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STRATEGIC MANAGEMENT OF DECARBONIZATION TECHNOLOGIES: INTERNATIONAL ECONOMIC INTEGRATION AND INNOVATIVE DEVELOPMENT

СТРАТЕГІЧНЕ УПРАВЛІННЯ ТЕХНОЛОГІЯМИ ДЕКАРБОНІЗАЦІЇ: МІЖНАРОДНА ЕКОНОМІЧНА ІНТЕГРАЦІЯ ТА ІННОВАЦІЙНИЙ РОЗВИТОК

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The article analyzes the latest data from the Copernicus Climate Change Observatory, which operates under the management of the European Commission, on exceptionally high air temperature anomalies in June 2025 in most of Europe. The article states that, under the existing conditions, in the interests of sustainable development of civilization, the imperative strategy for the development of the global economy is a decarbonization strategy, which involves growth using the broad innovation capabilities of the world's leading countries, their economic integration. In this regard, the need for targeted development of innovative technologies and investments is emphasized, taking into account the potential of universities and laboratories in Europe, the USA, Japan, other countries of the world, their financial resources for the implementation, in particular, of global projects in the following areas: research into thermonuclear energy, electromobility, development of promising battery technologies, wind and solar energy, use of hydropower. For the implementation of international innovative, the issues of strategic management effectiveness are of particular importance.

Keywords: strategic management, economic integration, innovation, technology, decarbonization, globalization, efficiency, sustainable development.

У статті аналізуються останні дані Служби спостереження за змінами клімату «Copernicus», яка функціонує під управлінням Європейської Комісії, про винятково високі аномалії температури повітря в червні 2025 року в більшій частині території Європи. Це дозволяє з високим ступенем достовірності стверджувати про постійне зростання температур, які вже зараз завдають великого економічного та соціального збитку в масштабах усієї планети. У статті зазначено, що в інтересах стійкого розвитку цивілізації імперативною стратегією розвитку глобальної економіки є стратегія декарбонізації, яка передбачає зростання з використанням широких можливостей інновацій провідних країн світу, їх економічної інтеграції та співпраці в інтересах домінуючого вдосконалення та найбільш повного утвердження кліматично нейтральних технологій в енергетиці, на транспорті, всіх сферах економіки. Аналіз показав, що доцільність економічної інтеграції в найважливіших інноваційних проектах обґрунтована багатьма причинами, зокрема, надзвичайно високим інноваційним потенціалом групи країн, які мають можливість більшу, ніж у будь-якої окремо взятої країни; в міжнародних проектах зусилля кожної країни можуть бути направлені на вирішенні тих завдань, які така країна може найбільш ефективно виконати; реалізація найважливіших завдань в ході міжнародних проектів визначає сутність глобальних цілей людства, її найближчі та наступні перспективи. У цьому зв'язку наголошується на необхідності цілеспрямованого розвитку інноваційних технологій та інвестицій з урахуванням потенціалу університетів і лабораторій країн Європи, США, Японії, інших країн світу, їх фінансових ресурсів для реалізації, зокрема, глобальних проектів у таких сферах: дослідження термоядерної енергетики, електромобільності, розробка перспективних технологій акумуляторних батарей, вітрової та сонячної енергетики, використання водного палива. Вітрова енергетика, як нам представляється, в перспективі буде найважливішим джерелом кліматично нейтральної енергії. Дуже вагомою є ситуація в Європі, де є перспективи міжнародних проектів вітрових електростанцій у Північному та Балтійському морях. Для реалізації міжнародних інноваційних проектів особливого значення набувають питання ефективності стратегічного управління.

Ключові слова: стратегічне управління, економічна інтеграція, інновації, технології, декарбонізація, глобалізація, ефективність, сталий розвиток.

Formulation of the problem. Systematic data from leading international climate research organizations increasingly show the growth of global negative climate changes. There is a very significant increase in temperatures, especially in the summer, droughts and losses of important agricultural crops, destructive hurricanes, floods, which leads to large-scale social and economic damage. In the interests of decarbonization of the global economy, sustainable development, economic prosperity and progress, cooperation in the innovation, financial, production sphere, joint efforts of the countries of Europe, the USA, Japan and the entire world community are necessary.

Analysis of recent research and publications. The problems of various aspects of strategic management, sustainable development of the global economy based on innovation, international integration and economic cooperation, analysis of the global consequences of climate change, development of decarbonization processes of the global economy, effective management of innovations in the most important areas, studying the possibilities of obtaining and storing progressive climate-neutral energy sources, as well as their use, attract the attention of large groups of experts and researchers, specialists in the field of management, and are also the subject of numerous publications in the world's leading publications in the relevant profile. Among the authors of such publications, it is necessary to note such experts and scientists as: Bilous S.P, Trokhymenko A.S., Kaminskyi V.V. [1], Dudnyk O.V. [2], Borysiak O., Mucha-Kuś K., Brych V., Kinelski G. [3], Couckuyt D., Van Looy A. [4], Gouda K.C., Thirumalai Raja R. [5], Sohns T.M., Aysolmaz B., Figge L., Joshi A. [6], Shu Zhang, Yubo Ma, Xinzhu Zheng, Qianting Zhu, Xu Tang [7]. The authors make significant contributions to the study and further development of important areas of innovation and the global economy and its decarbonization.

Previously unsolved parts of the overall problem. The scale of the global economy and the processes that are constantly occurring in it, especially the numerous manifestations of climate change and the response to such changes by the world community cannot be covered by research in full and in all details. It seems that the analysis of strategic management issues in the development, as well as the use of modern decarbonization technologies in the global economy and the most important elements of progress, which are international economic integration and innovative development, is of scientific and practical interest.

Presentation of the main research material. Large-scale climatic changes on the planet continue their increasing movement. Every new year is getting hotter and hotter. The relevance of this statement receives new confirmations.

The Copernicus Climate Change Service, a programme of the European Union, reports [8]: “Heatwaves contribute to the warmest June on record in western Europe. The European continent experienced two significant heatwaves in mid-June and late June-early July 2025. The first event peaked between 17 and 22 June, affecting large parts of western and southern Europe. The second heatwave occurred at the turn of the month, with even more extreme temperatures between 30 June and 2 July across the same region. During the second heatwave, surface air temperatures exceeded 40°C in several countries, and up to 46°C in Spain and Portugal. Both events were linked to persistent high-pressure systems, often referred to as ‘heat domes’, which trapped warm air and led to prolonged hot, sunny, and dry weather. Much of Europe experienced strong or very strong heat stress. In addition to high air temperatures, much of Europe experienced above-average feels-like temperatures and an above-average number of days with heat stress in June. Feels-like temperatures exceeding 38°C, corresponding to ‘very strong heat stress’, were recorded across much of southern and western Europe, particularly in Portugal, Spain, France, Italy, and much of the Balkans. Northeast of Lisbon, maximum feels-like temperatures reached 48 °C, corresponding to ‘extreme heat stress’, around 7 °C above the average June maximum.” [8].

Climatic changes have affected the entire planet, but their negative manifestations are especially acute in Europe, which is historically the most important region, where modern human civilization was largely formed, which continues to be the most important economic and innovative center of the planet, determining the nature of the world economy.

Extreme climate change of the planet requires adequate measures of the entire world community to decarbonize the economy. The strategy of decarbonization and effective strategic management must be based (Fig. 1). on the pursuit of the goals of sustainable development of the United Nations, and the global nature and extremely great importance of the tasks for modern civilization and future generations, as well as significant experience and obvious expediency, imply broad international cooperation, economic integration, and the use of innovative and investment potentials of the world's leading countries.

The most important tool of strategic management in the conditions of parliamentary democracy is the support of decarbonization projects by the population of countries, voters who form the government and influence decision-making. Without the support of voters, sustainable financing of many projects, especially large-scale ones that do not lead to a quick positive result, may end. The task of specialists, scientists and experts, managers of various levels are to fully and reliably inform the broad circles of the international public about the processes of climate change and the relevance of decarbonization in the interests of sustainable development.

The strategic essence of the global economy is large-scale international projects in key areas of the economy for humanity in the interests of long-term sustainable development that takes into account the interests of all nations, the preservation of the natural environment and

Figure. 1. Decarbonization strategy and its elements

Source: developed by the authors

climatic conditions suitable for the existence of civilization (Table 1). Significant advantages and opportunities of international projects are due to the following factors.

1. Extremely high innovative potential of a group of countries, which exceeds the capabilities of any single country. For the successful implementation of international innovative projects, it is advisable to participate in them by countries such as the USA, Germany, Great Britain, France, Europe as a whole, China, Japan, and South Korea, where the most important universities, laboratories, research centers of corporations, leading scientists and specialists are concentrated.

2. The investment and production potential of implementing innovative projects of a group of countries significantly exceeds the potential of an individual country.

3. In international projects, the efforts of each country can be focused on solving those tasks that such a country can most efficiently perform.

4. International projects make it possible to exclude the unnecessary duplication of efforts of several countries and the expenditure of significant resources in solving similar problems, which is only optimal.

5. The solution of the most important tasks of humanity in the course of international projects is determined by the very essence of global tasks that determine the fate of world civilization, its immediate and subsequent development prospects.

Among the most important projects of international integration within the framework of the strategy of decarbonization and innovative technologies, an exceptional place is occupied by the project of research on the possibility of using thermonuclear energy for the production of electricity. This idea is probably the most significant innovative idea in the history of the world. Here, as it seems to us, it is quite appropriate to introduce the term 'thermonuclear dualism', which means, on the one hand, the incredible complexity and uncertainty of the ability to ever solve the problem of creating thermonuclear energy at all, and the colossal energy possibilities in the case of solving such a problem, on the other.

Innovative in the highest sense in history, the experimental thermonuclear reactor ITER (International Thermonuclear Experimental Reactor), which is currently being created in Saint-Paul-lès-Durance, in the south of France, is a vivid manifestation of the most important international project, which has exceptional importance for the future of humanity. 27 member states of the European Union participate in ITER, as well as the USA, Japan, China, India, the Republic of Korea and some other countries [9].

As indicated in the ITER information [9], the project has a pronounced global character: “Taken together, the ITER Members represent three continents, approximately 40 languages, half of the world's population and 73 percent of global gross domestic product. In the offices of the ITER Organization and the Domestic Agencies, in laboratories and in industry, literally thousands of people are working toward the success of ITER”.

In the framework of strategic management, the analysis of the terms of implementation of objects within the framework of the ITER project is of interest. The initial plans looked like this (Fig. 2).

Such a distant prospect of the completion of the project and its colossal complexity, possible political, financial, innovative, technological, managerial and many other risks made the determination of the project implementation dates very approximate. Evaluation of the progress of work on the ITER project, made in July 2024 Pietro Barabaschi, ITER Director-General reported [11]: “The 2016 Baseline envisioned achieving First Plasma in 2025, as a brief, low-energy machine test, with relatively minimal scientific value, to be followed by four stages of assembly and construction, achieving full plasma current in 2033. The new baseline envisions the Start of Research Operation (SRO) in 2034, featuring a more complete machine, to be followed by 27 months of substantive research. The achievement of full magnetic energy will be about 3 years delayed from the previous baseline, from 2033, now targeted in 2036. Deuterium-deuterium fusion operation is targeted for 2035, about the same time as in the previous baseline. The Start of Deuterium-Tritium Operation Phase will be about 4 years delayed from the previous baseline, from 2035 to 2039”.

Analysis of the development of the thermonuclear project showed the following.

1. The international community understands the colossal importance of the thermonuclear project for providing human civilization with an almost inexhaustible source of energy and is fully determined to continue its active development with the participation of the world's leading countries.

2. The thermonuclear project is probably the most complex technological innovation project in

Table 1

International projects and priorities of decarbonization

№		Importance	Possibility of implementation	Conclusion
1	Thermonuclear energy	extremely important	The problem of creating thermonuclear energy appears to be extremely difficult and unattainable, at least in the near future.	Innovative efforts in this direction should be continued despite the uncertainty of success
2	Accumulators of electric cars	extremely important	Progress in this area and a high probability of ego development	Efforts in this direction should be increased, as this determines the success of electromobility
3	Small modular reactors	very important	In the near future, many projects of such reactors will most likely appear, among which it is possible to choose optimal options	Active international efforts to create and spread the most successful projects of such reactors are expedient
4	Wind power plants	extremely important	Progress in this area and a high probability of its development are primarily due to international projects in the North and Baltic seas	Projects of offshore wind power plants should be radically expanded, which is able to largely meet the needs of, in particular, Northern Europe
5	Aviation on hydrogen fuel	very important	The possibility of successful implementation is assumed, but a final conclusion on this matter cannot be presented at the present time	The importance of the transition of aviation to hydrogen fuel on a global scale requires active international efforts in the sphere of innovation and investment

Source: developed by the authors

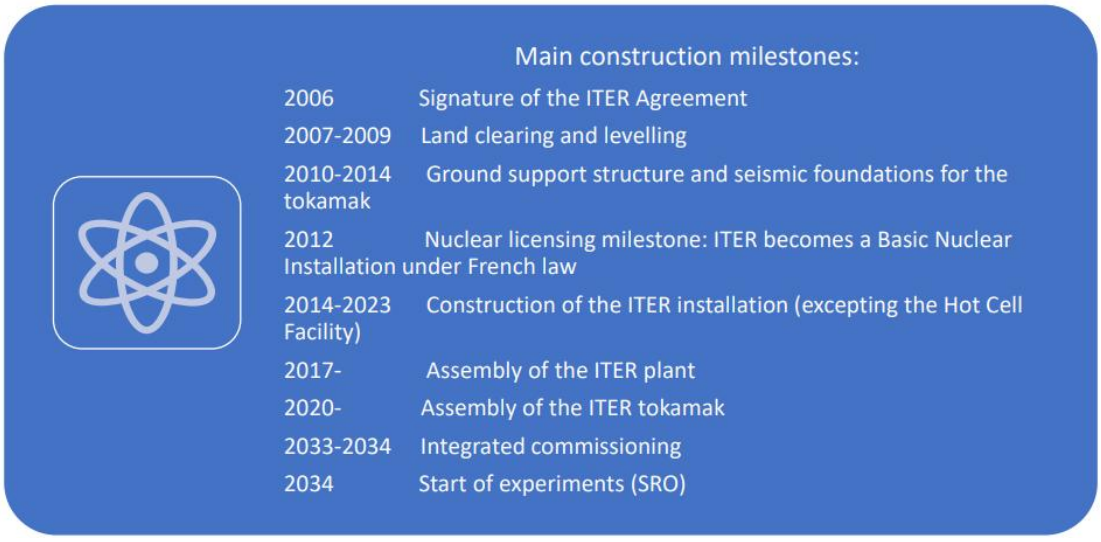

Figure 2. Main construction milestones of ITER

Source: [10]

the history of mankind and potentially the most large-scale in terms of economic significance, in case of its successful implementation.

3. There is no doubt that the activity of ITER will have the most important scientific significance, but the question remains whether it will lead to the expected practical results.

4. Already at the present time, as of mid-2025, it is quite obvious that the initial project implementation deadlines cannot be met, with

a high probability it can be assumed that the new, upwardly adjusted project implementation deadlines will not be met and its completion will be delayed in time, but it is impossible to predict exactly how much.

5. The problems of increasing the cost of the project are already noticeable and, very likely, will only increase.

6. Most likely, the main participants of the project will continue large-scale investment and innovation efforts for its development, despite the emergence of many problems that will accompany the project, and it will be implemented.

7. In our opinion, despite the extreme complexity, the goals of the project do not cause doubts and it should be continued, increasing the potential of international cooperation, investments and innovations even in conditions when the solution to the problem of the development of thermonuclear power plants is not obvious.

8. With a high probability, the completion time and the cost of the project will be significantly increased, which is caused by its colossal scale and complexity. In these conditions, long-term financing of the project is most likely possible only with broad public support of the voters of democratic countries and the authorities elected by them, which requires constant informing of broad circles of the public about the extreme importance and necessity of the project, which is a key tool of strategic management.

Among the mass modes of transport on a global scale, electric vehicle transport can be called the most strategically promising. The most important advantage of electric cars is their climate neutrality, which corresponds to the global processes of decarbonization and sustainable development. Individual electric cars are universal – no other type of transport for trips over relatively long distances can fully replace electric cars. Public transport runs on a schedule that may not meet people's needs. In addition, public transport routes do not cover significant geographical areas, the use of public transport requires transfers, waiting for dispatch, and often delays in the arrival of routes. All these factors create specific problems for the use of public transport for many people. Individual transport in the form of electric cars is free from such shortcomings.

The cost of electric energy when operating electric cars is significantly lower than the similar fuel costs of traditional cars. In different cases, there may be a several-fold difference in cost. Here, it is important to take into account additional current circumstances that can significantly affect the comparative efficiency of electric cars. Modern trends in the world oil market are very complex and contradictory in nature, but in general they are characterized by the following factors: high world oil prices and the general direction of their increase, even in spite of noticeable price fluctuations in certain periods. The trend of the general growth of world oil prices is connected with the noticeable growth of the planet's population, connected with this increase in oil consumption, the growth of oil consumption per capita, the reduction of available oil reserves in the world, which is inevitably accelerating due to the colossal annual production volumes. In these conditions, the economic benefits of using electric cars will only increase. This increase will be additionally supported by the dominant trend of a noticeable decrease in the cost of electric car batteries and the cost of electric cars themselves.

In the modern conditions of decarbonization, the fact that the owners of electric cars can quite reasonably experience a sense of involvement in the progressive forces of society in terms of innovative factors of sustainable development and participation in the multifaceted process of preserving the planet's climate, especially in the conditions of global warming, which is becoming more and more pronounced and causing great economic damage, is of key additional importance in modern conditions of decarbonization.

A negative and very significant factor, which probably holds back the global development of electric mobility to the greatest extent, is that the cost of electric cars at the present time still significantly exceeds the cost of traditional cars, which is primarily due to the high cost of the most important element of electric cars - batteries. The capacity of batteries in most cases is such that it does not allow them to make a mileage similar to the mileage of traditional cars on one charge. But the situation in the direction of increasing the capacity of batteries is constantly changing under the influence of innovations. However, in recent years, the cost of accumulator batteries and their energy capacity have decreased many times.

The problems of the development of electric mobility also include the insufficient number and capacity of chargers, the long charging time, which significantly complicates the use of electric cars, especially when traveling long distances.

The strategy for the development of electric mobility should provide for the gradual complete

replacement of traditional cars with internal combustion engines by electric cars, which represents the largest technological revolution of the 21st century. Such a strategy envisages a set of measures for the mass production of electric cars, the corresponding infrastructure, the most important tasks of the development strategy and innovative management are the development of new designs of batteries with a significantly higher energy capacity and lower cost, including through the use of new materials, acceleration of battery charging, development and production of electric cars with the lowest possible cost, but acceptable technical and other indicators that will allow such electric cars to be widely distributed on the world market.

Fully understanding the exceptional importance of creating effective innovative battery technologies for the main promotion of electric mobility throughout the world and the significant advantages of broad European and international cooperation, the European Commission created the European Battery Alliance [12]: “The European Battery Alliance (EBA) was launched in 2017 by the European Commission, EU countries, industry, and the scientific community. Batteries are a strategic part of Europe's clean and digital transition and a key enabling technology, essential to the automotive sector's competitiveness. Therefore, the Commission aims to make Europe a global leader in sustainable battery production and use.”

The European Commission considers the joint efforts of leading universities and research centers to be the most important factor in the strategy of complex innovations in the field of accumulator batteries in the interests of decarbonization of the economy and sustainable development and notes the following [13]: “Recognising the significance of batteries for renewable energy sources and electric vehicles, initiatives like BATTERY 2030+ and CSA3 are advocating for enhanced collaboration and innovation. The EU-funded B2030 CSA3 project will build upon the achievements of BATTERY 2030+ and expand its impact. The project seeks to oversee and implement ongoing research endeavours, identify opportunities to expedite research progress, update the BATTERY 2030+ roadmap, strengthen coordination and collaboration with other EU initiatives, and contribute to the enhancement of European battery education programmes. The overarching goal of the BATTERY 2030+ initiative is to develop advanced batteries for diverse industries and bolster Europe’s leadership position in both current and emerging markets. Collaborative, long-term research on future battery technologies has since 2019 been supported by the European Commission with the BATTERY 2030+ initiative. This project, BATTERY 2030+ CSA3, builds on earlier CSA efforts to coordinate and monitor research projects earmarked BATTERY 2030+ to work together towards the goals in the BATTERY 2030+ roadmap. The overall aim of the BATTERY 2030+ initiative, is to invent the batteries of the future by providing breakthrough technologies to the European battery industry across the full value chain; to strengthen long-term European leadership in both existing markets (road transport, stationary energy storage), and future emerging applications (aerospace, medical devices, internet of things).” [13].

BATTERY 2030+ CSA3 builds on, and extends beyond, the earlier achievements of the BATTERY 2030+ initiative with five objectives [13]:

1. Implementation and monitoring of the research activities contributing to the BATTERY 2030+ initiative.
2. Update and develop the BATTERY 2030+ roadmap, by mapping ongoing R&I activities and identifying emerging obstacles and research needs.
3. Accelerate the research by identifying and making available best practices and guidelines for ontology development, data sharing, and standardizations.
4. Contribute to European curricula in future battery technologies.
5. Promote and communicate the objectives and the achievements of the BATTERY 2030+ initiative and strengthen collaboration with other EU R&I battery initiatives.

The CSA3 consortium consists of many leading European universities and research institutes. These include, in particular, the following [13]: Utrecht University, CIC energiGUNE, CIDETEC, Centre National de la Recherche Scientifique (CNRS) & Université de Picardie Jules Verne (UPJV), The Technical University of Denmark (DTU), Swiss Federal Laboratories for Materials Science and Technology (Empa), Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), The Fraunhofer Society, Forschungszentrum Jülich (FZJ), Karlsruhe Institute of Technology (KIT), The University of Münster, Polytechnic University of Turin, SINTEF (Stiftelsen for industriell og teknisk forskning), The Delft

University of Technology (TU Delft), The Vrije Universiteit Brussel (VUB), as well as other organizations.

The number of international project participants and the complexity of the tasks emphasize the importance of effective strategic management for the successful implementation of projects and clearly shows the effectiveness of the development of the global economy.

Wind power, as it appears to us (Table 1), will be the most important source of climate-neutral energy in the future. Offshore wind energy is particularly promising. Its active development is taking place all over the world, but the situation in Europe, where international projects of wind power plants in the North and Baltic seas have prospects, is very indicative. Joint projects for the development of electrical networks, the production of wind turbines and other equipment, the supply of critical materials for the energy transition, the dispatching of energy supplies, and the simplification of the issuance of construction permits are of great importance. The European Commission provides such data [14]: “The EU is a global leader in the manufacturing of key wind turbine components, as well as in the foundations and cable industry. Moreover, according to Wind Europe, the EU installed 12.9 GW of new wind capacity in 2024 and predicts that over 2025–2030, the EU will install another 140 GW, which corresponds to 23 GW per year on average. We would then reach a total capacity of 351 GW by 2030… The revised Regulation on Trans-European Networks for Energy also introduced dedicated offshore grid planning provisions, requiring EU countries to agree on non-binding regional goals for offshore renewables by 2050, with intermediate steps in 2030 and 2040. Last year, EU countries agreed to work towards reaching 86-89 GW of offshore capacity by 2030, 259-261 GW by 2040, and 356-366 GW by 2050”. The dynamics of offshore wind power capacity development in the countries of the European Union is presented in Fig. 3.

Figure 3. Dynamics of offshore wind power capacity development in the European Union

Source: [14]

The International Atomic Energy Agency [15] notes the special properties of Small modular reactors (SMRs) and their important advantages: small size, modularity, the possibility of serial production at factories and relatively quick assembly of modules at the construction site, relatively low power and cost, and other advantages. In the near future, small modular reactors can potentially be one of the main types of climate-neutral energy.

In the 2020 edition of the International Atomic Energy Agency [16], it is indicated that during that period, projects of more than 70 SMRs were developed in the world, by the efforts of such countries as the United States of America, France, the United Kingdom, Canada, Denmark, the Czech Republic, Japan, the Republic of Korea, China, and others. A number of projects were developed by the joint efforts of representatives of companies from several countries. It seems that in this case there is a duplication of innovative and investment efforts in various projects that could be used more effectively. It would be expedient to form alliances of developers and specialists from several countries, for example, Europe, the USA, Japan, to create optimal projects and concentrate innovative and financial resources on them.

International decarbonization projects may also affect hydrogen-fueled aircraft and ships, solar power plants, hydroelectric power plants (for example, the "ZEROe" concept of the Airbus concern for the creation of zero-emission commercial aircraft), biofuels, and other important areas.

Conclusions. Thus, the study showed that the efforts of the world community in the direction of decarbonization of the world economy in the interests of sustainable development of civilization are in the center of attention of the economically leading countries of the world. Such efforts do not currently allow to stop the negative changes in the planet's climate. Effective strategic management and joint innovative projects of many countries, universities, research centers, scientific societies, especially Europe, the USA, and Japan in priority directions can be used as the most important tool for decarbonization. Such projects, in particular, include the creation of an experimental thermonuclear reactor ITER, European Battery Alliance, BATTERY 2030+ and CSA3, for the creation of innovative battery technologies for electric cars and many other purposes, projects for the development of wind energy in the Northern and Baltic Seas and in

the continental part of Northern Europe, the project for the creation of optimal technologies for Small Modular Reactors, the “ZEROe”, and other projects international integration. Successful development of priority innovative technologies requires effective strategic management and global efforts in the interests of sustainable development.

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