

COMPARATIVE ANALYSIS OF NATIONAL DECARBONIZATION POLICIES: IS IT POSSIBLE TO ACHIEVE CARBON NEUTRALITY BY 2050?

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ABSTRACT

The complexity of the task of decarbonizing the global economy requires an integrated and coordinated approach from the governments of developed and developing countries, the organization of effective international cooperation and scientific and technological progress in the field of environmental technologies and alternative energy sources. At present, despite the measures taken, the problem of achieving carbon neutrality is the difficulties of abandoning fossil fuels in countries showing significant economic growth and being the largest CO₂ emitters in recent decades. The purpose of this study is to review and analyse the current state of different energy sources consumption by the leading countries in CO₂ emissions, and the projected changes in the global energy system during the fourth energy transition considering possible decarbonization scenarios. The article presents a comparative analysis of national policies and initiatives for the transition to a low-carbon economy and assesses the prospects for achieving the stated targets for reducing CO₂ emissions by 2050.

Keywords: fossil fuels, decarbonization, energy policies, low-carbon economy.

1 INTRODUCTION

The increase in the concentration of greenhouse gases (GHG) in the atmosphere, associated with the active use of natural energy carriers (coal, oil, natural gas) as fuel for energy production, disrupts the heat exchange of the planet with the surrounding space, which leads to significant climate changes [1]–[3]. A low-carbon economy involves the development and use of more environmentally friendly energy sources that do not have a negative environmental impact or emit a minimum level of GHG. The governments of developed and developing countries are currently setting as a strategic goal the abandonment of the use of fossil fuels and an increase in the share of alternative energy sources (renewable energy sources (RES), nuclear power, hydrogen energy) in the structure of electricity production [4]–[8].

International cooperation is an important element of the strivings to mitigate environmental pollution and climate change on the planet [9]. For several decades, agreements have been actively developed and various programs and initiatives aimed at solving current environmental and climate challenges have been implemented. Also, conferences with the participation of high-ranking officials have been organized, targets and deadlines for their achievement have been set [10]. In 2016, the Paris Agreement came into force, the purpose of which is to keep the growth of the global average temperature well below 2°C and make efforts to limit its growth by 1.5°C. This target should be achieved through the implementation of a wide range of environmental measures and initiatives, among which the transition to a low-carbon economy has a role to play [11].

Despite, however, all the measures taken and the goals set, the dynamics of GHG in the world shows an upward trend: according to [12], the volume of global CO₂ emissions from the burning of fossil fuels increased by 66.64% between 1990 and 2021. More than 66% of all emissions since 2005 have been consistently accounted for by China, the USA, India, Russia, Japan and the European Union (EU27) (Fig. 1).



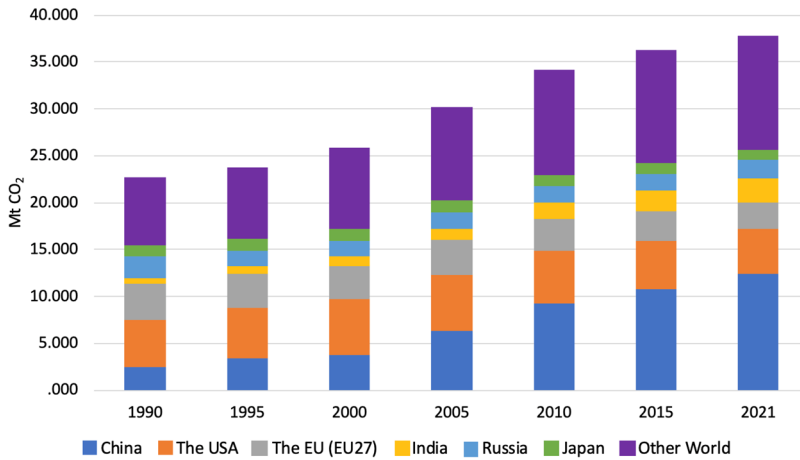


Figure 1: Global CO₂ emissions by country from 1990 to 2021. (Source: Compiled by the authors using data from [12].)

In 2021, China became the leader in CO₂ emissions from burning fossil fuels – 32.9%, followed by the USA (12.5%) and the European Union (EU27) (7.3%).

Economic growth stimulates an increase in energy demand, and traditional energy sources (coal, oil, natural gas) are often used to meet it due to their relative availability, cheapness and, consequently, low cost of electricity production in comparison with other sources. Fig. 2 shows the structure of global electricity production by fuel type.

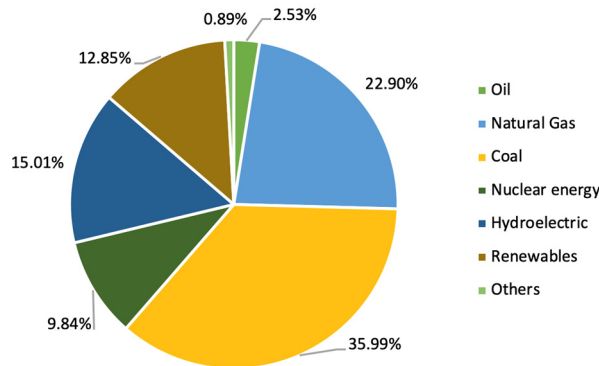


Figure 2: Global electricity production by fuel type in 2021, %. (Source: Compiled by the authors using data from [13].)

According to [12], more than 37% of global CO₂ emissions in 2021 were from the power sector, 20.4% from the industrial sector and 20.2% from the transportation sector. Thus, the power sector is the largest environmental polluter, therefore its eco-modernization should be a central part during the fourth energy transition. In 2021, 61.42% of all electricity in the world was produced from hydrocarbon fuels, while the share of RES, including hydropower,

is 24.85% [13]. Some of the largest CO₂-emitting countries are leaders in electricity production at traditional energy facilities, as well as in proven mineral reserves and the volume of their extraction may indicate a low level of motivation to switch to more expensive, but environmentally friendly energy sources [14], [15]. This fact significantly slows down the pace of transition to a low-carbon economy at the global level and calls into question the achievement of targets to reduce the negative impact on the environment in the long term.

The purpose of this study is to review and analyse the current state of consumption of various energy sources, and the projected changes in the global energy system (reduction of the role of fossil hydrocarbons, rapid expansion of the use of RES and electrification) during the fourth energy transition, taking into account possible scenarios. The article presents a comparative assessment of national policies and initiatives for the transition to a low-carbon economy and assesses the prospects for achieving the stated targets for reducing CO₂ emissions.

2 MATERIALS AND METHODS

2.1 Research framework

The study was conducted in several stages:

1. Compilation of characteristics of the energy sector of the countries that are the largest emitters of CO₂ emissions according to data for 2021 (China, USA, Russia, EU, Japan and India). Determination of the structure of electricity production by fuel type, analysis of changes in the gross consumption of fossil fuels in primary energy consumption in the period from 2011 to 2021 and identification of key features of the industry in each country.
2. A brief overview of the scenarios for decarbonization of the world economy presented by British Petroleum (BP) and International Energy Agency (IEA).
3. Comparative analysis of current policies on decarbonization of the economy in the countries under consideration, comparison of expected indicators with the current state of the energy sector and the scenarios considered at stage 2, and assessment of the prospects for abandoning fossil fuels. Fig. 3 shows the research framework.

2.2 Considered decarbonization scenarios

The prospects of abandoning fossil fuels and achieving carbon neutrality are widely analysed in the scientific community and by specialists involved in the predictive modelling. Within the framework of this study, six similar scenarios presented by the IEA and BP were considered (Table 1):

- Net zero emissions by 2050 (NZE) is the most favourable scenario presented by the IEA, built on the basis of effective international cooperation to achieve carbon neutrality, the development and use of the best available environmental and green technologies, and the rapid development of green energy.
- Announced pledges scenario (APS) (IEA) – assesses the possibilities of achieving carbon neutrality, taking into account the current situation and initiatives in the field of climate conservation and environmental protection.
- The stated policies scenario (STEPS) (IEA) is the least favourable scenario presented by the IEA, based on an analysis of current environmental and energy national policies.



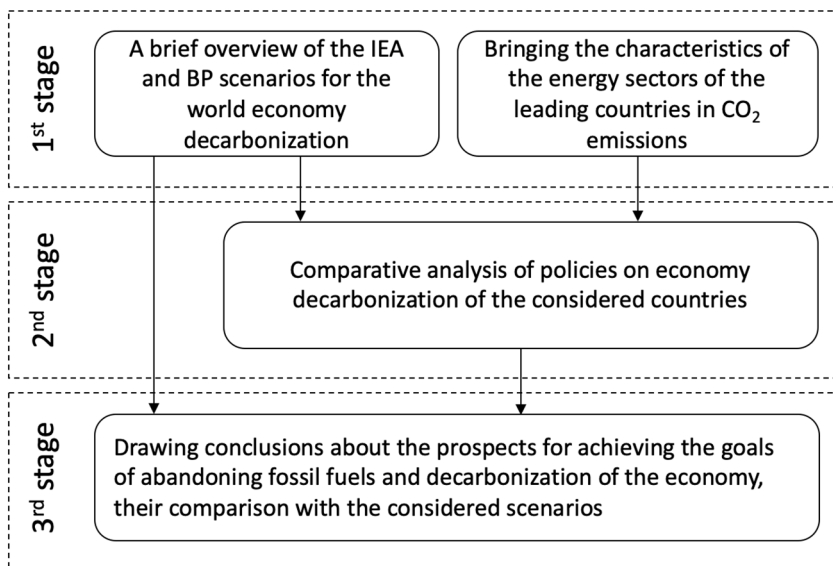


Figure 3: Research framework.

- Net zero (BP) is the most favourable scenario presented by BP, in which the achievement of carbon neutrality is achieved through an effective policy of abandoning minerals and the development of green energy. At the same time, the volume of CO₂ emissions in 2050 will not approach the 0 level but will amount to 2,400 Mt of CO₂.
- Accelerated (BP) is a scenario implying a significant increase in energy consumption by 2050 (mainly in developing countries), and partial achievement of the goals of decarbonization of the economy.
- New momentum (NP) is the least favourable scenario reflecting the current activity of the countries of the world to achieve carbon neutrality and reduce CO₂ emissions. According to the scenario, achieving carbon neutrality by 2050 is impossible.

Table 1: The key indicators of each considered scenario. (Source: Compiled by the authors using data from [16]–[18].)

| Scenario/expected indicators | NZE (IEA) | APS (IEA) | STEPS (IEA) | Net zero (BP) | Accelerated (BP) | New momentum (BP) |
|---|-----------|-----------|-------------|---------------|------------------|-------------------|
| Type of scenario | Positive | Moderate | Negative | Positive | Moderate | Negative |
| Endpoint | 2050 | 2050 | 2050 | 2050 | 2050 | 2050 |
| Expected indicators: | | | | | | |
| Total CO ₂ emissions, Mt CO ₂ | 0 | 12,399 | 31,979 | 2,400 | 9,900 | 31,100 |
| Share of renewables in energy supply, % | 70 | 51 | 29 | 72 | 57 | 35 |
| Share of fossil fuels in electricity production, % | 2 | 11 | 21 | 5 | 10 | 33 |
| Share of renewables in electricity production, % | 88 | 76 | 69 | 93 | 88 | 65 |

2.3 Brief review of energy sectors of considered countries

The key indicators of the energy sector of the leading countries in terms of CO₂ emissions are presented in Table 2, while the structure of primary energy consumption is shown in Fig. 4.

Table 2: The main indicators of the energy sector of the leading countries in CO₂ emissions for 2021. (Source: Compiled by the authors using data from [13] and [19].)

| Indicator | China | USA | EU (27) | Russia | Japan | India |
|--|--------|-------|---------|--------|-------|-------|
| Changes in primary energy consumption from fossil fuels (2021/2011), % | +61.06 | +13.3 | +7.9 | +20.7 | -12.0 | +73.2 |
| Electricity generation 2021, TWh | 8,539 | 4,371 | 2,963 | 1,158 | 1,024 | 1,686 |
| Shares of fossil fuels in electricity production, % | 61.10 | 65.90 | 34.20 | 61.36 | 64.66 | 78.00 |
| Shares of renewables in electricity production, % | 14.17 | 13.50 | 25.22 | 0.47 | 12.78 | 10.02 |

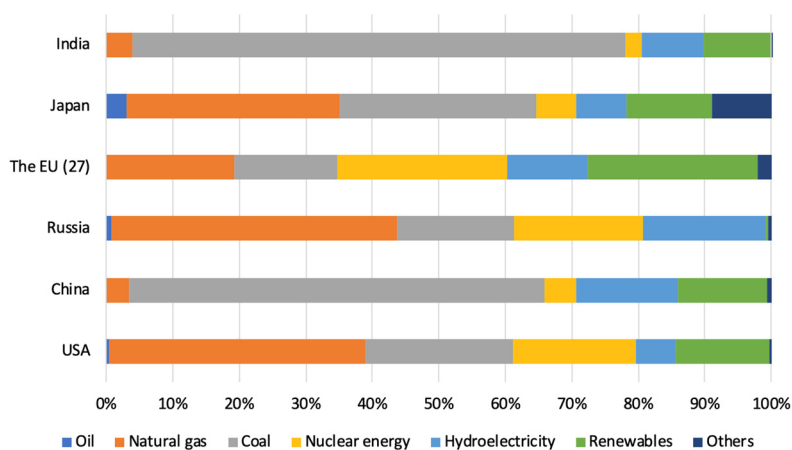


Figure 4: Structure of primary energy consumption in considered countries in 2021, % (Source: Compiled by the authors using data from [13].)

As can be seen from Fig. 4, coal, oil and natural gas are still widely used for energy production in the world. The leaders in their consumption among the countries under consideration are India, China and Japan.

3 RESULTS AND DISCUSSION

A characteristic feature of most of the leading countries in CO₂ emissions is the predominance of the use of fossil fuels in the structure of energy consumption. The largest increase in primary energy consumption obtained during the combustion of hydrocarbon fuels is demonstrated by India, China and Russia, moderate growth is observed in the USA and the EU, and a 12% decrease in the growth rate of minerals in the structure of energy consumption is observed in Japan. The EU is the leader in the use of renewable energy in the

structure of energy production (25.22%), while in Russia renewable energy accounts for less than 0.5% of the total volume of electricity produced.

Comparative analysis of national policies on decarbonization of the economy are presented in Table 3.

The EU (EU27) demonstrates the most positive trend: a moderate increase in primary energy consumption derived from fossil fuels, and the largest share of RES in the structure of electricity production. This might be due to more effective policies and measures taken in the field of climate conservation and environmental protection in comparison with other countries. The European Green Deal and the RePowerEU plan set strict goals for the abandonment of the use of natural energy carriers and the development of RES to achieve energy independence and carbon neutrality in the near future. Moreover, a carbon tax and ETSs are being actively introduced and developed in the last decade. According to Bolat et al. [35], these two economic tools might have a considerable positive effect on combating GHG emissions. Their complete or partial absence, as demonstrated by the comparative analysis, correlates with the pace of the shifting to a low-carbon economy. The governments of the EU countries also compensate part of the tariffs (feed-in-tariffs) for electricity received from RES, which encourages end consumers to give preference to 'clean' electricity [10].

The Chinese government has adjusted its long-term development strategy: now reducing CO₂ emissions and introducing more environmentally friendly energy sources into the country's energy system is one of the central challenges for the coming decades [36]. However, despite the measures taken, peak of CO₂ emissions, even if all planned measures are implemented, is expected in 2030, and the achievement of carbon neutrality only in 2060 [21]. China's abrupt abandonment of fossil fuels seems unlikely due to significant economic growth, high demand for energy within the country and some specific features of Chinese energy: the predominant share of coal-fired energy, uneven distribution of energy within the country and excess demand for electricity over its supply [37]. The share of coal in China's primary energy consumption is 62.56%, which means obtaining relatively cheap electricity from natural energy carriers available in China. A complete rejection of its use implies not only the development of renewable energy, but also an increase in imports of natural gas and oil from neighbouring countries, which will reduce national energy security.

Another important player in reducing CO₂ emissions is India, the country that has demonstrated the largest increase in the use of fossil fuels over a 10 year period (+73.2%). The peculiarity of the Indian energy sector is the scarce mineral reserves, the predominance of coal in the structure of electricity production and the absence of main gas and oil pipelines from natural resource exporting countries [38], [39]. In addition, India is the only country that does not have an official policy of the economy decarbonization and reduction of CO₂ emissions. It also does not use carbon tax and ETS to stimulate emissions reduction. According to the Indian government, achieving carbon neutrality requires significant changes at the national level and is expected no earlier than 2070. A positive factor is the installation of a tax on domestically produced and imported coal, which encourages the energy sector to switch to more environmentally friendly energy sources. In addition, in 2023, the government announced an initiative to develop the Indian Carbon Market in the coming years, as well as a change in the vector of energy development: the development of alternative energy and the implementation of measures to curb the increase in average temperature on the planet are becoming priorities [34].

The USA expects to achieve zero CO₂ emissions by 2050, which corresponds to the goals outlined in the Paris Agreement. However, many scientists note that the current U.S. policy in the field of abandoning fossil fuels and the development of renewable energy is ineffective



Table 3: Comparative analysis of national policies on decarbonization of the economy. (Source: Compiled by the authors using data from [10], [20]–[34].)

| Country | Policy documents | Key targets | Implementation of emission trading system (ETS) and carbon tax | Additional comments |
|---------|--|---|--|--|
| China | <ul style="list-style-type: none"> Working guidance for carbon dioxide peaking and carbon neutrality in full and faithful implementation of the new development philosophy China's mid-century long-term low GHG emission development strategy | <ul style="list-style-type: none"> Achieve carbon neutrality by 2060 The share of non-fossil in energy consumption: 20% by 2025, 25% by 2030, 80% by 2060 | <ul style="list-style-type: none"> China's national ETS (operating since 2021) Pilot ETS: Beijing, Fujian, Hubei, etc.) No carbon tax initiatives | <ul style="list-style-type: none"> China is expecting the peak of CO₂ emissions in 2030 The common strategy for economy decarbonization is under development |
| USA | <ul style="list-style-type: none"> The long-term strategy of the United States Pathways to Net-Zero GHG Emissions by 2050 | <ul style="list-style-type: none"> Achieve 100% carbon-free electricity by 2035 50%–52% reduction of CO₂ emissions (from 2005 levels) Achieve carbon neutrality in 2050 | <ul style="list-style-type: none"> ETS in force: California cap-and-trade program, Washington cap-and-invest, etc. Carbon tax is introduced in several states, but not on national level | <p>Currently, the US has a mandatory program, The Regional GHG Initiative (RGGI), aimed at reducing CO₂ emissions</p> |
| Russia | <ul style="list-style-type: none"> Energy strategy of the Russian Federation until 2035 The strategy of socio-economic development of Russia with a low level of GHG emissions by 2050 | <ul style="list-style-type: none"> Achieve carbon neutrality in 2060 Net CO₂ emissions will decrease by 60% from the level of 2019 by 2050 The share of RES in the structure of electricity production will be 6% by 2035 | <ul style="list-style-type: none"> Carbon tax pilot project starts in the end of 2023 ETS Sakhalin (under development) | <p>More than 49% of national exports are accounted for by exports of energy products (coal, gas, natural gas), consequently, Russia may face severe economic problems resulting from the abandonment of fossil fuels</p> |

Table 3: Continued.

| Country | Policy documents | Key targets | Implementation of emission trading system (ETS) and carbon tax | Additional comments |
|---------|--|--|--|--|
| EU27 | <ul style="list-style-type: none"> The European green deal REPowerEU | <ul style="list-style-type: none"> Reduction of net GHG emissions by at least 55% by 2030, compared to 1990 levels Achieve carbon neutrality by 2050 Above 32% share of renewable energy by 2030 At least 32.5% improvement in energy efficiency by 2030 | <ul style="list-style-type: none"> ETS in force: German national ETS, Austrian national ETS; Switzerland ETS, etc. Carbon tax is implemented | Each EU member state is required to develop its own national long-term strategy and national energy and climate plans (NECPs), where should be placed various environmental targets including CO ₂ emissions target, RES development target, etc. |
| Japan | <ul style="list-style-type: none"> The 6th strategic energy plan 'S+3E' (safety plus energy security, economic efficiency, and environmental sustainability) Green growth strategy through achieving carbon neutrality in 2050 | <ul style="list-style-type: none"> Achieve carbon neutrality by 2050 46% cut in GHG by 2030 from 2013 levels Boost renewable energy share in electricity production to 36%–38%, double 2019 levels | <ul style="list-style-type: none"> ETS in force: Saitama ETS, Tokyo cap-and-trade ETS Carbon tax is implemented | The strategy specifies 14 promising fields that are expected to grow and provides them with action plans from the viewpoints of both industrial and energy policies |
| India | India's long-term low-carbon development strategy | <ul style="list-style-type: none"> Decarbonization energy sector to 50% by 2030 Achieve 500 GW of fossil fuel-free generating capacity by 2030 Achieve carbon neutrality by 2070 | No ETS/carbon tax | <ul style="list-style-type: none"> Indian government introduced plans to develop Indian Carbon Market in 2023 Instead of carbon tax, Indian government placed a tax on both imported and domestically produced coal |

and achieving the established indicators while maintaining the current dynamics seems impossible [40]–[42]. The United States has significant reserves of natural energy carriers, according to data for 2021, more than 60% of primary energy consumption is accounted for by coal, oil and natural gas, the production of energy from which is much cheaper in comparison with RES. In addition, the USA is actively developing the bioenergy industry: in 2021, the United States became the world leader in the production of biofuels (643 thousand tons of oil equivalent or 40.7% of global biofuel production) and the production of electricity from them. The U.S. government is implementing a wide range of economic and legal instruments that encourage industry to reduce CO₂ emissions and switch to cleaner energy sources: ETS are functioning in several states, carbon taxes are being introduced, renewable portfolio standards, feed-in-tariffs, etc. have been introduced at the national level [10].

Russia demonstrates lower rates of renewable energy development in comparison with most countries, which is due to the significant predominance of traditional energy, in particular gas, in the structure of the energy complex. Despite the fact that natural gas is a more environmentally friendly type of fuel compared to oil and coal, a certain amount of CO₂ is also released as a result of its combustion, which does not fully meet the long-term goals of decarbonizing the economy at the global level. The Russian government does not set ambitious goals for the development of alternative energy and the complete abandonment of fossil fuels: by 2050, net GHG emissions are expected to decrease by 60% from the level of 2019 and by 80% from the level of 1990, and the share of RES will be only 6% by 2035 – the lowest indicator among the major energy consumers. However, in the next few years, it is expected to launch pilot projects on the introduction of a carbon tax and the start of the operation of ETS.

Japan is the only country from the list under consideration that has demonstrated a 12% decrease in the use of fossil fuels in the structure of primary energy consumption from 2011 to 2021. However, the share of fossil fuels in primary energy consumption is still around 64%. Japan was the first Asian country to establish a carbon tax and two ETS operate on its territory [43]. In addition, as tools to stimulate the development of renewable energy, the abandonment of fossil fuels and the implementation of environmental measures, the Japanese government has introduced such tools as voluntary credits, Joint Crediting Mechanism, that is designed to certify the amount of GHG emissions reduced and removed by sinks and non-fossil fuel energy certificates. Despite the positive dynamics, some researchers note that Japan may not achieve carbon neutrality by 2050 due to the relatively low rate of reduction of anthropogenic pressure on the environment [43], [44].

Based on the comparative analysis, the following conclusions could be drawn:

- the likelihood of achieving carbon neutrality by 2050 at the global level: the largest consumers of natural resources with the most rapid growth in energy consumption in recent decades (China, India, Russia) set goals to achieve carbon neutrality only by 2060 or 2070;
- the abandonment of fossil fuels in countries with significant fossil fuel reserves will occur at a slower pace, which will negatively affect the prospects for a significant reduction in CO₂ emissions after 2030;
- the implementation of ETS and carbon tax can have a positive impact on the dynamics of reducing CO₂ emissions in the industrial sector of the economy at the national level;
- significant changes in the structure of global energy consumption by 2030 are also unlikely due to the strong dependence of the energy sectors of India and China on hydrocarbon fuels. The gradual development of RES will eventually be able to displace



traditional energy sources in these countries, but this requires a large-scale eco-modernization of the energy sector.

- most of the world's largest economies are still focused on fossil fuels, as it is often cheap and familiar. The transition to new, RES or low-carbon technologies may require large investments, rethinking business models and changing familiar practices, which will require significant time, labour, financial and intellectual resources.

Thus, the prospects for most of the leading countries to reduce CO₂ emissions and abandon fossil fuels correspond to moderate and negative scenarios for decarbonization of the economy. The EU (EU27) is the only candidate to achieve real carbon neutrality by 2050.

4 CONCLUSIONS

A comparative analysis of the national policies of the leading countries on CO₂ emissions in the field of decarbonization showed that only the EU policy can correspond to the positive scenarios of the IEA and BP, the decarbonization policies of the USA and Japan – a moderate scenario, the policies of China, India, Russia – a negative one. Thus, according to the most realistic scenarios, the abandonment of the use of fossil fuels and the achievement of zero CO₂ emissions by 2050 at the global level is unlikely.

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