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MANAGEMENT OF DECARBONIZATION OF THE ECONOMY: SMALL MODULAR REACTORS AND ELECTRIC VEHICLES – KEY SUCCESS FACTORS

МЕНЕДЖМЕНТ ДЕКАРБОНІЗАЦІЇ ЕКОНОМІКИ: МАЛІ МОДУЛЬНІ РЕАКТОРИ ТА ЕЛЕКТРОМОБІЛІ – КЛЮЧОВІ ФАКТОРИ УСПІХУ

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The intensity of climate change on the planet under the influence of human economic activity is analyzed. 2023, according to experts, was the hottest year in the entire history of climate observations. The highest content of harmful gases in the atmosphere was also noted. Climate change causes great economic damage to humanity. In March 2024, heads of state and government and other high-ranking representatives of 32 countries gathered in Brussels for the inaugural Nuclear Energy Summit. The Summit supported global efforts to develop nuclear energy in areas such as investment, innovation, and training to address climate change and improve the energy security of the global economy. An analysis of the system of elements of economic decarbonization, their current and future value, problems of development of such elements was carried out, which showed the most important importance in the near future for the global development of small modular reactors and offshore wind energy in combination with mass production and use of electric vehicles. The key to decarbonizing the economy is effective management.

Keywords: climate change, Nuclear Energy Summit, management, energy, small modular reactors, decarbonization, innovation, investment, prospects, wind power plants, hydrogen fuel.

Аналізується інтенсивність зміни клімату планети під впливом господарської діяльності людства. 2023 рік, на думку експертів, став найспекотнішим за всю історію спостережень. Відзначено найвищий вміст шкідливих газів у атмосфері. Зміна клімату завдає величезних економічних збитків світовій економіці. У березні 2024 року глави держав та урядів, а також інші високопоставлені представники 32 країн зібралися в Брюсселі на перший Саміт з ядерної енергетики, який підтримав глобальні зусилля щодо її розвитку в таких галузях, як інвестиції, інновації та навчання для вирішення проблем зміни клімату та підвищення енергетичної безпеки глобальної економіки. У позиції учасників саміту відзначено потребу людства в кліматично нейтральній енергії, зроблено акцент на глобальні зусилля, узгоджені дії всіх країн світу, необхідність використання коштів міжнародних фінансових організацій для інвестицій у розвиток атомної енергетики та збільшення її потужності. Показано загальне переконання у необхідності комплексного розвитку атомної енергетики та відновлюваних джерел енергії, якщо людство має на меті досягнення нульових викидів шкідливих газів в атмос-



феру. Глобальний форум виступає як яскравий політичний сигнал визнання атомної енергетики для всього світу і важливий інструмент досягнення нульових викидів. Вказується на необхідність прискорення темпів енергетичного переходу. Відзначається важлива зміна у громадській думці у бік розвитку атомної енергетики. Наголошено, що для такого розвитку принципово є довіра світової спільноти на основі прозорості, доступності та повноти інформації. Важливим завданням визнано поєднати зусиль громадян, політиків, представників промисловості у розвитку ядерної енергії. Проведено аналіз системи елементів економічної декарбонізації, їх поточного та перспективного значення, проблем розробки таких елементів, що показав ключове значення у найближчому майбутньому для глобального розвитку виробництва малих модульних атомних реакторів та морської вітроенергетики у поєднанні з масовим випуском та використанням електромобілів. Важливим для декарбонізації економіки є ефективне управління.

Ключові слова: зміна клімату, Саміт з атомної енергії, менеджмент, енергетика, малі модульні реактори, декарбонізація, інновації, інвестиції, перспективи, вітряні електростанції, водневе паливо.

Formulation of the problem. The intensity of global climate change continues to increase. Numerous manifestations of negative changes significantly affect the global economy. The global community must develop and actively implement correct and comprehensive management measures that correspond to the current situation. These measures should ensure global economic growth, sustainable development, innovative progress and environmental conservation.

Analysis of recent research and publications. Analysis of the latest research and publications. Problems of global economic development, the study of climate change, and the development of climate-neutral industries attract great interest from scientists and experts. Among the authors of the studies, it is necessary to note such scientists as Claudia Kemfert, Christian von Hirschhausen, Leonard Goeke, Rolf Wüstenhagen, Martin Kittel, Adrian Rinscheid, Jens Turau. The authors make an important contribution to the study of current problems in the global economy.

Previously unsolved parts of the overall problem. Numerous studies by scientists on climate change and the development of various areas of global energy do not consider in detail some issues of management of such a complex and complex process as the decarbonization of the world economy. It is of interest to further study the directions and specific measures for decarbonization management, priorities and sequence of decisions, a set of issues of innovation, investment, staffing, and involvement of the public. It is also necessary to study the issues of making management decisions on the problems of decarbonization and their implementation.

Presentation of the main research material. World Meteorological Organization (WMO) introduced the public and specialists to the general circles of the public and specialists in the beginning of the climate state «State of

the Global Climate 2023» [1]. The document strengthens the pessimistic expectations of scientists: our Earth is heated to experience a record rate of heating. In February 2024, humanity for the first time in its history existed 12 months with temperatures higher than pre-industrialists by 1.5 °C. According to the report «State of the Global Climate 2023» [1], «The air masses of heat, floods, droughts, forest fires and active tropical cyclones caused suffering and chaos, turning the daily life of millions of people and inflicting multi-billion dollar economic losses». The report noted that 2023 was the warmest year in the history of observations: the average global temperature was 1.45 °C (with an error of ± 0.12 °C) above the pre-industrial basic level. The indicated document also twitches: the concentration of three main greenhouse gases – carbon dioxide, methane and nitrogen oxide – reached a record level in 2022. CO₂ levels are half higher than in the pre-industrial era, which leads to heat retention in the atmosphere. It is also indicated that preliminary data for the 2022–2023 hydrological year show that the global set of reference glaciers suffered the largest loss of ice in the history of observations (1950–2023), which is caused by the extremely negative balance of mass both in the west of North America and in Europe. Glaciers in European Alps survived the season of extreme melting [1].

Climate changes cause great damage to people around the world, lead to large-scale economic consequences. In the report “The human cost of disasters: an overview of the last 20 years (2000–2019)” [2] authoritative organizations – United Nations Office for Disaster Risk Reduction and Centre for Research on the Epidemiology of Disasters the consequences of climate change are indicated: an increase in the number of natural disasters with serious destructive consequences. The largest number of natural disasters for the period from 2000 to 2019.

It occurred in Asia, in total these are 3068 natural disasters, then there were a total of 1756 such events in America and a total of 1192 natural disasters in Africa. As for different countries of the world (Figure 1, [2]), it is necessary to indicate China (577 natural disasters), the United States of America (467 natural disasters), they are followed by India (321 cases), the Philippines (304 case), Indonesia (278 case).

Next is the report “The human cost of disasters: an overview of the last 20 years (2000–2019)” indicates the following [2]: “In the 20-year period between 2000 and 2019, EM-DAT recorded 7,348 disasters events, which claimed a total of approximately 1.2 million lives and affected more than 4.03 billion people. On average, there were 367 disaster events each year, the majority of which were floods and storms (44% and 28% respectively)” [2] (Figure 2).

In the report “The human cost of disasters: an overview of the last 20 years (2000–2019)” an important analysis of the types of natural disasters is also given: “Worldwide, floods are the most common type of disaster, accounting for 44% of total events considered in this report (Figure 2). Floods are hydrological events, a disaster subgroup that also includes landslides which are responsible for 5% of total events (Figure 2). Storms are the second most common type of disaster event, accounting for 28% of events worldwide. Storms most frequently affect coastal communities near the world’s oceans and are considered part of

the meteorological disaster sub-group, along with extreme temperatures (6% of events). Climatological events are a less prevalent disaster sub-group that include droughts and wildfires, which account for 5% and 3% of total events respectively. Finally, geophysical events, such as earthquakes and volcanic activity, make up a total of 9% of all events, the majority of which are earthquakes (including tsunamis)” [2].

In March 2024, a very representative summit of countries supporting nuclear energy was held in Brussels, which was organized jointly by the International Atomic Energy Agency and the Belgian government. The leaders of a number of states and representatives of 32 countries on the nuclear energy summit supported measures in areas such as financing, technological innovations, cooperation in the field of regulation and training in order to ensure the expansion of nuclear potential to solve the problem of climate change and increase energy security [3]. The analysis of the speeches of the participants of this forum on the development of energy, the decarbonization of the global economy is of interest.

Director General of the International Atomic Energy Agency Rafael Mariano Grossi noted the following [3]:

1. The parallels between the past and the present, an indication of the relevance of nuclear energy 70 years after the performance of US President Eisenhower. The need of mankind is

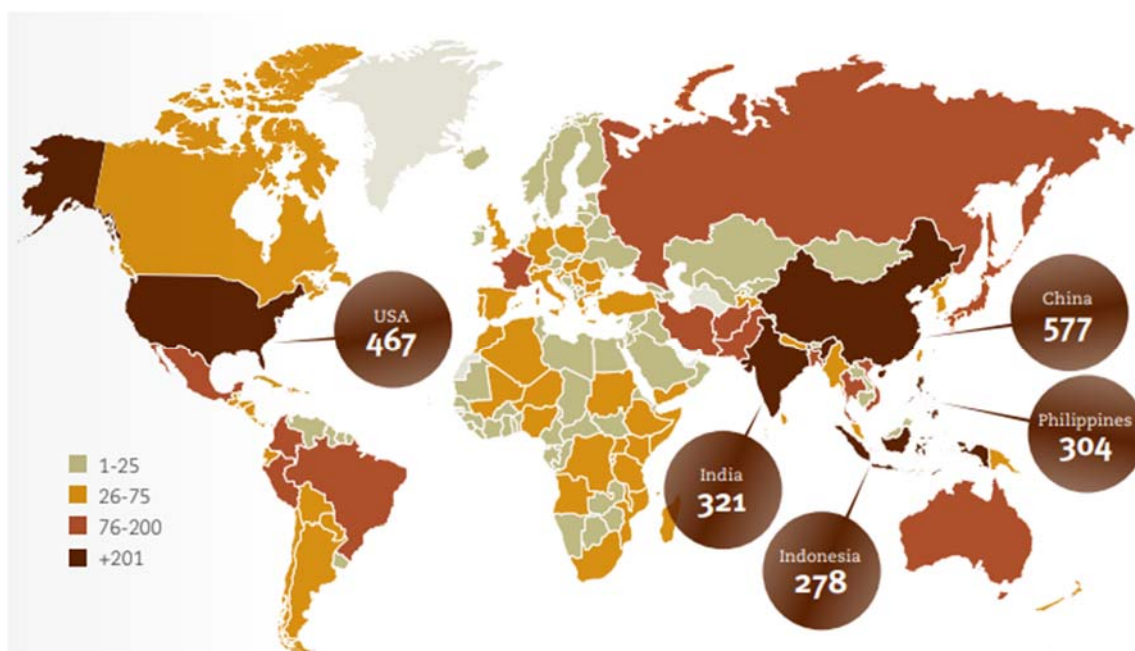


Figure. 1. Number of disasters reported per country/territory (2000–2019)

Source: [2]

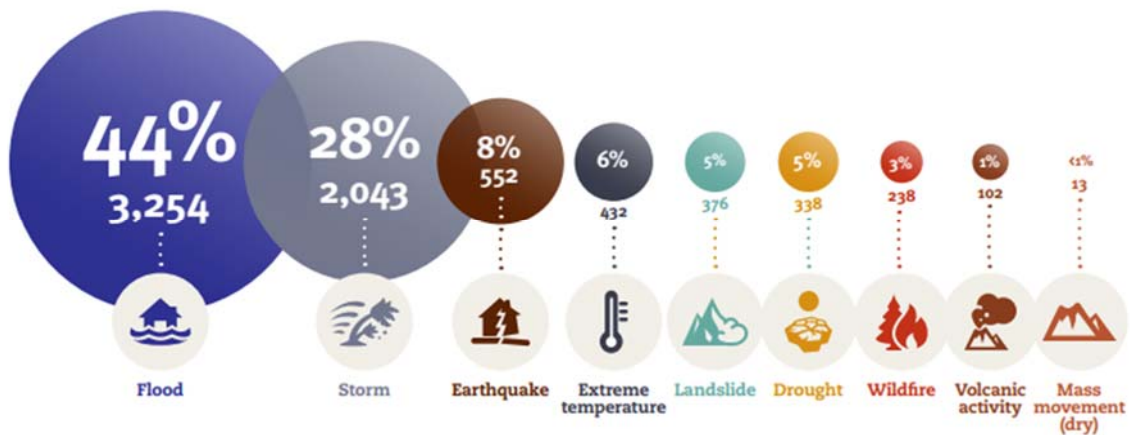


Figure. 2. Percentage of occurrences of disasters by disaster type (2000–2019)

Source: [2]

noted for a pure energy from an environmental point of view.

2. The emphasis on global efforts, coordinated actions of the countries of the world. The need to use international financial funds for investment in the development of atomic energy and an increase in its capacity.

3. COP28 rating as a forum with a clear position: "...to be pro-environment is to be pro-nuclear"[3]. COP28 assessment as a summit, which showed that "shows the nuclear taboo is over, starting a new chapter for nuclear commitment" [3].

Prime Minister of Belgium Alexander De Croo [3; 4] indicated:

1. A radical change in Belgium's previous position on closing nuclear power plants in favor of continuing their operation. A growing conviction in the need for integrated development of nuclear energy and renewable energy sources if humanity aims to achieve zero emissions of harmful gases into the atmosphere.

2. The Global Forum is a strong political signal for the entire world to recognize nuclear energy as an important tool for achieving zero emissions. The importance of not only discussing development issues, but also implementing decisions in life.

3. The need to accelerate the pace of the energy transition. There is a high level of public awareness about nuclear energy, a sharp change in public opinion towards the development of nuclear energy.

4. Public trust based on transparency, accessibility and completeness of information is important for the development of nuclear energy. The task is to join forces, consolidating the expectations of citizens, politicians, industry

representatives and all interested parties, in the context of the use of nuclear energy.

5. Attention is paid to innovative solutions, in particular, small modular reactors, which will become a stable source of energy for the global economy. A deep modernization of the world energy sector based on innovation is necessary.

6. As a basic source of electricity for many countries, "nuclear energy will continue to play a critical role" [4].

7. Innovation in the nuclear industry aims to develop flexible and smart energy systems that are resilient, provide security of supply, are carbon neutral and have the lowest possible operating costs. Innovations like these suggest the industry is moving in the right direction.

8. Belgium is investing the most heavily in its history in renewable energy. The country aims to quadruple electricity production from North Sea wind turbines to 8 GW by 2040, which will meet the electricity needs of 50 percent of all Belgian households.

9. Wind energy development in Belgium needs to be complemented by other low-carbon energy sources, such as nuclear power.

10. Belgium expects to participate in innovative research in the field of dismantling nuclear installations and developing fourth-generation SMRs [3; 4].

Ursula von der Leyen, President of the European Commission Ursula noted that [3]:

1. There are currently different views on nuclear energy in the European Union. The prospects for nuclear energy are not guaranteed, given the downward trend in the share of nuclear energy in the EU since the 1990s. Nuclear power must play a vital role in Europe's energy sector, given the urgent need to combat climate change.

2. Nuclear power plants can be considered safe. Countries that are considering closing nuclear power plants "consider their options carefully before foregoing a readily available source of low-emission electricity" [3]. Innovation in nuclear energy is needed, with the development of small modular reactors mentioned.

Romanian President Klaus Iohannis [3] said that the country is ready to actively develop its nuclear power program, with the possibility of using traditional large and small modular reactors.

Prime Minister of Bulgaria Nikolai Denkov [3] pointed out the country's very long period of use of nuclear energy, the importance of further investments, nuclear energy will be an important area of the country's energy sector.

Serbia's President Aleksandar Vučić congratulated the organisers for holding a summit which was "much more important than many meetings and gatherings bureaucratically organised just to see each other and not to do things"[3]. Serbia's President also said that his country is interested in building three or four small modular reactors with appropriate innovation and investment support.

The Chinese President's Special Envoy Vice Premier Zhong Guoqing [3], said China had 55 nuclear energy units in operation with 36 under construction. The importance of this for combating global climate change is noted.

Croatian Prime Minister Andrej Plenković said [3] that nuclear power is critical to achieving the net-zero emissions target and called for funding for nuclear power development from the European Investment Bank and other financial institutions.

Czech Prime Minister Petr Fiala noted the importance of existing power plants in terms of energy security, costs and climate goals, and said international cooperation will bring all of us bigger benefits" [3].

Finland's Prime Minister Petteri Orpo noted the importance for this country of using centralized heating using nuclear energy and producing hydrogen. In addition, Petteri Orpo emphasized the importance of safe storage of radioactive waste deep in the earth under appropriate geological conditions [3].

Prime Minister of the Netherlands Mark Rutte pointed out that many citizens previously had concerns about nuclear energy, but people's views have changed, "...never before has it been so obvious that for the transition to succeed we need every source" [3].

Slovakia's Prime Minister Robert Fico [3] said his government was planning to construct 1200 MW additional nuclear power capacity.

Slovenia's Prime Minister Robert Golob noted the following: support nuclear energy from his country's citizens currently exceeds 65% – "it has never been higher"[3]. The development of nuclear energy requires investments, as well as loans from international banks at affordable rates.

French President Emmanuel Macron said [3]:

1. Supported the alliance for the development of nuclear energy.

2. Emphasized that nuclear energy is a critical tool that allows us to join efforts to reduce emissions, create new jobs and improve energy security.

3. Emmanuel Macron said, that many countries wanted to electrify mobility "but if the electricity is produced by fossil fuels it is a stupid move"[3].

4. It is important to combine increasing the energy efficiency of the economy, increasing the share of renewable energy sources, as well as the development of new nuclear technologies.

Pakistan's Foreign Minister Mohammad Ishaq Dar noted the following [3]: nuclear energy is a priority in Pakistan's energy sector and the country's climate change policy. Small modular reactors are capable of providing energy to consumers in remote or hard-to-reach areas.

Turkey's Foreign Minister Hakan Fidan pointed out [3]: the Akkuyu nuclear power plant alone can provide 10% of Turkey's electricity consumption. The country plans to build traditional large nuclear reactors and small modular reactors.

Masahiro Komura, Parliamentary vice minister for foreign affairs, said [3]: it is very important to implement climate neutral energy to the maximum extent possible. A strategy is needed to attract large amounts of investment for the development of nuclear energy.

John Podesta Senior Advisor to the President for Clean Energy, Innovation and Implementation [3]:

1. Pointed to the commitment made at COP28 to triple nuclear power capacity by 2050, with the US increasing such capacity by 200 GW.

2. The US will participate in climate conservation efforts and help other countries around the world "build safe, secure, reliable, nuclear power"[3].

The joint declaration of the forum states [5]: "We, the leaders of countries operating nuclear

power plants, or expanding or embarking on or exploring the option of nuclear power, and the Director General of the International Atomic Energy Agency (IAEA), gathered in Brussels for the inaugural Nuclear Energy Summit to reaffirm our strong commitment to nuclear energy as a key component of our global strategy to reduce greenhouse gas emissions from both power and industrial sectors, ensure energy security, enhance energy resilience, and promote long-term sustainable development and clean energy transition". Climate change presents an existential threat to our planet and all humankind. The warning signs are mounting worldwide, from raging wildfires to historic floods, making the need to achieve global net-zero greenhouse gas emissions increasingly urgent. In this regard, an increasing number of countries have set their targets for climate neutrality, carbon neutrality, greenhouse gas neutrality, or net zero emissions. The ambitious target of global net zero emissions necessitates a comprehensive approach to radically reduce emissions of the world's most emission-intensive sectors including electricity generation, transportation, and industry. The summit participants state with certainty: "Climate change presents an existential threat to our planet and all humankind". Further in this regard they indicate the following [5]:

1. Climate change poses a very tangible threat to all life on earth, the signals of which are large-scale floods and forest fires.

2. Need to achieve "global net-zero greenhouse gas emissions increasingly urgent". This task is becoming especially important for an increasing number of countries around the world.

3. The most important and difficult to achieve "target of global net zero emissions" requires, as it is especially emphasized, comprehensive solutions in the direction of radical reduction of emissions in the most emissions-intensive sectors of the world economy, to which the summit participants include primarily "electricity generation, transportation, and industry."

4. It is emphasized that nuclear energy is a reliable source of zero-emission electricity generation, such energy is also a reliable basis for clean energy systems and can provide such systems with the resilience necessary for their successful operation.

5. The conference participants emphasized the need to develop technological innovations in the field of nuclear energy, improve operational characteristics, operational safety and economic indicators of nuclear power plants, "enhancing

the resilience and security of global nuclear energy industrial and supply chains".

6. The conference participants noted the need to create favorable market conditions for the development of nuclear energy, pointing to the factors of a fair and open global economy, the importance of broad exchanges and cooperation between different countries. The importance of introducing modern nuclear reactors and small modular reactors was pointed out, and the importance of "coordinated cooperation in nuclear fuel supply, nuclear power equipment manufacturing and resource security to ensure the stability of the nuclear energy industrial and supply chains" was especially emphasized.

7. Representatives from different countries emphasized the importance of investment in the development of nuclear energy. The importance of public investment as well as private investment was pointed out. It is also recommended to use different financial instruments: direct government financing, guarantees required in appropriate cases for suppliers of debt and equity assets, income distribution schemes and price risks.

8. A key factor in the functioning and development of nuclear energy is the training of highly qualified personnel, which are necessary in such an innovative, complex field that requires special safety measures. The need for education, training, research and the necessary motivation of personnel of the required number are noted. High-quality training, development of the necessary professional skills, in some cases retraining and the periodic need to improve the qualifications of personnel in accordance with increasing requirements – these measures are absolutely necessary in the nuclear industry. International cooperation and exchange of experience, joint innovation and investment are useful here.

Nuclear energy occupies an important place in the economies of the countries whose prominent representatives took part in the conference in Brussels in March 2024 (Table 1). According to International Atomic Energy Agency [6; 7], the leading country in the world in terms of the number of nuclear power units – 93, the capacity of nuclear power plants – 96,950 MW, and the production in 2022 with their help of electricity – 772,220 GWh, which was 18.2% of the total production, was the USA. The historically dominant share of atomic energy in the country's energy balance is France (62.6%), which has 56 reactors with a capacity of 61,370 MW, which made it possible to produce 279,000 GWh of electricity. China ranks second in the world in

Table 1

Power and number of nuclear reactors

Country	Capacity, GW(e)	Number of Reactors	Nuclear share, %
USA	96,95	94	18,2
France	61,37	56	62,6
China	54,2	56	5
Japan	11,05	12	6
Finland	4,39	5	35
Bulgaria	2,01	2	32,5
Romania	1,3	2	19,3
Czech Republic	3,93	6	37
Belgium	3,92	5	46,4
Slovakia's	2,31	5	59
Slovenia's	0,69	1	43
Netherlands	0,48	1	3,3
Pakistan	3,26	6	16
World	375,6	417	-

Source: [6; 7]

power generation at nuclear power plants – 417,786 GWh and is increasing capacity.

A number of countries in Europe and the world that do not yet have nuclear power plants or have a small number of reactors have shown their position on the development of nuclear energy. A very interesting and important trend in the global nuclear energy industry is the emphasis on the development of small modular reactors. This innovative trend is becoming truly global.

An analysis of the system of elements of economic decarbonization, their current and future value, as well as the problems of developing such elements (Table 2) showed the following.

Traditional nuclear power plants with high-power reactors are and will be an important factor in global energy. But a significant part of them are already outdated and require replacement. Construction time and cost are very high. Small modular nuclear reactors are now the most promising. They can be built quickly, even mass-produced at factories and only installed at the site of such a power plant. The cost of such small stations is relatively low. This is the very near future of global energy. This is something that can help decarbonization now. Small modular reactors have a very high capacity factor, much higher than wind and, especially, solar stations. Wind and solar power are a more distant prospect, but they will also be extremely important.

Climate-neutral energy must be combined with the production and use of electric vehicles, sea and river vessels, aircraft and other vehicles powered by hydrogen fuel. But it is also a more complex and distant task. Decarbonization must extend to all other areas of the global economy.

The most important and extremely negative problem of modern civilization is a very common practice that can be characterized by the term Political Decidophobia – the practice of fear of politicians in many countries to make decisions that are most important for civilization, sometimes very difficult, but do not require delay, and to bear responsibility for them. Political Decidophobia has already become the cause of global climate change and its consequences, the increase in negative dynamics. Science has long shown the way to decarbonize the global economy. But Political Decidophobia does not make it possible to confidently and energetically follow this path. No decisions have been made to significantly reduce the use of coal and oil; they are constantly being postponed.

The development of wind and solar power plants is lagging behind the required pace. Even the correct, but insufficient decisions taken in this direction are also not implemented. For example, the decision to develop wind energy, especially offshore wind energy, in Europe. In this regard, overcoming Political Decidophobia is a critical management challenge, perhaps more important than implementing technological innovation in decarbonization.

Table 2

Elements of economic decarbonization

№	Decarbonization element	Value	Development problems
1	Traditional nuclear power plants	Refers to green energy. They provide a very significant share in the electric power industry in a number of countries, for example, in France (62.6%), Belgium (46.4%), Slovakia (59%), Czech Republic (36.7%), Sweden (29.5%) [6, 7]. High efficiency and capacity factor. Low energy cost.	To a large extent, they are used for a long time and require replacement. The cost and time of construction of large units and large stations in general are very high, as is their payback. The energy of such stations may be excessive. Difficulty in placement.
2	Small modular reactors	Refers to green energy. Very promising. Speed of construction and flexibility of placement. Low construction costs and energy costs. Can be used for small cities. Modularity allows you to increase the power as needed.	Free from many of the problems of traditional large nuclear reactors.
3	Electric cars	Climate neutral. Very promising. In the future, traditional cars will be replaced. Growing rapidly, especially in China, Europe, Japan and the USA.	They have a relatively high cost, especially the cost of batteries. Limited mileage. Problems of infrastructure development. Existing problems can be solved gradually, but require time, innovation and investment.
4	Solar power plants	Refers to green energy. Very promising. Speed of construction and flexibility of placement. They are developing very actively.	Depends on the geographic latitude of the area, time of year and weather conditions. The amount of energy generated is not very high due to the relatively low value of the capacity factor. The cost of energy and the payback period of the plants are relatively high. Requires backup energy sources for stable operation of the electrical network.
5	Wind power plants	Refers to green energy. Very promising. They are developing very actively. More efficient than solar stations and have a higher capacity factor. Offshore wind farms are especially effective. In the future they may be the dominant source of energy.	Depends on wind energy and the season of the year. The power is inferior to nuclear power plants. The capacity factor value is less than that of nuclear power plants. The construction time and cost of large wind farms are quite high, especially in the case of offshore stations. Existing problems can be solved gradually, but require time, innovation and investment. Requires backup energy sources for stable operation of the electrical network.
6	Hydrogen transport	An extremely promising direction. In the future, hydrogen will be the fuel for aviation, sea and river vessels, and part of railway and road transport.	Hydrogen production requires primary climate-neutral energy sources. The development is accompanied by a set of technical and other problems that do not yet allow the widespread use of hydrogen fuel. Existing problems can be solved gradually, but require time, innovation and investment.

Conclusions. Thus, based on the results of the study, the following was established. Climate change on the planet and its incredible intensity are the focus of attention of international scientific organizations, politicians and leaders of leading countries, and the general public. Humanity is increasingly asking questions about ensuring sustainable development, global economic growth while preserving the environment, and the development of climate-neutral industries. In March 2024, heads of state and government and other high-ranking representatives of 32 countries gathered in Brussels for the inaugural Nuclear Energy Summit. The Summit supported global efforts to develop nuclear energy in areas such as investment, innovation, and training to address climate change and improve the energy security of the global

economy. The position of the summit participants noted humanity's need for climate-neutral energy, emphasized the coordinated actions of all countries of the world, the need to use funds from international financial organizations for innovation and investment in the development of nuclear energy and increasing its capacity. The study analyzed the system of elements of economic decarbonization, their current and future significance, the problem of developing such elements, which showed the critical importance in the near future for the global development of small modular nuclear reactors and offshore wind energy in combination with the mass production and use of electric vehicles. The key to decarbonizing the economy is good governance and decision-making that responds to the prevailing global environment.

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