zero emissions. The plan provides for the development of offshore wind energy, the production of low-carbon hydrogen, the development of nuclear energy, the transition to zero-emission transport, the stimulation of green public transport, air and water transport with zero emissions, green construction, the attraction of investments in carbon capture, use and storage, protection of natural ecosystems, and fostering green finance and innovation. The UK is already a global leader in offshore wind energy. It plans to quadruple the capacity of offshore wind farms by 2030.

Over the past five years, the UK has practically abandoned coal-fired power generation: in 2015, British coal-fired thermal power plants produced 23% of all electricity in the country, in 2020 – less than 2%. The transition was mainly due to the rapid development of renewable energy; the share of electricity production from wind and solar energy in the country increased from 14% in 2015 to 29% in 2020 [Ember, 2021]. By 2024, the UK will decommission all coal-fired power plants. From 2030, the UK plans to introduce a ban on the sale of new cars with internal combustion engines.

United States

The United States does not yet have a law making the transition to carbon neutrality a legally binding goal, but this goal is already part of some strategic documents. For example, on

27 January 2021, U.S. president Joe Biden signed the Executive Order on Tackling the Climate Crisis at Home and Abroad [The White House, 2021], according to which the climate crisis should be at the centre of the U.S. international and national security policy and the U.S. must achieve net-zero emissions no later than 2050.

Also, the goal of achieving net-zero greenhouse gas emissions by 2050 is present in President Biden's plan for a clean energy revolution and environmental justice [Biden-Harris Democrats, 2020]. The plan calls for a 100% clean energy transition by 2050. On 1 April 2021, Biden presented his plan to renovate infrastructure and industry. According to it, a complete transition to clean energy should be carried out by 2035 [Biden-Harris Democrats, 2021]. Nuclear and renewable energy currently produce 38% of all electricity in the country.

The U.S. has traditionally been a leader in R&D and innovation. Biden's 2020 plan [Biden-Harris Democrats, 2020] provides for the creation of the Advanced Research Projects Agency-Climate (ARPA-C), a new interdepartmental agency that will focus on research in the following areas: small modular nuclear reactors, cooling and air conditioning using refrigerants, buildings with zero clean energy consumption, hydrogen production from renewable energy sources at competitive prices, obtaining carbon-free industrial heat required for the production of steel, concrete, and chemicals, production of carbon-neutral building materials, decarbonization of the food and agricultural sectors, capturing and storing carbon in the soil, and capturing carbon dioxide from the exhaust gases of power plants to store it deep underground or use it for industrial purposes. This department will be created by analogy with the Advanced Research Projects Agency-Energy (ARPA-E) and the Defense Advanced Research Projects Agency (DARPA).

In addition to clean energy, U.S. plans for the transition to carbon neutrality include the development of electric transport, improving the energy efficiency of buildings (reducing the carbon footprint of buildings by 50% by 2035), improving agricultural practices, and introducing low-carbon technologies in the manufacturing sector.

Japan

The first announcement of Japan's intention to move toward carbon neutrality by 2050 was made by Prime Minister Suga Yoshihide in October 2020. Before that, Japan had planned to cut greenhouse gas emissions by 80% by 2050. The goal of achieving carbon neutrality was fixed at the legislative level through amendments to the Act on Promotion of Global Warming Countermeasures [2021].

In December 2020, Japan presented the Green Growth Strategy Through Achieving Carbon Neutrality by 2050 [METI, n. d.]. The strategy contains industrial policy measures and sets out the goal to achieve positive economic growth while ensuring environmental protection. The document identified 14 sectors in which transformations are needed and also set a target for the share of RES in electricity production at the level of 50–60%. The strategy provides for the electrification of industry and transport, the active development of offshore wind energy and energy storage, low-carbon hydrogen fuel, nuclear energy (including safer, next-generation reactors), as well as carbon capture, storage, and use technologies (CCUS) due to Japan's heavy dependence on fossil fuels. In particular, actions are planned in such difficult sectors for decarbonization as water transport, aviation, and cargo transportation. In addition, the strategy involves the introduction of sustainable agricultural, forestry, and fishery practices and the development of a circular economy. The document provides for R&D with the state (state fund with a capital of 2 trillion yen) and private financing, the implementation of demonstration projects, and the commercialization of new low-carbon technologies.

The main source of greenhouse gas emissions in Japan is the electric power sector, which accounts for more than half of all emissions in the country, and which is more than 70% dependent on fossil fuels [Nakano, 2020]. Currently, Japan is implementing its fifth energy baseline plan, adopted in 2018. According to this plan, by 2030 the share of RES in electricity production will be 22–24%, the share of nuclear energy – 20–22%, and the share of coal and gas – 63%. In addition, the fifth plan includes targets for energy conservation, hydrogen energy, energy storage, and the implementation of decentralized energy systems. The sixth basic energy plan will be adopted in the summer of 2021. The nuclear energy target is expected to remain the same, while the renewable energy target will almost double to 35–39% by 2030, by reducing the use of fossil fuels.

China

China has not yet presented a long-term strategy for achieving net-zero emissions, but in September 2020, at the United Nations (UN) General Assembly, Chinese president Xi Jinping announced his intention to move toward net-zero greenhouse gas emissions by 2060 [FMPRC, 2020]. China accounts for nearly 30% of the world's total greenhouse gas emissions [C2ES, n. d.]. According to the International Energy Agency (IEA), in 2018, China's greenhouse gas emissions had increased by 356% compared to 1990, showing a slight decrease only in the period from 2013–16, after which growth resumed [IEA, 2021e].

In China, since 1953, the main goals and directions of the country's socio-economic development have been planned for five years. Policy within the 13th Five-Year Plan (2016–20) was largely determined by the Paris Climate Agreement, which China joined in 2016. The goals of the plan for energy included reducing the share of coal in primary energy consumption to at least 58% by 2020, compared to 64% in 2015, mainly due to the large-scale development of RES. The goal was achieved – by the end of 2020, the value of this indicator was 56.8% [Reuters, 2021]. The plan also set a limit on the total capacity of coal-fired power plants at 1,100 GW in 2020, but this limit was exceeded already in 2019. This suggests that coal will continue to be China's largest source of electricity in the near term.

China's coal policy is driven by both environmental and economic priorities, that is, inefficient use of coal is primarily reduced by closing down old power plants and small coal-fired boilers that combust coal in an inefficient manner. The rest of the coal-fired power plants are equipped with technologies for cleaning coal before combustion. Reducing the use of coal at the household level is also a priority policy area due to the large number of households using coal for heating and domestic needs.

China, being a leader in the use of fossil fuels, is at the same time a world leader in the field of renewable energy. In 2020, 10% of Chinese electricity was produced using only solar PV and wind energy [Ember, 2021]. Most of the top 10 manufacturers of solar PV panels and wind turbines are Chinese companies. The share of all RES in electricity generation in China is over one quarter.

In March 2021, the Chinese government presented the main provisions of the 14th Five-Year Plan (2021–25). The new plan provides for an increase in the share of non-fossil fuels in the total energy consumption to 20% by 2025, an increase of 40% in the installed capacity of nuclear power plants, and a decrease in the energy intensity of GDP by 13.5%. Compared to China's 13th Five-Year Plan, the new plan does not look ambitious. The new plan also does not contain targets for reducing coal capacities and allows the building of new coal-fired power plants and an increase in the consumption of oil, coal, and natural gas. This approach is conservative and insufficient to achieve carbon neutrality by 2060.

Countries Without Strategic Documents for the Transition to Carbon Neutrality

In 2020, Brazil committed to the transition to carbon neutrality by 2060 but, in April 2021, President Jair Bolsonaro announced to bring this deadline forward to 2050. However, the transition to climate neutrality is still merely an intention, as it is not enshrined in any strategic documents or plans, and the possibility of bringing the date forward from 2060 to 2050 was contingent on attracting foreign aid in the amount of $10 billion a year to fight illegal logging of the Amazonian forests [Spring, Paraguassu, 2021]. Deforestation is the largest source of greenhouse gas emissions in Brazil due to, among other things, weak government policies to protect forests. In addition, the loss of Brazilian forests has been accelerating: in 2019, more than 1 million hectares of Amazonian forests were destroyed, which is 34% more than in 2018 and 120% more than in 2012 [Climate Action Tracker, 2020].

Brazil's energy system is very different from the systems of other major economies due to the significant share of renewables in it – they account for about 45% of primary energy consumption and more than 80% of electricity production. The basis of renewable energy in the country is hydropower (accounting for over 60% of all electricity production), as well as biomass and biofuels [IEA, 2021c]. Brazil's latest 10-year energy plan envisages that by 2029, the installed capacity of solar power plants will be 8.4 gigawatts (GW) and wind power plants – 24.4 GW [Climate Transparency, 2020]. In addition, while Brazil is expanding the use of bioethanol and biodiesel in the transport sector, there are no targets to phase out sales of cars with internal combustion engine vehicles in the country.

In March 2021, the Indonesian government announced its intention to achieve climate neutrality by 2070 – later this date was changed to 2060. However, this goal is not approved, and there are no strategic documents outlining plans to achieve it [Farand, 2021]. For Indonesia, the main challenge is the decarbonization of the energy sector, in which coal-fired generation plays a significant role. In addition, Indonesia is the largest exporter of coal by weight. In May 2021, there was a decision to stop the construction of new coal-fired power plants. The possibility of phasing out coal-fired generation by 2060 is being considered, given that coal currently provides 60% of the country's electricity production [IEA, 2021d]. It is also possible to introduce a carbon tax in Indonesia.

For India, the timeline for the transition to climate neutrality is still not determined. This is because a drastic reduction in greenhouse gas emissions could limit access to energy for the most vulnerable groups of the population. The country's rapid economic growth led to a sharp doubling in energy consumption during 2000–20. The country's energy balance is based on coal, which provided 44% of the primary energy demand in 2020 [IEA, 2021b]. The demand for coal in the country is likely to grow in the coming years, but India is also actively developing renewable energy and setting ambitious goals in this area. By 2030, India plans to quadruple the installed capacity of RES, up to 450 GW, including due to the competitiveness of solar energy.

For Russia, the timeline for the transition to climate neutrality has also not yet been determined, and there are no strategic documents outlining the implementation of such a goal. In 2018, fossil fuel combustion accounted for 79% of Russia's greenhouse gas emissions excluding land use, land use change, and forestry [UNFCCC, 2020]. Natural gas is the main source of energy consumed in Russia. The share of renewable energy sources in the electric power industry is about 18%, mainly due to hydroelectric power plants, the vast majority of which were built in the USSR. Solar and wind energy are just beginning to develop in the country – in 2020, only 0.3% of all electricity was produced from these sources, which is significantly lower than the global average of 9.4% [Ember, 2021].

Promising Areas for Low-Carbon Economic Development and International Cooperation

It should be noted that all of the national plans discussed above, as well as the EU's plans to achieve carbon neutrality, are schematic and emerging. This means that in the future, they will be refined and modified. Nevertheless, in the plans of the world's largest economies, the following priorities can be identified.

First, the main task is the decarbonization of the energy sector, which is the largest emitter of greenhouse gases in most countries. The decarbonization of the electric power industry is already proceeding at a fairly fast pace, with heating and transport sectors lagging behind, especially in such difficult niches in terms of reducing greenhouse gas emissions as aviation, shipping, and road freight transport. Critical elements of the energy transition also comprise the development of energy storage facilities and new low-carbon energy carriers such as green hydrogen. Special attention is paid to green construction and energy-efficient buildings. Second, it is necessary to decarbonize industry on a large scale and reduce the negative environmental impact of the manufacturing sector by introducing the principles of a circular economy, in particular, through the use of renewable raw materials (including the replacement of oil, gas, and coal with such raw materials in chemical processes) and minimizing waste volumes. It is necessary to transfer industrial processes to renewable energy sources in order to reduce the energy and resource intensity of industries. Third, several strategic documents outline plans to transition to sustainable agriculture, forestry, and fisheries in order to reduce emissions in these sectors, as well as to preserve and restore forests and natural ecosystems that can absorb carbon dioxide from the atmosphere. Some programmes for the transition to carbon neutrality pay special attention to R&D, the development of new low-carbon technologies, and the introduction of innovations.

In the coming decades, these areas will receive the greatest development in the largest economies of the world that are planning a transition to carbon neutrality. Also, these areas, including research, will be especially promising for international cooperation. Through the timely development of low-carbon industries and participation in the creation of new low-carbon technologies, countries that are highly dependent on fossil fuels, including Russia, can reduce the risks of a global transition to net-zero emissions, diversify their economies, and open new economic opportunities.

Based on national plans to achieve carbon neutrality, some countries intend to decarbonize the energy sector using nuclear energy, in particular the U.S., France, and Japan. That is, they at least do not plan to abandon nuclear energy until 2050. This intention is erroneous because nuclear power plants pose a threat to the environment and public health due to the risk of accidents, the fact that the by-product of their operation is hazardous radioactive waste that cannot be recycled or permanently stored, and because the costs of generating electricity for new nuclear power plants exceed the costs of generating electricity from both fossil fuels and renewable energy sources [Lazard, 2020]. In addition, the necessity and expediency of the development of nuclear energy is currently being questioned in many significant economies. In particular, Germany has decided to abandon nuclear energy by the end of 2022. In Japan, after the accident at the Fukushima-1 nuclear power plant in 2011, there has been significant resistance to the development of nuclear power from the population and non-profit organizations. Before the accident, 30% of Japanese electricity was produced at nuclear power plants, and the plan was to increase this share to 40%. However, after the accident, in 2012–15, it decreased to 0–2% given that all reactors were closed for safety checks. In 2019, nuclear power plants in Japan produced only 6.4% of all electricity [IEA, 2021f]. There is also strong opposition to the

development of nuclear energy in the U.S. and France. These factors will significantly limit the development of this industry in the respective countries.

Another misconception is the intention of some countries to develop CCUS. These technologies do not solve the problem of environmental pollution, destruction of natural ecosystems through the extraction of natural gas and coal, greenhouse gas emissions during the extraction (in particular, methane emissions), and transportation of fossil fuels. Taking into account greenhouse gas emissions throughout the entire life cycle, CCUS technologies can reduce emissions from electricity generation by only 10.8% over 20 years of operation of a coal-fired power plant [Jacobson, 2019]. In addition, CCUS technologies stimulate the extraction and combustion of fossil fuels, and the very idea of extracting fossil fuels, combusting them, capturing the carbon emitted, and then storing the carbon in order to combat climate change is highly controversial. This idea is even more controversial when it is considered that electricity generated by coal-fired power plants using CCUS technologies costs up to three times more than solar and wind power [Lazard, 2020].

The Level of Development of Low-Carbon Industries in Russia

Regarding the state of the main low-carbon industries in Russia, such as renewable energy and hydrogen, green buildings, sustainable transport, and the circular economy in the industrial sector, as already noted, these industries will flourish in the coming decades. Consequently, these industries have high potential in terms of the development of the Russian economy and in terms of the implementation of international cooperation and international trade with the participation of Russia. At the same time, it should be noted that the promising areas for the development of the Russian low-carbon economy and international economic cooperation, of course, are not limited to just these four areas, but also include sustainable agriculture, sustainable forest sector management, and household waste management.

Renewable Energy Sources and Hydrogen Energy

RES are resources, "the reserves of which are replenished naturally, primarily due to the flow of solar radiation coming to the Earth's surface, and in the foreseeable future, they are practically inexhaustible" [Popel, 2008]. These sources include solar energy, wind energy, biomass, water flows, and geothermal energy.

Even though the USSR was one of the leaders in the field of renewable energy – in particular, in the field of hydropower and wind energy – in the 2010s, Russia had to start developing renewable energy sources (not counting large hydroelectric power plants that have a negative impact on the environment due to changes in the landscape, flooding of territories, and destruction of natural ecosystems) practically from scratch. In the renewable electric power industry, in the period from 2013 to 2021, a complex system of state support was formed, which now covers all market niches: the wholesale electricity and capacity market (since 2013), retail electricity markets (since 2015), and microgeneration (since 2021). There are no state policies to promote renewables in the heating power industry or in the transport sector, although in the heating power industry there has recently been an increase in demand for heat pumps and pellet boilers due to their economic attractiveness.

Modern utility-scale solar PV and wind power plants (SPP and WPP) began to be built in Russia only after 2015. To date, several dozens of solar power plants and more than 10 wind farms have been built, several modern facilities that manufacture equipment for solar PV and wind energy have been created, including the production of wind turbine blades in Ulyanovsk,

the assembly of nacelles for wind turbines in Dzerzhinsk and in the Gorelovo settlement of Leningrad Region, the production of towers for wind turbines in Taganrog, the production of a generator stator, rotor, and main bearing of a wind turbine, generator, hub, and nacelle in Volgodonsk, the production of solar panels in Podolsk, and the production of solar modules and cells in Novocheboksarsk. Transfer of foreign technologies was carried out and educational programmes for personnel training have been created

However, the development of renewable energy sources is not included in Russia's priorities in the energy sector. The Energy Strategy of Russia for the Period up to 2035, adopted in 2020, presupposes the preservation of the traditional directions for the development of the fuel and energy complex for Russia: an increase in the production of natural gas and coal, with the preservation of the current volumes of oil production. RES, excluding large hydropower plants, are given an insignificant role in the strategy and are assigned only to the task of increasing the efficiency of energy supply in remote and isolated territories. According to the existing official plans for renewable energy, by 2025, the installed capacity of solar PV, wind, and small hydropower plants will reach about 2.5% of the total installed capacity, and the share of these sources in electricity production will comprise about 1%. By 2035, these values may grow to 5.4% and 2.3%, respectively [Lanshina, 2021]. In 2020, 9.4% of global electricity was produced only using solar PV and wind energy. Russia is one of the three Group of G20 (G20) countries, along with Saudi Arabia and Indonesia, whose share of solar PV and wind energy in the electric power production is still close to zero [Ember, 2021].

Unlike RES, hydrogen energy has recently attracted considerable attention in Russia, including within the framework of the updated energy strategy, where it is viewed as a promising direction, including for exports. The strategy sets a goal to increase the export of hydrogen to 0.2 million tons by 2024 and 2 million tons by 2035. However, it mainly envisions hydrogen produced from fossil fuels or using nuclear power, while globally, most attention is now paid to the development of green hydrogen, produced by water electrolysis using electricity from renewable energy sources. Hydrogen from water electrolysis using nuclear energy is already being actively pursued by the state corporation Rosatom. Rosatom is entrusted with the planning and implementation of pilot projects for the production of hydrogen using nuclear energy in Russia and abroad, the development of Russian technologies for the production, storage, and transportation of hydrogen, and the formation of long-term strategic and technological partnerships in this area. The industry integrator of this direction is JSC Rusatom Overseas, whose goal is to expand the foreign portfolio of orders of Rosatom's enterprises and to maintain Russia's leading position in the global nuclear market.

Thus, Russia already has some competencies in the production of equipment for solar PV and wind energy, as well as experience in the construction and operation of solar PV and wind power plants. However, this experience is still insignificant and requires further development in terms of deepening the localization of production operations, replacing outdated thermal power plants with modern SPPs and WPPs, construction of new renewable energy power plants for the production of green hydrogen, development of green hydrogen production, and formation of state policies aimed at stimulating the integration of RES in the heating and cooling sector and in the transport sector.

Green Buildings

Green buildings are defined as buildings that, through their design, construction or operation, reduce or eliminate negative impacts and have a positive impact on the climate and the environment [WGBC, n. d.]. There are several international green building standards, such as the Building Research Establishment's Environmental Assessment Method (BREEAM), the

Leadership in Energy and Environmental Design (LEED), and the German Sustainable Building Council (DGNB), which assess the environmental and energy efficiency of building design.

In Russia, the green building sector is still at the initial stage of development. As of May 2021, the number of certified buildings in the country amounted to only 211 units, of which 46% are offices, 23% are retail real estate, 15% are warehouse and industrial facilities, and the remaining 16% are distributed among other types of buildings [Knight Frank, 2021]. For comparison, in the UK the number of certified green buildings is about 19,000 while in the United States there are about 138,000 [GBIG, n. d.]. However, in Russia, the usual technologies of energy saving are actively deployed, such as LED lamps and motion sensors, thermal insulation of windows and doors, and temperature control. Among the reasons for such a slow development of the green construction industry in Russia is the low cost of energy in Russia, the lack of significant financial incentives for this industry from the state, and the lack of understanding of the importance of introducing green standards, as well as the long payback period of such projects, especially with the use of environmentally friendly building materials, which is a key risk in Russia's unstable macroeconomic environment [Korol, 2017].

Russia has significant potential for the further introduction of energy- and heat-saving technologies, the introduction of environmentally friendly building materials, as well as the certification of buildings in accordance with international green building standards.

Eco-Friendly Vehicles

Eco-friendly, or sustainable, transport is transport that minimizes the negative impact on the environment without compromising the efficiency of the transport system. At the moment, environmentally friendly vehicles include cars, trucks, passenger cars, and buses operating on alternative energy sources such as electricity, hydrogen, and biogas.

In Russia, environmentally friendly vehicles are gaining popularity. For example, from 1 September 2018, within the framework of the Energy of Moscow project, the first electric buses in Moscow began operating; by 2030, state unitary enterprise Mosgortrans plans to completely switch to electric buses. However, successes in the electrification of vehicles are noticeable only in the field of passenger transport, and only in Moscow, where electric buses accounted for 7.1% (or 600 units) of the total vehicle fleet of passenger buses in 2020. In addition, in Moscow, trolleybuses were replaced by electric buses, which is not entirely logical since the trolleybus represents environmentally friendly transport. Within the framework of the State Programme of the City of Moscow "The Development of the Transport System," there are plans to increase the share of electric buses to 14.4% by 2021, and to 23% by 2022. By 2030, the city plans to fully switch from fossil-fuelled buses to electric buses.

In other cities, the transition to electric buses is not a popular trend in the field of transport policy due to their high cost and the need to create charging infrastructure. In St Petersburg, in 2018, the state unitary enterprise Passazhiravtotrans purchased several electric buses that only operate on route number 28. The company is actively developing vehicles using compressed natural gas (methane), and the fleet of buses running on natural gas comprises 163 units. Between 2017–20, the St Petersburg carrier Gorelectrotrans launched nine electric bus routes with dynamic charging, which in fact represent modernized trolleybuses since they depend on the overhead electric network. In 2020, one test route of an electric bus was launched in Samara, but it was suspended a year later. In Naberezhnye Chelny, three electric buses are operated for employees of the research and development centre of the KamAZ auto plant. Instead of electric buses, Russian regions are developing tram and trolleybus networks, which are less expensive.

The number of electric vehicles in Russia is extremely low. As of 1 January 2021, only 10,800 electric vehicles were registered [Avtostat, 2021], which is 71% higher than in 2020. For

comparison, in the U.S. in 2019, more than 800,000 electric cars and about 570,000 hybrid cars were registered. China, which is the leader in the electric car fleet, registered 2,600,000 electric vehicles and 770,000 hybrid vehicles in 2019. There are 970,000 electric vehicles and 780,000 hybrid vehicles in the EU [IEA, 2020g].

To stimulate the demand for electric vehicles, it is necessary to create a modern and extensive infrastructure of charging stations. In Russia, according to various estimates, the number of operating charging stations is about 450 units [Stepanova, Nikitina, 2021]. This is not enough even for the existing number of electric cars, since there should be at least one charging station for 10 electric vehicles, that is, there should be at least 1,000 working stations in Russia. In addition, there is no single system of charging stations and no single set of requirements for power and type of connection. For this reason, it is difficult to assess their real number and capacity, or whether these stations are connected to the network.

The Ministry of Economic Development of the Russian Federation plans to build 20,000 charging stations by 2024 and 150,000 by 2030. In particular, this is due to import substitution plans, since from 2024, imports of the production of electric vehicles will be limited through the introduction of additional tax levies in order to stimulate the production of a Russian electric by KamAZ [Kotlyar, 2021], which is the only Russian automaker with a working prototype of an electric vehicle.

Thus, the electrification of personal and passenger vehicles in Russia is at an early stage of development. The number of electric vehicles and charging stations is small and insufficient to mark a significant development in the industry. In the electrification of passenger transport, Moscow is noticeably leading with a share of electric buses of 7.1%; other Russian cities do not plan to introduce this technology on a large scale due to its high cost and the need to develop the corresponding infrastructure.

Russia needs to create a unified network of electric charging stations, to significantly increase the number of such stations, as well as to introduce policies aimed at the supply of renewable electricity for charging electric vehicles, to develop the production of Russian electric vehicles and to stimulate the transition from internal combustion engines to electric motors (for example, through a ban on the sale of new vehicles with internal combustion engines from a certain year, following the example of the EU).

Circular Economy and Green Technologies in the Industrial Sector

A circular economy is defined as an economic system aimed at achieving zero waste and zero emissions throughout the entire life cycle of a product, including the extraction of raw materials, industrial processing, consumption, and disposal of waste [Nobre, Tavares, 2021]. The essence of the concept of a circular economy is the introduction of value on products, materials, and waste, in contrast to the traditional linear economic model based on the "take-produce-consume-throw away" scheme, and its main principle is to achieve maximum efficiency in the manufacturing of products and waste recycling in order to limit the leakage of resources.

In Russia, the introduction of a circular economy in the industrial sector is at the theoretical stage rather than a current trend. There are several isolated examples of Russian initiatives in this area, such as the GreenTire project in the Green Moscow cluster. Within the framework of the project, the plan is to create a service and production complex of a full cycle for the operation, to extend service life, and to reuse large-sized tires. The leaders and pioneers in the implementation of circular economy models in production are the Russian offices of transnational corporations. IKEA in Russia has followed the resource recovery model and launched several ongoing projects to recycle and reuse chipboard, cardboard, cardboard corners, paper cups, and stretch film. The company says it currently recycles 77% of waste generated in its stores

and has an ambitious target of 100% by 2030 [IKEA, 2021]. It should be noted that the above examples are solely the initiative of companies since in Russia environmental legislation does not oblige companies to recycle, but to process, dispose, and neutralize production waste. In the EU countries, for example, the main beneficiary in the transition to a circular economy is the state, which introduces strict standards for industrial and manufacturing enterprises in the management of industrial waste.

If the introduction of a circular economy in the industry is a systemic and long-term process, then another related area of greening production – the introduction of green technologies – is more accessible to Russian companies. Green technologies are defined in several sources as technologies and methods that help to reduce a negative impact on the environment by emitting fewer harmful substances, removing such substances from emissions before dumping, or through the disposal and recycling of industrial residues [OECD, 1999; UN, 1997]. These technologies include increasing energy efficiency at an enterprise, reducing fuel losses through the introduction of appropriate technologies, recycling waste, and replacing fossil fuels with RES.

Among the largest Russian oil and gas and industrial enterprises, the following priorities in the implementation of green technologies can be identified: increasing the energy efficiency of enterprises and reducing energy consumption (Gazpromneft, Rosneft, Lukoil, GAZ Group, Metalloinvest) and the modernization of production equipment. Green technologies introduced in metallurgy comprise direct iron reduction and steel smelting in electric furnaces (Metalloinvest), greener electrolytic cell technology (RUSAL), and transition to dry gas cleaning units (RUSAL). In the chemical industry, the following green technologies are being introduced in Russia: a complex for deep processing of hydrocarbons into polyolefins (polymers) (ZapSibNeftekhim plant of SIBUR) and the production of polyester polyols based on recycled carbon dioxide (Covestro). These technologies are aimed at reducing greenhouse and harmful gas emissions in the metallurgical and chemical industries. It should be noted that they are mainly implemented by the largest Russian exporters in order to comply with the legislation of the importing countries so as not to lose access to international markets.

The introduction of the best available technologies (BAT) can make a significant contribution to the greening and decarbonization of the industrial sector. In Russia, in the past few years, large-scale work has been carried out on the transition to BAT – in particular, in 2014 amendments to the Federal Law "On Environmental Protection" were adopted to determine the legal basis for state policy in the field of BAT, 51 sectoral and inter-sectoral BAT reference books were developed taking into account Russian and international experience, and the federal project "Implementation of the Best Available Technologies" is being implemented within the framework of the national project "Ecology." In accordance with the updated Law on Environmental Protection, BAT should have the lowest level of environmental impact per unit of time or volume of products produced, be cost-effective, use resource and energy conservation methods, and be applied on an industrial scale for two or more projects in Russia. The purpose of BAT implementation is to reject outdated and ineffective technologies and replace them with more advanced and environmentally friendly analogues. However, while work on the transition to BAT in Russia is not transparent enough, industrial companies exert too much influence on it, and there is no strategy for the implementation of BAT.

Thus, in Russia, there is no single trend for the transition to a circular economy and the introduction of green technologies in the industrial sector. The leaders in the transition to a new green economy are either Russian branches of large transnational corporations, which use operating models already established in other countries, or the largest Russian industrial exporting companies, which are forced to introduce green technologies to maintain their positions in international trade. At the same time, since the circular economy is still an emerging technology cluster globally, Russia has the opportunity to take a leading position in this sphere, subject to

timely (immediate) active involvement in R&D, as well as in the process of commercialization of relevant technologies.

Conclusion

The priority of all the strategic documents discussed in this article regarding the achievement of carbon neutrality by the world's largest economies by the middle of the century is the energy transition, which consists of the most ambitious development of RES in all energy sectors (electricity, heating and cooling, and transport), increasing energy efficiency, and reducing the volume of fossil fuel use, especially coal, since fossil fuel combustion is the main source of greenhouse gas emissions in most countries. Also, important attention in all programmes is paid to the reduction of emissions in the industrial sector (the introduction of circular economy principles, which implies a reduction in waste generation, waste recycling, and the replacement of coal with green hydrogen or other green energy sources in industrial processes), as well as in the agricultural and forestry sectors, through the introduction of the principles of organic farming and sustainable forest management. It is these technologies and industries that will grow rapidly in the near future.

Some countries erroneously plan to decarbonize the energy sector using nuclear power and CCUS technologies. These technologies are too expensive and dangerous for the environment, life, and the health of the population. In addition, some major economies are planning to phase out nuclear power; for instance, Germany will close all nuclear reactors by the end of 2022. In other countries, such as Japan, the U.S., and France, there is significant resistance to the development of nuclear energy from the population and non-profit organizations, which will also limit the development of this industry. Despite these shortcomings, all of the world's leading economies that have set themselves to the goal of carbon neutrality and have developed corresponding strategic documents will face a large-scale low-carbon transformation in the coming decades, which will reshape existing production technologies, supply chains, and product life cycles. This will inevitably have a negative impact on the Russian economy, which is highly dependent on the supply of carbon-intensive products to other countries.

To reduce the negative impact of the global transition to carbon neutrality on the Russian economy, Russia should pay close attention to the development of those technologies that will be most in demand in the coming years. In Russia, these technologies, in particular, RES, green hydrogen, green construction, environmentally friendly vehicles, and elements of a circular economy in the industrial sector, are at the initial stage of development, and many of them, including key low-carbon technologies such as renewable energy, have received little attention to date. Thus, modern renewable energy technologies have been developing in Russia only since 2015 and provide an insignificant contribution – for example, the share of wind and solar energy in electricity production is only 0.3%, while in the world one out of 10 kilowatt-hours is produced from these sources. The number of certified green buildings in Russia is in the hundreds, while in other large economies of the world, there are tens of thousands. Electric transport has received significant development only in Moscow and only in the electric bus sector, due in part to the displacement of trolleybuses, while in general, the country has an extremely low level of development of charging infrastructure. There are few examples of the introduction of the principles of a circular economy in industry; some companies, mainly the largest exporters, are introducing more affordable green technologies, but this practice is also not sufficiently targeted or widespread.

Accelerated development of the listed technologies and industries, and ensuring international cooperation in them, including cooperation in the field of R&D, transfer of foreign

technologies, development of Russian technologies and high-tech products both for supplying the domestic market and for export supplies, can bring benefits to the Russian economy, protect it from the risk of a decrease in global demand for fossil fuels, contribute to its diversification, facilitate its recovery from the crisis after the pandemic, and ensure that Russia has high rates of economic growth in the long term. In particular, Russia needs to deepen the localization of the production of equipment for renewable energy sources, gradually replace the outdated capacity of thermal power plants with modern solar power plants and wind farms, build new renewable energy plants for the production of green hydrogen, master the production of green hydrogen, formulate a state policy aimed at stimulating the implementation of RES in the thermal energy and transport sectors, introduce energy and heat saving technologies, stimulate the use of environmentally friendly building materials (as well as certification of buildings in accordance with international green building standards), create a unified network of electric charging stations, significantly increase the number of such stations, pursue a policy aimed at supplies of renewable electricity for charging electric vehicles, develop the production of Russian electric vehicles, stimulate the transition from internal combustion engines to electric motors (for example, through a ban on the sale of new cars with internal combustion engines from a certain year, following the example of the EU), introduce the best available technologies, develop green technologies, and introduce the principles of a circular economy in industrial sector.

References

Act on Promotion of Global Warming Countermeasures (2021). 1998 Law No 117. Available at: https://elaws.e-gov.go.jp/document?lawid=410AC0000000117 (accessed 16 July 2021) (in Japanese).

Biden-Harris Democrats (2020). The Biden Plan for a Clean Energy Revolution and Environmental Justice. Available at: https://joebiden.com/climate-plan/ (accessed 17 July 2021).

Biden-Harris Democrats (2021). The Biden Plan to Build a Modern, Sustainable Infrastructure and an Equitable Clean Energy Future. Available at: https://joebiden.com/clean-energy/ (accessed 11 July 2021).

Black R., Cullen K., Fay B., Hale T., Lang J., Mahmood S., Smith S.M. (2021). Taking Stock: A Global Assessment of Net Zero Targets. Energy & Climate Intelligence Unit (ECIU)-Oxford Net Zero. Available at: https://ca1-eci.edcdn.com/reports/ECIU-Oxford_Taking_Stock.pdf?mtime=20210323005817&focal=none (accessed 17 July 2021).

Center for Climate and Energy Solutions (C2ES) (n. d.). Global Emissions. Available at: https://www.c2es.org/content/international-emissions/ (accessed 11 July 2021).

Chen J.M. (2021). Carbon Neutrality: Toward a Sustainable Future. *The Innovation*, vol. 2, no 3. Available at: https://doi.org/10.1016/j.xinn.2021.100127.

Climate Action Tracker (2020). Brazil. Available at: https://climateactiontracker.org/countries/brazil/ (accessed 30 June 2021).

Climate Transparency (2020). Brazil. Climate Transparency Report 2020. Available at: https://www.climate-transparency.org/wp-content/uploads/2020/11/Brazil-CT-2020-WEB2.pdf (accessed 30 June 2021).

Ember (2021). Global Electricity Review. Available at: https://ember-climate.org/project/global-electricity-review-2021/ (accessed 12 June 2021).

Energy & Climate Intelligence Unit (ECIU) (2021). Net Zero Emissions Race. Available at: https://eciu.net/netzerotracker (accessed 11 July 2021).

European Commission (EC) (2019). Communication From the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions: The European Green Deal. COM(2019) 640 final. Brussels, 11 December. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588580774040&uri=CELEX:52019DC0640 (accessed 15 July 2021).

European Commission (EC) (2021). Delivering the European Green Deal. Available at: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en (accessed 11 July 2021).

European Council (2020). European Council Meeting (10 and 11 December 2020): Conclusions. EUCO 22/20. Brussels, 11 December. Available at: https://www.consilium.europa.eu/media/47296/1011-12-20-euco-conclusions-en.pdf (accessed 15 July 2021).

European Council (2021). Council Adopts European Climate Law. Press Release, 28 June. Available at: https://www.consilium.europa.eu/en/press/press-releases/2021/06/28/council-adopts-european-climate-law/ (accessed 9 July 2021).

Eurostat (2021). CO_2 Emissions From Energy Use Clearly Decreased in the EU in 2020. Available at: https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20210507-1 (accessed 11 July 2021).

Farand C. (2021). UK Calls on Indonesia to Set Out Roadmap to Net Zero Emissions. Climate Home News, 3 June. Available at: https://www.climatechangenews.com/2021/06/03/uk-calls-indonesia-set-roadmap-net-zero-emissions/ (accessed 9 July 2021).

Federal Constitutional Court (2021). Constitutional Complaints Against the Federal Climate Change Act Partially Successful. Press Release No 31/2021, 29 April. Available at: https://www.bundesverfassungsgericht.de/SharedDocs/Pressemitteilungen/EN/2021/bvg21-031.html (accessed 11 July 2021).

Federal Government of the Federal Republic of Germany (FRG) (2019). Climate Action Programme 2030. Available at: https://www.bundesregierung.de/breg-en/issues/climate-action/klimaschutzprogramm-2030-1674080 (accessed 21 July 2021).

Federal Government of the Federal Republic of Germany (FRG) (2021). Generationenvertrag für das Klima [Generational Contract for the Climate]. Available at: https://www.bundesregierung.de/breg-de/themen/klimaschutz/klimaschutzgesetz-2021-1913672 (accessed 12 July 2021) (in German).

Federal Ministry of Finance of the Federal Republic of Germany (FRG) (2021). Sofortprogramm für mehr Klimaschutz [Immediate Programme for More Climate Protection]. Available at: https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Schlaglichter/Klimaschutz/klimaschutz-sofortprogramm.html (accessed 11 July 2021) (in German).

Federal Office of Justice of the Federal Republic of Germany (FRG) (2019). Bundes-Klimaschutzgesetz (KSG) [Federal Climate Protection Act (KSG)]. Available at: https://www.gesetze-im-internet.de/ksg/BJNR251310019.html (accessed 17 July 2021) (in German).

Fraunhofer ISE (2021). Public Net Electricity Generation in Germany 2020: Share From Renewables Exceeds 50 Percent. News, 4 January. Available at: https://www.ise.fraunhofer.de/en/press-media/news/2020/public-net-electricity-generation-in-germany-2020-share-from-renewables-exceeds-50-percent.html (accessed 11 July 2021).

Gov.UK (2021). The Ten Point Plan for a Green Industrial Revolution. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf (accessed 11 July 2021).

Green Building Information Gateway (GBIG) (n. d.). Places. Available at: http://www.gbig.org/places/ (accessed 2 July 2021).

IKEA (2021). Tsiklicheskaya ekonomika [Cyclical Economy]. Available at: https://www.ikea.com/ru/ru/this-is-ikea/sustainable-everyday/ciklicheskaya-ekonomika-pub70ec0220 (accessed 11 July 2021) (in Russian).

Intergovernmental Panel on Climate Change (IPCC) (2019). Global Warming of 1.5 ºC. Available at: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/09/IPCC-Special-Report-1.5-SPM_ru.pdf (accessed 30 July 2021) (in Russian).

International Energy Agency (IEA) (2021a). Country Profile: France. Available at: https://www.iea.org/countries/france (accessed 9 July 2021).

International Energy Agency (IEA) (2021b). India Energy Outlook 2021. IEA Flagship Report. Available at: https://www.iea.org/reports/india-energy-outlook-2021 (accessed 9 July 2021).

International Energy Agency (IEA) (2021c). Country Profile: Brazil. Available at: https://www.iea.org/countries/brazil (accessed 9 July 2021).

International Energy Agency (IEA) (2021d). Country Profile: Indonesia. Available at: https://www.iea.org/countries/indonesia (accessed 11 July 2021).

International Energy Agency (IEA) (2021e). Country Profile: China. Available at: https://www.iea.org/countries/china (accessed 9 July 2021).

International Energy Agency (IEA) (2021f). Country Profile: Japan. Available at: https://www.iea.org/countries/japan (accessed 9 July 2021).

International Energy Agency (IEA) (2020g). Global EV Outlook 2020. IEA Technology Report. Available at: https://www.iea.org/reports/global-ev-outlook-2020 (accessed 1 July 2021).

Iqbal N., Abbasi K.R., Shinwari R., Guangcai W., Ahmad M., Tang K. (2021). Does Exports Diversification and Environmental Innovation Achieve Carbon Neutrality Target of OECD Economies? *Journal of Environmental Management*, vol. 291. Available at: https://doi.org/10.1016/j.jenvman.2021.112648.

Jacobson M. Z. (2019). The Health and Climate Impacts of Carbon Capture and Direct Air Capture. *Energy & Environmental Science*, vol. 12, pp. 3567–74. Available at: https://doi.org/10.1039/c9ee02709b.

Knight Frank (2021). 37% kompaniy po vsemu miru planiruyut uvelichit' dolyu "zelenykh" ofisov v svoyem portfele nedvizhimosti [37% of Companies Around the World Plan to Increase the Proportion of Green Offices in their Real Estate Portfolio]. News, 24 May. Available at: https://kf.expert/news/37-kompanij-po-vsemu-miru-planiruyut-uvelichit-dolyu-zelenyh-ofisov-v-svoem-portfele-nedvizhimosti (accessed 2 July 2021) (in Russian).

Korol T. O. (2017). The Role of Natural and Environmental Factors in the Implementation of Green Building Technologies in Russia. *RUDN Journal of Ecology and Life Safety*, vol. 25, no 1, pp. 155–168. Available at: https://doi.org/10.22363/2313-2310-2017-25-1-155-168 (in Russian).

Kotlyar M. (2021). Ministry of Economic Development Plans to Develop Electric Transport for ₽418 Billion. RBC Group, 18 May. Available at: https://www.rbc.ru/economics/18/05/2021/60a2eea79a794792e1387b24 (accessed 1 July 2021) (in Russian).

Lanshina T. (2021). Russia's Wind Energy Market: Potential for New Economy Development. Friedrich Ebert Stiftung (FES). Available at: https://www.fes-russia.org/fileadmin/user_upload/documents/210316-FES-MOS-windenergy-ru.pdf?fbclid=IwAR3jqNAltsIkuSzGRk-TmkUZTmIb7SBvyBiUfE4OENtgoMOECm-lOzoeDZ24 (accessed 11 July 2021) (in Russian).

Lazard (2020). Lazard's Levelized Cost of Energy Analysis: Version 14.0. Available at: https://www.lazard.com/media/451419/lazards-levelized-cost-of-energy-version-140.pdf (accessed 29 July 2021).

Li Y., Lan S., Ryberg M., Perez-Ramirez J., Wang X. (2021). A Quantitative Roadmap for China Towards Carbon Neutrality in 2060 Using Methanol and Ammonia as Energy Carrier. *iScience*, vol. 24, iss. 6. Available at: https://doi.org/10.1016/j.isci.2021.102513.

LOI n° 2019-1147 du 8 novembre 2019 relative à l'énergie et au climat [Law No 2019-1147 of 8 November Relating to Energy and Climate] (2019) Available at: https://perma.cc/5XYM-8VDA (accessed 15 July 2021) (in French).

Ministry of Ecological Transition (2020). National Low Carbon Strategy. Available at: https://unfccc.int/sites/default/files/resource/en_SNBC-2_summary_4-pages.pdf (accessed 9 July 2021).

Ministry of Economy, Trade and Industry of Japan (METI) (n. d.). Green Growth Strategy Through Achieving Carbon Neutrality. Available at: https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/index.html (accessed 4 November 2021).

Ministry of Foreign Affairs of the People's Republic of China (FMPRC) (2020). Statement by H. E. Xi Jinping President of the People's Republic of China at the General Debate of the 75th Session of the United Nations General Assembly. 22 September. Available at: https://www.fmprc.gov.cn/mfa_eng/zxxx_662805/t1817098.shtml (accessed 5 July 2021).

Nakano J. (2020). Japan Seeks Carbon Neutrality by 2050. CSIS Commentary, 2 November. Center for Strategic and International Studies. Available at: https://www.csis.org/analysis/japan-seeks-carbon-neutrality-2050 (accessed 30 June 2021).

Neier H., Neyer J., Radunksy K. (2018). International Climate Negotiations. Issues at Stake in View of the COP 24 UN Climate Change Conference in Katowice and Beyond. Available at: https://www.europarl.europa.eu/RegData/etudes/STUD/2018/626092/IPOL_STU(2018)626092_EN.pdf (accessed 11 July 2021).

Nobre G.C., Tavares E. (2021). The Quest for a Circular Economy Final Definition: A Scientific Perspective. *Journal of Cleaner Production*, vol. 314. Available at: https://doi.org/10.1016/j.jclepro.2021.127973.

Organisation for Economic Co-operation and Development (OECD) (1999). The Environmental Goods and Services Industry: Manual for Data Collection and Analysis. Available at: https://doi.org/10.1787/9789264173651-en.

Popel O.S. (2008). Vozobnovlyayemyye istochniki energii: rol' i mesto v sovremennoy i perspektivnoy energet [Renewable Energy Sources: Role and Place in Modern and Future Energy System]. *Russian Chemical Journal*, vol. 52, no 6, pp. 95–106. Available at: http://chem.msu.ru/rus/jvho/2008-6/95.pdf (accessed 23 July 2021) (in Russian).

Reuters (2021). China to Cut Coal Use Share Below 56% in 2021. 22 April. Available at: https://www.reuters.com/world/china/china-cut-coal-use-share-below-56-2021-2021-04-22/ (accessed 11 July 2021).

Safi A., Chen Y., Wahab S., Zheng L., Rjoub H. (2021). Does Environmental Taxes Achieve the Carbon Neutrality Target of G7 Economies? Evaluating the Importance of Environmental R&D. *Journal of Environmental Management*, vol. 293. Available at: https://doi.org/10.1016/j.jenvman.2021.112908.

Spring J., Paraguassu L. (2021). Brazil's Bolsonaro, Under U.S. Pressure, Vows Climate Neutrality by 2050. Reuters, 22 April. Available at: https://www.reuters.com/business/environment/bolsonaro-says-brazil-will-reach-climate-neutrality-by-2050-2021-04-22/ (accessed 11 July 2021).

Stepanova J., Nikitina O. (2021). Get Ready to Charge. Kommersant, 19 May. Available at: https://www.kommersant.ru/doc/4816869 (accessed 1 July 2021) (in Russian).

Stern N., Valero A. (2021). Innovation, Growth and the Transition to Net-Zero Emissions. *Research Policy*, vol. 50, issue 9. Available at: https://doi.org/10.1016/j.respol.2021.104293.

The Climate Change Act 2008 (2050 Target Amendment) Order 2019. Statutory Instrument 2019 No 1056. Available at: https://www.legislation.gov.uk/uksi/2019/1056/contents/made (accessed 11 July 2021).

The White House (2021). Executive Order on Tackling the Climate Crisis at Home and Abroad. Presidential Act, 27 January. Available at: https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/ (accessed 9 July 2021).

United Nations (UN) (1997). Glossary of Environment Statistics: Studies in Methods. Series F, No 67. Available at: https://unstats.un.org/unsd/publication/SeriesF/SeriesF_67E.pdf (accessed 4 November 2021).

United Nations Framework Convention on Climate Change (UNFCCC) (2020). Russian Federation: 2020 National Inventory Report (NIR). Available at: https://unfccc.int/documents/226417 (accessed 12 July 2021).

Wan B., Tian L., Fu M., Zhang G. (2021). Green Development Growth Momentum Under Carbon Neutrality Scenario. *Journal of Cleaner Production*, vol. 316. Available at: https://doi.org/10.1016/j.jclepro.2021.128327.

World Bank (WB) (2021). Gross Domestic Product 2020, PPP. World Development Indicators Database. Available at: https://databank.worldbank.org/data/download/GDP_PPP.pdf (accessed 16 July 2021).

World Green Building Council (WGBC) (n. d.). About Green Building. Available at: https://www.worldgbc.org/what-green-building (accessed 2 July 2021).