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Perspectives of Decarbonization of World Economy in the Context of Implementation of the UN Paris Climate Agreement[1]

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Abstract

The United Nations (UN) Paris Climate Agreement requires unprecedented efforts to prevent global warming above 1.5–2°C. Despite geopolitical, economic, and other disruptions, cooperation in the climate sphere is one of the key directions of international interaction among the world's leading economies. Many countries have adopted decarbonization strategies and carbon neutrality targets by 2050–2070. Economic analysis of decarbonization scenarios shows that zero-carbon technologies in energy, industries, and other sectors could play a crucial role in reduction of carbon emissions worldwide. Achievement of Paris Agreement goals could be more efficient if the mechanisms of international climate cooperation, carbon pricing, and regulation were broadly applied.

Keywords: climate change, Paris Agreement, decarbonization, greenhouse gases, low carbon development.

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Introduction

Global climate change is one of the most important challenges facing humanity. Further development of the world economy without taking climate change risks into account increases the anthropogenic impacts on Earth's climate system due to greenhouse gas (GHG) emissions and the reduction of the carbon sequestration capacity of forests and soils; it also threatens to cause unprecedented socio-economic and environmental damage from destruction of infrastructure, shortage of water resources, exacerbation of food security problems, and other catastrophic consequences with human health impacts [IPCC, 2021]. The estimated damage of "business as usual" development is as high as 5–20% of world gross domestic product (GDP) annually by the end of this century [Stern, 2006].

A key focus of international efforts to combat global warming is to reduce emissions of carbon dioxide and other greenhouse gases into the atmosphere. In order to reach the goals of the United Nations (UN) Paris Climate Agreement, adopted in 2015, it is necessary to achieve a carbon neutral world economy, preferably by the middle of the 21st century, that can ensure that temperature growth remains at the level of 1.5–2°C [IPCC, 2018]. However, the current commitments of the parties do not ensure complete decarbonization of the world economy, and the gap approaches tens of billions of tons of CO2 [UNEP, 2021].

Scenarios of deep decarbonization of the world's largest economies have been developed under the Deep Decarbonization Pathways Project since 2013, which covered 16 leading economies [DDPP, 2014; 2015] and became a foundation for designing national strategies for achieving carbon neutrality (for example, see The White House [2016] and the Government of the FRG [2016]). The project results helped to formulate a number of provisions of the Paris Agreement. Further studies of the deep decarbonization potential of various countries continued under several large-scale international research projects [Fragkos et al., 2020; Pahle et al., 2021; Schaeffer et al., 2020], studies of Russian and international scientific groups [Bashmakov, 2020; CENEf, 2009; Makarov, Chen, Paltsev, 2020; Makarov, Mitrova, Kulagin, 2020; Safonov et al., 2020].

The objective of this article is to assess the opportunities and prospects for decarbonization of the world economy and to analyze the scenarios of achieving carbon neutrality as well as the policies and measures taken by the leading countries and regions to meet the Paris Agreement goals. The main hypothesis is that the current commitments of the Parties and measures to reduce the anthropogenic impact on the climatic system are not sufficient for achieving the main goal of the Paris Agreement (prevention of global warming by over 1.5–2°C compared to pre-industrial levels). However, the potential to achieve that goal remains, so it is necessary not only to strengthen national and regional climate strategies, but also to ensure large-scale international cooperation in decarbonization of the world economy.

This article presents results of the economic-mathematical modelling and expert estimates provided by international organizations and scientific groups. It determines the main drivers of deep decarbonization of the world economy in the 21st century, reveals the positions of leading countries in achieving their Paris Agreement commitments, discusses the main directions of implementing climate change mitigation strategies, and considers the opportunities for international cooperation in reducing GHG emissions and increasing carbon removals.

It is important to note that the processes of transformation of the world economy toward deep decarbonization, green energy transition, and carbon neutrality, which began with the adoption of international agreements to combat climate change, are currently affected by crises related to the COVID-19 pandemic, global energy price shocks, and the geopolitical events unfolding since February 2022. The unprecedented sanctions against Russia, massive withdrawal of investors and capital, technological restrictions, embargos on import of fossil fuels, metals,

and other industrial products from Russia, as well as some other factors will have a dramatic and long-lasting impact on socio-economic development of the country. At the same time, the climate track in international cooperation remains one of the top priorities for all Parties to the Paris Agreement. Overcoming a climatic crisis on a planetary scale requires the continuation and expansion of cooperation between countries in the field of GHG emission reduction in the coming years. In this regard, the tasks of transforming the economy, energy systems, and decarbonization of industries are relevant both for Russia and for other countries, and international cooperation makes it possible to achieve climate goals most effectively and with minimal costs.

International Climate Agreements

The modern theory of global climate change was formulated in the early 1970's by the Soviet climate scientist M.I. Budyko. His "energy-balance" model became an important foundation for further climate research. Budyko presented findings of his research at an international symposium on climatology held in Leningrad in 1971, at which he stated that global warming will begin in the near future and may reach several degrees in the next century [Budyko, 1972].

In the mid-1970s, large-scale scientific studies of so called gas exchange between the earth's surface, the ocean, and the atmosphere began, along with studies of the physical processes of climate change and their impacts on socio-economic and ecological systems. The results of these studies provided the basis for the establishment of the Intergovernmental Panel on Climate Change (IPCC), which issued its First Assessment Report (FAR) on climate change issues in 1990, as well as the preparation of the UN Framework Convention on Climate Change (UNFCCC), which was adopted at the Conference on Sustainable Development in Rio de Janeiro in 1992 and entered into force in 1994. More than 180 countries, including the Russian Federation, have become Parties to the UNFCCC.

In December 1997, after intensive international negotiations, the convention was supplemented with the legally binding commitments of the Parties to reduce GHG emissions, as well as the economic mechanisms for international cooperation in achieving national goals and a number of other provisions that were signed at the Third Conference of the Parties (COP 3) to the UNFCCC in Kyoto, Japan. The Kyoto Protocol has defined the format of international cooperation on climate change issues from 2008 through 2020.

At the UNFCCC Copenhagen conference in 2009, the parties failed to agree on the continuation of their obligations to jointly control carbon emissions after the first period of quantitative commitments on GHG emission reduction under the Kyoto Protocol (2008–12). It became obvious that division of the negotiation process into two tracks (the Parties to the UNFCCC and the Parties to the Kyoto Protocol) hinders the achievement of a general, comprehensive agreement that suits all interested Parties. As a result, it was decided to develop a new approach to international climate cooperation based on other principles for coordinating national goals to reduce GHG emissions and formats of cooperation between countries, mechanisms of climate financing, and technology transfer. In 2015, the Paris Agreement was adopted at the 21st UNFCCC Conference, which entered into force in November 2016. One hundred eighty-six countries (including Russia) became Parties to this agreement so far.

The Paris Agreement (Article 2) aims to strengthen the global response to the threat of climate change in the context of sustainable development and efforts to eradicate poverty, including by:

(a) holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;

(b) increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low GHG emissions development, in a manner that does not threaten food production; and

(c) making finance flows consistent with a pathway toward low GHG emissions and climate-resilient development.

More than 130 countries have developed and officially adopted strategies for decarbonizing their economies and approved goals for achieving carbon neutrality (when anthropogenic GHG emissions do not exceed the amount of carbon removals), including the U.S., the UK, the EU, Japan, and Korea (by 2050), Kazakhstan, China, and Russia (by 2060), and India (by 2070).

The fulfilment of these ambitious tasks will require a radical transformation of the economy, energy systems, and industrial technologies, as well as a transition to environmentally friendly transport, development of new climate-friendly approaches to agriculture and forestry, and changes in consumer behaviour and business models. At the same time, coordination of the efforts of key actors (states, regions, cities, international organizations, financial institutions, technological companies, businesses, and scientific organizations) is extremely necessary for a more synchronous, harmonized transition to a new, zero-carbon model for the world economy. In this sense, further steps to implement the Paris Agreement, including development of the national strategies for decarbonization of the economy, expansion of carbon markets, and carbon pricing schemes, are extremely important for Russia and the world.

Research Methodology

To analyze the dynamics of GHG emissions and sequestration, the processes of transformation of energy and industries, and other key indicators of the world economy's development aiming at climate change mitigation goals on global and regional levels, advanced economic-mathematical models are often applied. These include partial equilibrium models for analysis of energy systems and individual sectors of the economy as well as complex integrated assessment models, which often include socio-economic indicators, land use, forestry and water resources, climate impacts, and other aspects of development.

This article presents the findings of research projects conducted with the participation of specialists from the Higher School of Economics (HSE) under large-scale international research initiatives, in which the integrated assessment models (e.g., the MESSAGEix-GLOBIOM model of IIASA) and partial equilibrium models (MARKAL/TIMES and others) were applied for the leading countries and regions. The model projections were harmonized and calibrated taking into account the global and national scenarios for the Group of 20 (G20) up to 2100 [Riahi, Krey, Bertram, 2019]. The methodology of comparative analysis of low-carbon development strategies of various regions and leading countries was applied. The high priority policies and measures of decarbonization were investigated, and shortcomings and opportunities of states in achieving the goals of the Paris Agreement were identified. The prospects for international cooperation in GHG emissions reduction, including the possibilities of using the mechanisms of Article 6 of the Paris Agreement for decarbonization projects and programmes were analyzed, including development of carbon market instruments for a large-scale interaction of economic actors in implementation of low-carbon development strategies, introduction of zero-carbon technologies, and increasing carbon sequestration by the ecosystems.

The Long-Term Carbon Emission Scenarios

The analysis of decarbonization at both the global and the macro-regional levels up to 2100 was carried out for the following three scenarios:

1. The NDC scenario is based on the officially submitted nationally determined contributions (NDCs), adopted policies and measures in the energy sectorm and land use [den Elzen, 2016; Grassi, Dentener, 2015; Kitous, 2016] as well as on information provided by countries to the UNFCCC secretariat. However, not all countries presented GHG emission reduction targets by 2030 in absolute figures. For example, China and India defined their targets in terms of GHG emissions per unit of GDP, the certain share of renewable energy in their energy mix, as well as their forest planting activities, which are quite difficult to translate into absolute indicators. Therefore, target emission levels have been estimated conservatively.

2. The NP1000 scenario assumes implementation of national policies and measures to reduce GHG emissions with the global carbon emission budget of 1,000 billion tons of CO2 equivalent in the period from 2011 through 2100. According to this scenario, the increase in global temperature may not exceed 2°C compared to the pre-industrial levels during the current century with the probability of at least 66% [Luderer et al, 2018; Rogelj et al, 2016].

3. The NP400 scenario considers implementation of national policies and measures to prevent an increase in global temperature over 1.5°C with the probability of 66%, while the global GHG emissions budget is estimated at the level of 400 billion tons of CO2 equivalent in the period from 2011 through 2100 [Luderer et al, 2018]. As the current level of emissions is about 50 billion tons of CO2 equivalent per year, this scenario could lead to negative GHG emissions provided the volume of carbon sequestration exceeds GHG emissions.

The dynamics of global GHG emissions vary significantly by the considered scenarios (Fig. 1). Prolongation of the current weak mitigation targets specified in the nationally determined contributions (NDCs) of the Parties under the Paris Agreement beyond 2030 (NDC scenario) is leading to an approximately twofold increase in GHG emissions from 2011 through 2100, while the growth of carbon sequestration in forest ecosystems may increase by sixfold. The other more ambitious scenarios require a drastic reduction of GHG emissions and achievement of negative emissions by 2080 (NP1000 scenario) or even by 2060 (NP400 scenario). The volume of carbon sequestration in natural ecosystems should increase by more than 10 times in scenarios NP1000 and NP400 from 2011 through 2100.

In the NDC scenario, consumption of liquid fuels increases by 25% in the period from 2020 to 2050, then decreases by 15% in 2051–2070 followed by an increase of 35% by 2100 (Fig. 3). The NP1000 scenario assumes a 10% increase in the consumption of oil refinery products in the period from 2020 to 2030, followed by a sharp reduction by over 50% until 2060 and relative stabilization in the period from 2060 to 2100. The NP400 scenario requires a decisive threefold reduction in the consumption of liquid fuels from 2020 through 2050[2] with a minor increase in consumption further on until 2100, which implies a radical restructuring of the world oil market, a reduction of traditional (without carbon capture and storage technologies) oil use as an energy source, and substitution of crude oil with other zero-carbon liquid fuels (such as biofuels and green hydrogen).

Consumption of gaseous fuels is growing in all scenarios (Fig. 4), which is primarily due to substitution of coal and crude oil by less carbon-intensive natural gas or other types of gas fuels (such as biogas and synthetic gas). The NDC scenario assumes an almost linear growth

[2] The conjunctive growth of fossil fuel use caused by the geopolitical crisis of 2022 will likely have a limited influence on the long term development of energy producing and consuming sectors due to the long cycles of implementation of energy, infrastructural, and industrial projects. For example, construction and exploitation of traditional power plants and transport infrastructure is aimed at life-cycles of more than 40–50 years. The short term fluctuations of energy demand and fuel prices are not a determining factor for development of energy and some other sectors. The energy crisis of 2022 in Europe will also likely stimulate faster transition to green energy sources and zero-carbon transport, and the more active implementation of decarbonization strategies in order to reduce dependency on fossil fuel supplies in the mid-term future.

of gas consumption by 80% from 2020 through 2100 (Fig. 3). The NP1000 scenario assumes a rapid increase in gas consumption of almost threefold from 2020 through 2080, followed by a negligible decline up to 2100. In the NP400 scenario, gas consumption doubles in the period from 2020 through 2060 with further stabilization until 2080 and further slight decline by 2100. In all scenarios, global electricity generation grows almost linearly by about four times over the period from 2020 through 2100 (Fig. 5). This is mainly attributed to the expansion of end-use electrification proposed in many low-carbon development strategies (that is, the electrification of transport and industrial facilities, among others). The production and consumption of hydrogen is considered an important direction of development. In all scenarios, a significant increase in hydrogen use is expected as follows (Fig. 6): in the NDC scenario the hydrogen boom is envisaged only after 2050, in the NP1000 scenario a sharp increase of hydrogen production is expected after 2040, while in the NP400 scenario hydrogen starts playing an important role after 2030. Hydrogen production technologies and its use in metallurgy, transport, energy, and other industries are developing quickly, and companies from Europe, Russia, Latin America, Saudi Arabia, and other countries are beginning to compete on the world market.

The net zero emissions scenarios (NT400 and NT1000) assume impacts of several factors, such as energy efficiency improvement, technological progress and development of new energy markets, and large-scale electrification of the economy, as well as the adoption of measures related to reducing methane emissions (for example, due to natural gas leakage and gas flaring), enhancement of carbon sequestration by natural ecosystems, introduction of low-carbon technologies in metallurgy, production of cement and chemicals, and some others. Detailed reviews of prospective low-carbon technologies and energy resources, including carbon capture and storage (CCS) technologies, biofuel, and green hydrogen production, including costs, technical characteristics, and resource potential are presented in the regularly updated reports by the International Energy Agency (for example, see IEA [2020]).

Assessment of the costs of decarbonization is an extremely difficult and complex task. The national low-carbon development scenarios for the 16 largest countries, which account for about 80% of global CO2 emissions, showed that the annual costs of achieving deep decarbonization by 2050 amount to 0.8–1.3% of GDP [DDPP, 2015], while a significant part of these costs is capital investments, which have a positive impact on GDP growth.

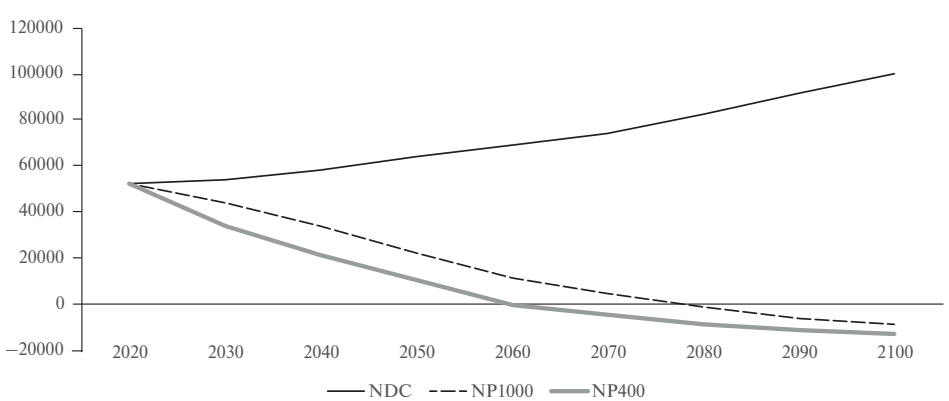

Fig. 1. Global GHG Emissions, MtCO2e/year

Source: Compiled by the authors based on Database IIASA, CD-LINKS Scenario Database, Version 2.0 (https://iiasa.ac.at/models-tools-data/cd-links-scenario-explorer).

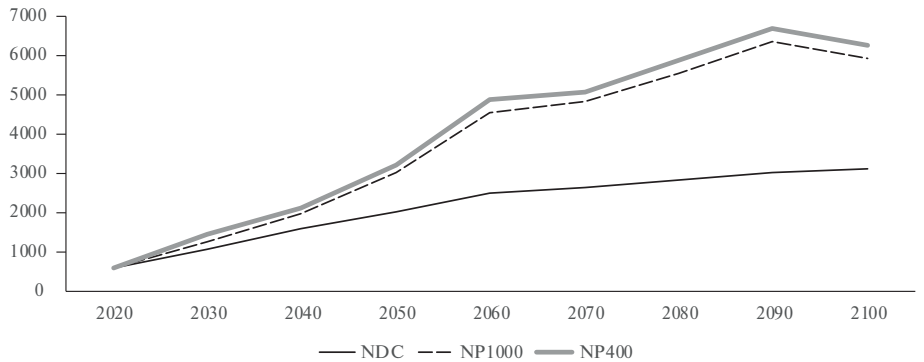

Fig. 2. Global Carbon Sequestration, MtCO2e/year

Source: See the source under Fig. 1.

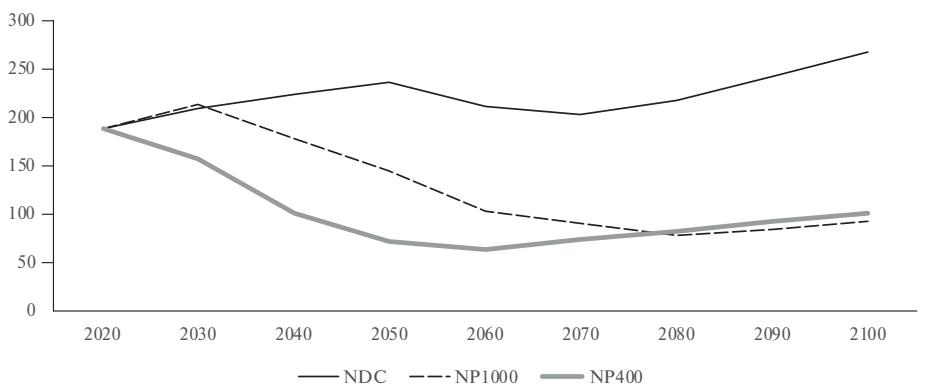

Fig. 3. Global Consumption of Liquid Fuels, EJ/year

Source: See the source under Fig. 1.

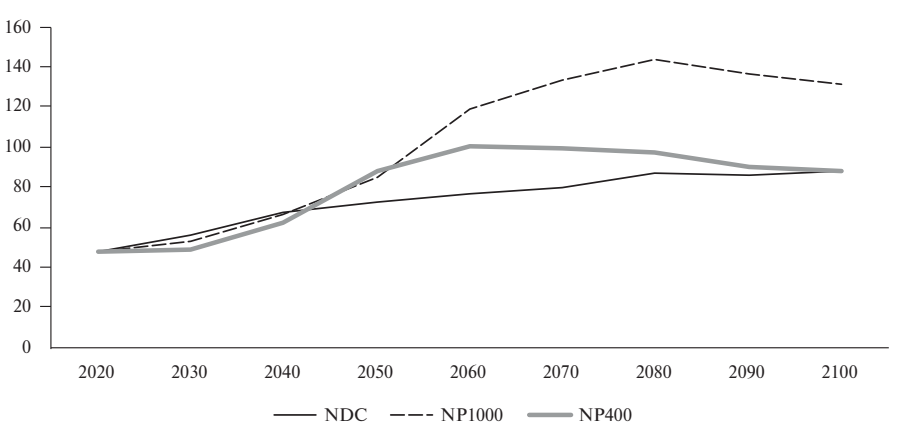

Fig. 4. Global Consumption of Gaseous Fuels, EJ/year

Source: See the source under Fig. 1.

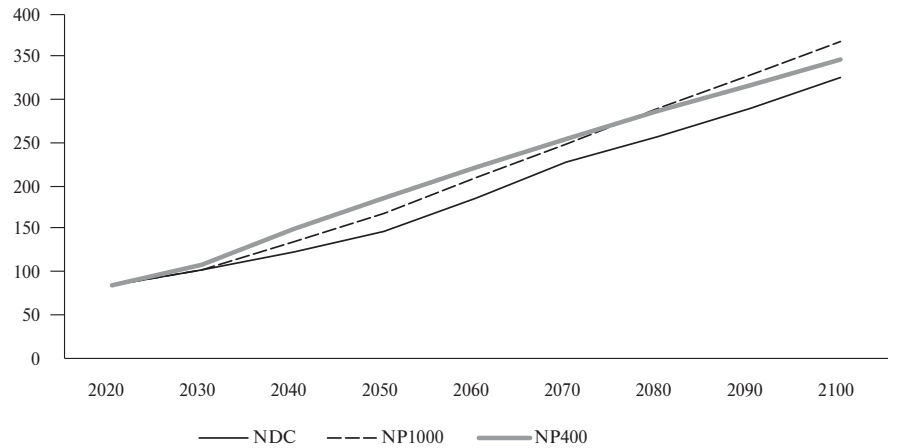

Fig. 5. Global Electricity Generation, EJ/year

Source: See the source under Fig. 1.

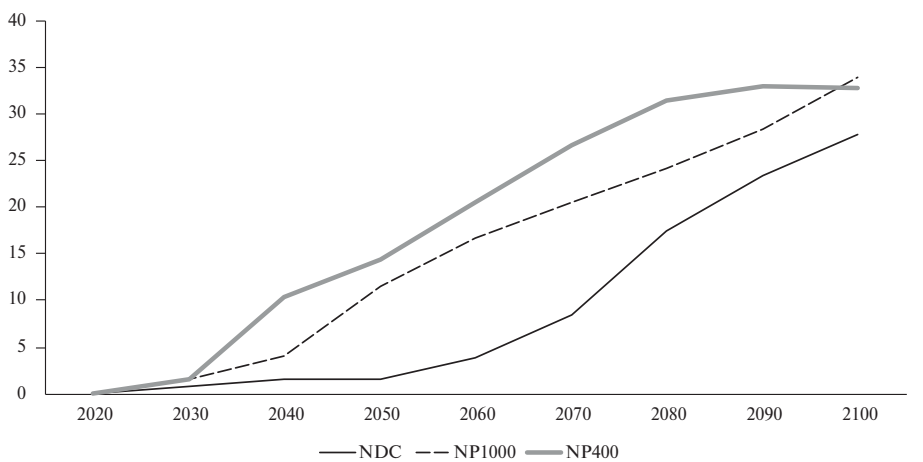

Fig. 6. Global Hydrogen Consumption, EJ/year

Source: See the source under Fig. 1.

The projections of key indicators related to implementation of the Paris Agreement vary significantly across countries and regions. The modelling results for three above-mentioned scenarios are presented for the following groups of countries (regions): the Organisation for Economic Co-operation and Development (OECD) and the European Union (OECD+EU), Asia excluding Japan (ASIA), the Middle East and Africa (MAF), Latin America (LAM), and the countries of the former Soviet Union, including Russia and excluding the Baltic States (REF). Total GHG emissions (Fig. 7) in the NDC scenario grow by 23% over the period from 2020 through 2050, while in the ASIA region the growth will be 36%, in MAF—71%, in REF—15%, in LAM—7%, while in OECD+EU it is expected to decline by 10%. However, in more ambitious scenarios (NP400 and NP1000) the situation is drastically different. In the NP1000

scenario, total GHG emissions decline by 55% from 2020 to 2050, all regions reduce their emissions by 48–76%, and the burden of decarbonization efforts among the regions is quite uneven. In the NP400 scenario, total GHG emissions decline by 81% from 2020 through 2050, in the ASIA region—by 78%, in MAF—by 70%, in REF—by 88%, in LAM—by 91%, in OECD+EU—by 83%.

Carbon sequestration by natural ecosystems is expected to grow in all considered scenarios from 2020 through 2050 (Fig. 8): 3.5 times in the NDC scenario, 5.3 times in the NP1000 scenario, and 5.5 times in the NP400 scenario. The largest increase of carbon sequestration due to the Amazon forests is expected in the LAM region (from 5.5 to 16.8 times, depending on the scenario), due to tropical forests in the African continent in the MAF region (3.3–9 times), and due to boreal forests in REF region, including Russia (from 4 to 5.7 times). In the OECD+EU region, carbon sequestration could increase by 3.4–4.7 times, while in the ASIA region it may reach 3–3.5 times. The main challenge for tropical forests is deforestation for agricultural purposes (such as livestock farming in Brazil and plantations for palm trees in Indonesia). In contrast, the boreal forests of Russia, Canada, and Northern Europe are exposed to wildfires, diseases, and pests, as well as mass timber harvesting. More rational and climate-smart forest management, as well as development of forest-based sectors (such as wooded construction materials, wooden houses, second- and third-generation biofuels, biotextiles, and much more) could significantly increase capacity for carbon sequestration.

Figure 9 shows the dynamics of liquid fuel consumption in 2020–50. The largest consumers are the OECD+EU and ASIA regions, and the latter in all scenarios shows the largest share in global consumption by 2050, which can be explained by a sharp increase of the population in Asian countries, rising wellbeing of households, and an increase in fuel consumption for transportation. The MAF and LAM regions account for approximately the same shares in projected liquid fuel consumption, while the REF region, including Russia, demonstrates a relatively small consumption of liquid fuels.

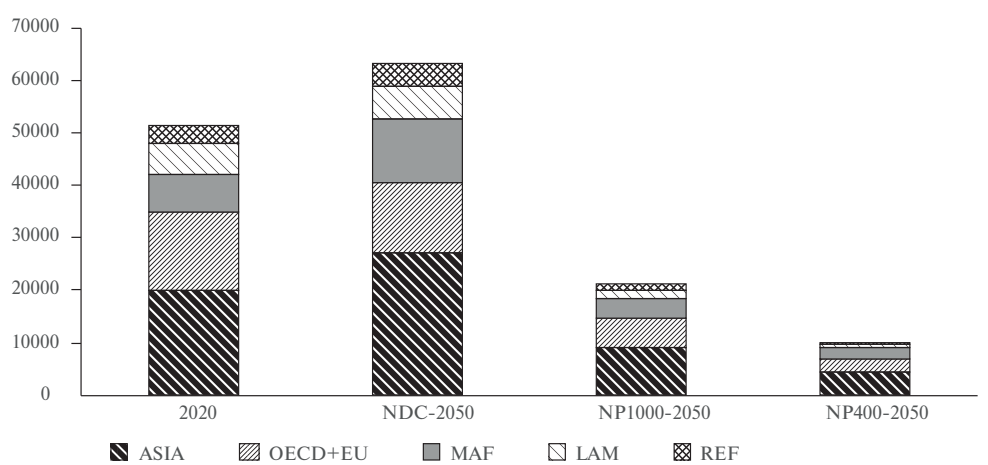

Fig. 7. GHG Emissions by Regions, 2020–50, MtCO2/year

Source: See the source under Fig. 1.

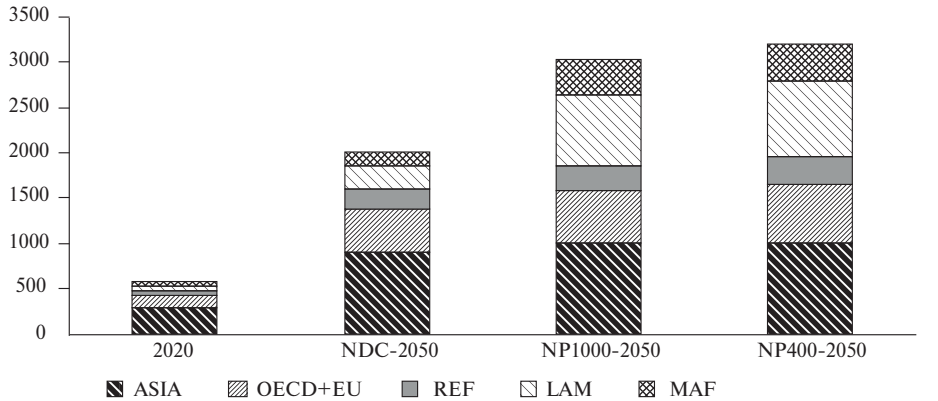

Fig. 8. Carbon Sequestration by Regions, 2020–50, MtCO2/year

Source: See the source under Fig. 1.

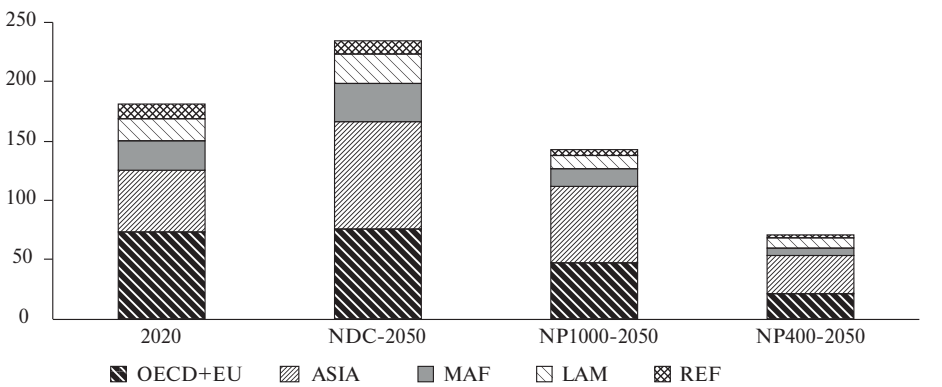

Fig. 9. Liquid Fuels Consumption by Regions, EJ/year

Source: See the source under Fig. 1.

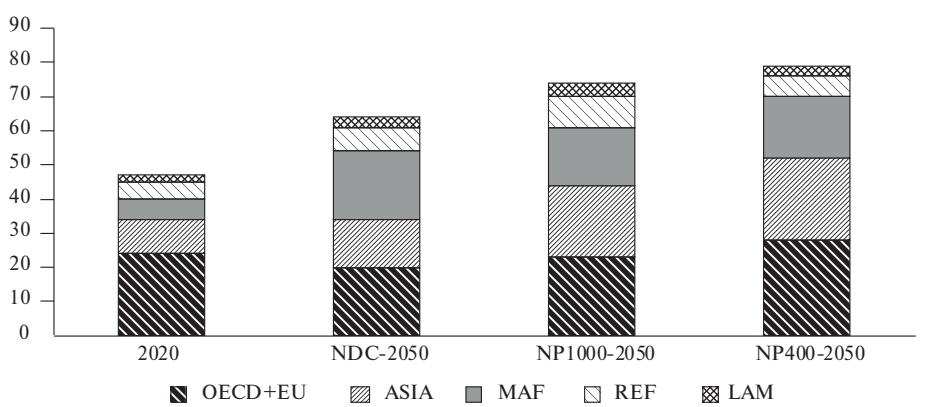

Fig. 10. Gaseous Fuels Consumption by Regions, EJ/year

Source: See the source under Fig. 1.

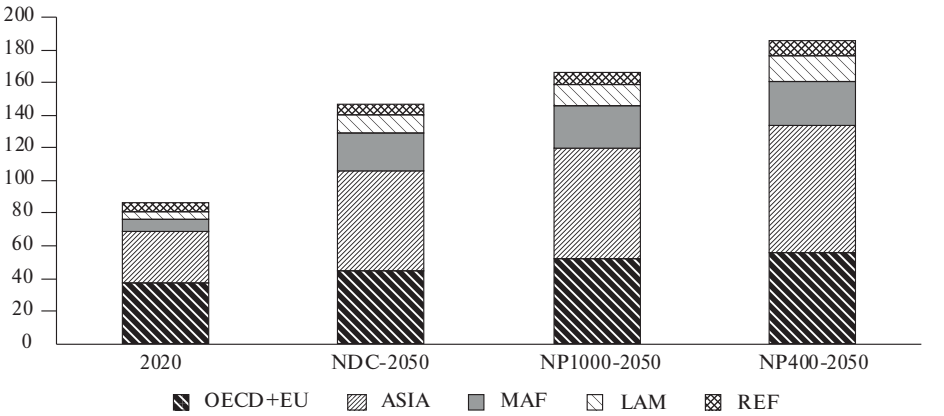

Fig. 11. Electricity Generation by Regions, EJ/year

Source: See the source under Fig. 1.

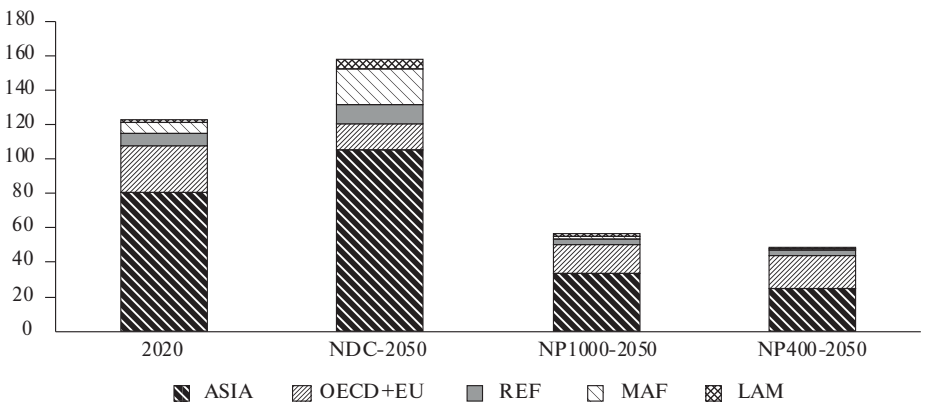

Fig. 12. Coal Consumption by Regions, EJ/year

Source: See the source under Fig. 1.

Consumption of gaseous fuels is expected to grow during 2020–2050 in all scenarios. The leaders are the OECD+EU, ASIA and MAF regions. REF and LAM also show an increase in gas consumption, but it remains relatively low in the considered period (Fig. 10). Electricity generation increases significantly in the OECD+EU, ASIA and MAF regions, while REF and LAM account for insignificant shares of total electricity production (Fig. 11).

Being the most carbon-intensive and environmentally "dirty" fuel, coal consumption causes the greatest political debates and requires adoption of new, unprecedented regulatory measures. In the NDC scenario, coal consumption for power and heat generation increases by 28% by 2050, mainly due to rising consumption in the ASIA, MAF, and REF regions, a slight increase in LAM, while OECD+EU reduces coal consumption (Fig. 12). However, in the NP1000 and NP400 scenarios it is projected that coal use will decrease in all regions by two-fold and more in 2020–2050, and that ASIA and OECD+EU will remain the main consumers (nearly 50% and 40% of global demand, respectively).

Climate Strategies of the World's Leading Countries

Analysis of the climate change mitigation goals of the largest countries included in the G20, which are responsible for about 75% of global GHG emissions, demonstrates that these goals are determined, primarily, by their socio-economic development priorities (Table 1). The key elements of decarbonization strategies relate to development of innovative carbon-free technologies and sectors of national economies (including a new generation of bioeconomy solutions), a large-scale increase in energy and material efficiency in all sectors of production and consumption, transition from fossil fuels to zero-carbon energy resources (such as green hydrogen, biofuels, renewable energy sources, carbon capture, and storage/utilization technologies), an enhanced carbon sequestration and reduction of carbon emissions in forestry and land use sectors.

Table 1. Climate Policy Goals and Measures for Low-Carbon Development in the World's Leading Economies

Country	Climate Policy Goals	Key Measures
Australia	• achievement of carbon neutrality by 2050 • the main focus relates to technological innovation, green energy transition, socially inclusive economic growth, job creation, and environmental preservation	• minimizing the carbon intensity of the energy sector through the use of renewable energy sources (RES), CCS/carbon capture, utilization, and storage (CCUS) technologies, energy storage systems, and energy efficiency improvements • maximizing the electrification of end-use, transport, using alternative fuels (hydrogen, etc.) • increasing the carbon sequestration in the forestry and land use sectors
Brazil	• reduction of GHG emissions by 37% from 2005 levels in 2025 and by 50% from 2005 levels in 2030 • achievement of climate neutrality by 2060	• reducing the amount of deforestation • improving agrotechnical works • using renewable energy sources, expanding the use of biofuels • introducing new technologies in construction, industry, and energy
China	Main goals include: • achievement of CO2 emissions peak by 2030 and carbon neutrality by 2060 • reduction of CO2 emissions per unit of GDP by more than 65% compared to 2005 levels • increase in the fossil fuels share in primary energy consumption to around 25% • increase in the amount of accumulated biomass in the forest fund by 6 billion m^3 compared to 2005 levels • achievement of the total installed capacity of wind and solar energy of 1.2 billion kilowatts by 2030	• using energy with low GHG emissions (development of CCS/CCUS technologies in the power industry) • electrifying and improving energy efficiency • using renewable energy sources and alternative energy sources • prioritizing technologies and socio-economic objectives • using new prospective technologies (including closed fuel cycle technologies in the nuclear power industry and hydrogen production) • extending use of carbon-free transport (electric and hydrogen vehicles, development of public transport systems, promotion of the use of bicycles, and other zero- and low-carbon vehicles)
France	• reduction of GHG emissions by at least 55% by 2030 compared to 1990 levels • achievement of carbon neutrality by 2050	• energy sector: managing energy demand by improving energy efficiency and changing consumer patterns; diversifying the energy structure, in particular, through the development of renewable energy sources and the phase-out of coal in the electric and thermal power industry (from 2022) • industry sector: transitioning to low-carbon production systems • improving the energy efficiency of buildings (thermal insulation and equipment), including introduction of new standards for new buildings and for the renovation of obsolete housing stock • achieving maximum level of forest carbon sequestration, encouraging sustainable farming, and minimizing nitrogen fertilization • developing a bioeconomy with a low carbon footprint • reducing the amount of waste generation

Country	Climate Policy Goals	Key Measures
Germany	• reduction of GHG emissions by 55% by 2030 compared to 1990 levels • achievement of carbon neutrality by 2050 (as part of the EU)	• increasing energy efficiency, including improvement of energy standards for new and existing buildings, which are subjects to large-scale reconstruction, and introduction of heating systems based on renewable energy sources • reducing the primary energy demand in residential, commercial, and administrative buildings by at least 80% from 2008 levels by 2050 through improved energy efficiency and use of renewable energy • developing electromobility infrastructure and phasing-out the use of cars with internal combustion engines • extensively using hydrogen (mainly green) • introducing innovative methods of fertilizer handling in agriculture and increasing GHG absorption due to the expansion of forest areas
India	• reduction of specific GHG emissions per unit of GDP by 33–35% by 2030 compared 2005 levels • increase of the share of energy produced from non-fossil fuels to approximately 40% of total installed capacity by 2030 • increase carbon sequestration by 2.5–3 billion tons of CO2 by increasing forest cover by 2030 • achievement of carbon neutrality by 2070	• implementing new more efficient and environmentally friendly technologies in the heat and power industry • promoting the renewable energy production and increasing the share of alternative fuels in the fuel balance • reducing GHG emissions from the transport sector • increasing the energy efficiency in the economy, especially in industry, transport, construction, and housing sectors • reducing GHG emissions from waste • developing climate resilient infrastructure • promoting environmentally friendly and healthy lifestyles • implementing the Green India Mission and other afforestation and reforestation programmes
Indonesia	• reduction of GHG emissions by 29% compared to the business-as-usual scenario (BAU) by 2030 • reduction of GHG emissions by up to 41% by 2030 with international support for financing, technology transfer and development, and capacity building • achievement of carbon neutrality by 2060	• energy saving and promoting clean and renewable energy sources • improving the efficiency of land use and spatial planning, and sustainable management of forests and wetlands • increasing agricultural productivity • improving waste management
Japan	• reduction of GHG emissions by 46% by 2030 compared to 2013 levels • achievement of carbon neutrality by 2050	• completing transition to carbon-free technologies in energy sector (including RES, nuclear power plants, and so on) • increasing energy efficiency (increasing energy savings in 22% by 2030) • using hydrogen, CCS, CCU, and carbon recycling technologies • achieving 3.5% of the target emission reduction by 2050 through carbon removals by forests
Mexico	• reduction of GHG emissions by 36% and black carbon emissions by 70% by 2030 compared to the BAU scenario • reduction of GHG emissions by 50% by 2050 compared to the BAU scenario and 2000 levels	• accelerating transition to clean energy • supporting energy efficiency and sustainable consumption • creating sustainable cities with mobility systems, integrated waste management, and low carbon construction • supporting sustainable agriculture and forestry to maintain and increase GHG absorption • reducing short-lived GHG emissions resulting in improved air quality, reduced risks to human health, and other social benefits
Russia	• limitation of GHG emissions should not exceed 70% by 2030 compared to 1990 levels • achievement of carbon neutrality by 2060	• increasing energy efficiency • developing carbon-free and low-carbon energy (gasification, nuclear power plants, hydroelectric power plants, renewable energy sources, and possible use of CCS/CCUS technologies) • promoting hydrogen production (target—reaching 20% of the global hydrogen market) • developing transport infrastructure and environmentally friendly transport • maintaining and increasing carbon sequestration potential in forestry and agriculture

Country	Climate Policy Goals	Key Measures
Saudi Arabia	• prevention and elimination of GHG emissions by 278 million tons of CO2-eq. per year by 2030 • achievement of carbon neutrality by 2060	• tightening energy efficiency standards in industry, construction, and land transport sectors • achieving installed RES capacity of 9.5 GW by 2030 • producing 0.65 million tons per year of green hydrogen by 2025 • improving fuel cost effectiveness in transport sector • improving efficient water management
South Africa	• achievement of the "peak, plateau, and decline" trajectory of GHG emissions beginning in 2020 • reduction of GHG emissions to 398–510 Mt CO2-eq by 2025 and to 350–420 Mt CO2-eq by 2030 • long-term goal—reduction of GHG emissions in absolute terms to 212–428 Mt CO2-eq. (for upper and lower limits depending on scenarios) by 2050	• improving energy efficiency • developing renewable energy sources • developing CCS/CCUS technologies in the electric power industry • realizing green transport strategy • separating waste collection and thermal waste disposal • promoting afforestation, special farming, and agroforestry practices
UK	• reduction of GHG emissions by at least 68% by 2030 compared to 1990 levels • achievement of carbon neutrality by 2050	• generating electricity entirely by low-carbon sources by 2035 • completely utilizing associated petroleum gas (APG) and increasing green hydrogen production • supporting deep decarbonization of the industry sector through the efficient use of resources and energy, transition to alternative energy sources, and the introduction of CCUS • energy saving in the utilities sector, introducing low-carbon heating systems by 2035 • ending sales of new gas and diesel vehicles by 2030 in the transport sector • increasing forest plantations and peat restoration • reducing GHG emissions from waste by increasing the use of municipal biodegradable waste from landfills and potential savings from other parts of the sector such as wastewater • reducing fluorine-containing GHG emissions • introducing improved and innovative agricultural practices • applying bioenergy with carbon capture and storage (BECCS) technology and direct air carbon capture and storage (DACCS) methods
Korea	• reduction of GHG emissions by at least 40% by 2030 compared to 2018 levels • achievement of carbon neutrality by 2050	• increasing energy efficiency in industry and housing sectors • using renewable energy sources • implementing CCUS technologies • using fuel cells and green hydrogen • developing intelligent networks • developing electric and hydrogen transport • improving the quality of sinks (forest management, restoration of mud flats)
USA	• reduction of net GHG emissions by 50–52% by 2030 compared to 2005 levels • long-term goal—achievement of carbon neutrality by 2050 in terms of net GHG emissions (including GHG absorption by forests and other ecosystems)	• decarbonizing electricity generation, achieving 100% green electricity generation by 2035 • achieving savings in energy end use and transitioning to other environmentally friendly fuels • reducing energy losses • reducing methane and other non-CO2 GHG emissions • implementing GHG capture and storage technologies • developing environmentally friendly transport • maintaining and increasing carbon sequestration potential in forestry and agriculture
Turkey	• reduction of GHG emissions by 21% by 2030 compared to the business as usual (BAU) scenario • the country has not announced the goal by 2050 yet	• increasing installed capacity for electricity generation from RES, fully using hydropower potential, and commissioning a nuclear power plant by 2030 • reducing losses in the transmission and distribution of electricity up to 15% by 2030 • creating microgeneration, cogeneration, and electricity generation systems from local resources • improving energy efficiency of industrial installations

Country	Climate Policy Goals	Key Measures
		• increasing the share of sea and rail transport, developing multimodal transport, introducing sustainable transport corridors in urban areas, promoting alternative fuels and environmentally friendly vehicles, reducing fuel consumption • increasing energy efficiency in housing sector • achieving fuel savings through land consolidation in agricultural areas, recovery of rangelands, control of fertilizer use, introduction of modern farming practices, and support of minimum tillage practices • reusing, recycling, and using other processes for recovery of secondary raw materials, using as an energy source, or disposal of waste • increasing forest area, preventing land degradation, implementing the forestry restoration action plan and the national afforestation campaign

The group of the most developed industrial countries has more diverse opportunities to ensure economic growth through innovative technologies, including renewable and alternative energy sources (such as green hydrogen and nuclear power).

For instance, the U.S.' climate strategy aims at reaching carbon neutrality by 2050 via reduction of GHG emissions and increased carbon sequestration by forest. The increase of renewable energy use is linked with development of high-tech industries (polycrystalline silicon, lithium, composite materials, and so on) and the intention to secure a stronger position in the market of solar panels, which is currently dominated by China.

The UK, Japan, France, and Korea are focused on energy efficiency improvement, increase of electricity generation by the nuclear power plants, and increase carbon sequestration by natural ecosystems. Germany aims at reduction in consumption of coal and, in the medium-term, of natural gas (by 2040–2050), as well as the expansion of production and consumption of hydrogen.

The big developing countries are striving to ensure inclusive economic growth that includes green energy transition (if it does not affect the development of other sectors), creation of jobs, and improvement of the quality of the environment.

Enhancement of climate policy in China is possible due to the extensive problem of air pollution in its industrial centres. On the national level, control of GHG emissions and local pollutants largely relies on the same regulatory framework. In 2021, the country launched a national GHG emissions trading system, which may become the world's largest in the near future. China's climate change mitigation goals include peaking and reducing GHG emissions in the current decade.

In China, Japan and Germany, the climate policy has predominantly become an instrument of technological policy aimed at consolidating the technological leadership of national businesses and scaling up exports of low-carbon products and technologies. In Saudi Arabia, the severe shortage of natural resources has become a major driver for the introduction of a circular economy approach. In Brazil, the climate policy largely deals with improving efficiency of forestry management. In the United States, the climate policy discourse in recent years has been linked to the painful issue of mitigating social and economic inequality in the country.

Being the largest country in terms of territory, Russia plays an important role in the global climate: its forest area is 871 million hectares (20% of the world's forests), agricultural land covers 221 million hectares (10% of the world's arable land), and fossil fuel reserves exceed 350 billion tons in oil equivalent (toe) or 14,653 EJ. In 2021, the national strategy of socio-economic development with low GHG emissions by 2050 was adopted, which provides two main scenarios—inertial and intensive [Government of the RF, 2020]. The latter assumes that net GHG emissions can be reduced by more than 80% by 2050 compared to 2020 levels. Sectoral studies show that Russia has a huge potential to reduce GHG emissions with very low or even

negative costs. For instance, McKinsey & Company analyzed 60 measures in different sectors that can help reduce energy consumption by 23% and GHG emissions by 19% by 2030 compared to the business-as-usual scenario [McKinsey, 2009]. The deep decarbonization scenarios modelled using the TIMES model show that energy CO2 emissions can be reduced by 87% by 2050 compared to 2010 levels, while the annual costs of energy decarbonization are estimated at $12 billion by 2030 and $42 billion by 2050 [Safonov et al., 2020].

International Cooperation in Combating Climate Change

After long and difficult international negotiations, the agreement on implementation of Article 6 of the Paris Agreement was reached at the 26th Conference of the Parties to the UNFCCC (COP 26) in Glasgow (2021), which adopted the following mechanisms of cooperation to combat climate change:

Article 6.2. The guidelines on internationally transferred mitigation outcomes (ITMO) units trading between the parties were adopted. They provide opportunities for expanding the global carbon market, trading by internationally recognized carbon units, and fulfilling the national commitments by investing in foreign cost-effective carbon projects.

Article 6.4. Rules, conditions, and procedures for special projects and programmes that create emission reduction units (A6.4ER) were adopted. The Supervisory Body was established to approve the methodologies and procedures for implementation of the international carbon projects. Absence of negative social and environmental impacts is one the key requirements for project approval, and there are no restrictions on the types of project activities.

Article 6.8. A work programme on non-market cooperation was adopted that includes a broad range of options for international cooperation based on bilateral and multilateral regulations (such as border adjustment carbon fees, taxes, standards, and requirements). There are various examples of such cooperation, including the EU Carbon Border Adjustment Mechanism, which requires compensation of carbon footprint of the products imported into the EU (similar measures are currently considered in the US and other countries); the ICAO CORSIA programme requiring the offset of GHG emissions from international flights through the purchase of carbon credits based on voluntary standards; and the Joint Crediting Mechanism proposed by Japan.

The global carbon market has developed rapidly in recent years. According to the World Bank, there are already 68 carbon pricing schemes operating on regional, national, and subnational levels covering about 12 billion tons of CO2-equivalent per year or 23% of global GHG emissions [World Bank, n.d.]. The total turnover in the world's carbon markets in 2021 amounted to $851 billion [Nordeng, 2022].

In addition to direct trading with carbon emission allowances and credits, there are other mechanisms aiming to enhance decarbonization, such as issuance of green bonds worth more than $1 trillion in 2021 [Climate Bonds Initiative, 2021], withdrawal from project financing in coal and other fossil fuels, divestment from carbon-intensive and polluting industries, which amounted to $40 trillion in 2021 [IEEFA et al, 2021], and numerous programmes to support the development of renewable energy sources, green transport, energy storage technologies, bioeconomy markets, afforestation, climate smart forestry and agriculture.

Conclusions

The measures proposed by the parties to the Paris Agreement to decarbonize the world economy are insufficient to keep global warming below 1.5–2°C. Much more ambitious and fast actions are required to reduce GHG emissions and increase carbon sequestration. Countries and regions have very different capacities and potential to implement climate change mitigation projects and programmes. To ensure faster achievement of carbon neutrality, cooperative strategies to direct the financial, technical, and other resources to achieve the maximum effects (not only carbon, but social and environmental benefits) must be pursued.

The world carbon market, financial instruments, sustainable development mechanisms, national and subnational initiatives, and climate-smart business practices provide foundations for the successful implementation of the Paris Agreement, however they are insufficient so far.

International cooperation to combat climate change creates favourable opportunities for Russia not only for the green transition of its national economy, but also for participation in the global processes of decarbonization of the world economy due to a huge potential of zero-carbon energy sources, the world's largest forest ecosystems, and land resources. Achievement of the Paris Agreement goals without Russia's active participation would be very difficult and costly.

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