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MODEL OF ECONOMIC DECARBONIZATION IN THE CONTEXT OF CLIMATE CHANGE: ISSUES OF MANAGEMENT AND INNOVATION

МОДЕЛЬ ДЕКАРБОНІЗАЦІЇ ЕКОНОМІКИ В УМОВАХ КЛІМАТИЧНИХ ЗМІН: ПИТАННЯ МЕНЕДЖМЕНТУ ТА ІННОВАЦІЙ

Kharin Serhii

Doctor of Engineering, Professor,
Dnipro University of Technology
ORCID: <https://orcid.org/0000-0002-8500-163X>

Papizh Yuliia

Ph. D in Economics, Associate Professor,
Dnipro University of Technology
ORCID: <https://orcid.org/0000-0001-6460-7862>

Korovin Serhii

Master's student at the Department of Finance,
Taras Shevchenko National University of Kyiv
ORCID: <https://orcid.org/0009-0001-1894-1840>

Харін Сергій Анатолійович, Папіж Юлія Сергіївна
Національний технічний університет «Дніпровська політехніка»

Коровін Сергій Олександрович
Київський національний університет імені Тараса Шевченка

The issues of the influence of human economic activity on natural conditions are analyzed. Record parameters for climate change on the planet have been noted in recent years: 2023 is recognized as the warmest year, according to global temperature observations, since 1850. It shows that 2023 was 0.60°C warmer than the 1991–2020 average and 1.48°C warmer than pre-industrial levels 1850–1900. An analysis of data from authoritative international climate organizations also showed that the global average sea surface temperature in 2023 remained persistently and unusually high. To achieve climate neutrality in the global economy, a comprehensive development model has been proposed, which combines the management of the formation of environmental thinking among the general public, the creation of environmental energy capacities and its rational use in the context of decarbonization.

Keywords: climate, change, management, energy, ecology, model, decarbonization, innovation, power plants, economic efficiency, prospects, wind, solar power plants, small modular reactors, hydrogen fuel, moderate consumption.

Аналізуються питання впливу економічної діяльності людства на природні умови. Відзначено рекордні параметри зміни клімату планети в останні роки: 2023 рік визнаний найтеплішим роком, за даними глобальних температурних спостережень, починаючи з 1850 року. Показано, що 2023 рік був на 0,60 °C тепліше, ніж в середньому за 1991–2020 роки, і на 1,48 °C тепліше, ніж у доіндустріальний рівень 1850-1900 років. Аналіз даних авторитетних міжнародних кліматичних організацій показав також, що глобальна середня температура поверхні моря у 2023 році залишалася стійко та незвичайно високою. Все більш активна зміна клімату планети, що постійно посилюється, робить необхідним постійне і детальне інформування найширших кіл громадськості про гостроту проблеми та її невідворотні наслідки. Ці наслідки можуть торкнутися протягом найближчих кількох років сотні мільйонів людей на всій землі та створити для багатьох з них дуже несприятливі умови для проживання. Внаслідок підвищення рівня Світового океану у певній перспективі можуть бути затоплені водою великі прибережні ділянки суші. Для збереження клімату планети необхідне широке застосування інновацій у різних галузях глобальної економіки планети, які забезпечують максимально ефективно



на даний момент використання всіх видів ресурсів, особливо енергетичних ресурсів, які негативно впливають на кліматичні зміни на планеті. Це стосується всіх можливих сфер господарської діяльності, найбільш важливими у цьому випадку будуть енергетика, металургія, гірничодобувна промисловість, машинобудування, виробництво будівельних матеріалів, будівництво, опалення житла та інших будівель, хімічна промисловість, транспорт та інші галузі. Для досягнення кліматичної нейтральності глобальної економіки запропоновано комплексну модель менеджменту інновацій, яка поєднує в собі управління формуванням екологічного мислення широких верств громадськості, створенням потужностей екологічної енергетики та її раціонального використання у контексті декарбонізації.

Ключові слова: клімат, зміна, менеджмент, енергетика, екологія, модель, декарбонізація, інновації, електростанції, економічна ефективність, перспективи, вітрові, сонячні електростанції, малі модульні реактори, водневе паливо, помірне споживання.

Formulation of the problem. Active climate change on the planet continues to manifest itself more and more intensely. The economic consequences of climate change are constantly increasing. This requires immediate and optimal management decisions that reflect the complexity of the situation, which will ensure sustainable development, constant economic growth based on innovation while preserving the nature of the planet.

Analysis of recent research and publications. Many recent studies have addressed issues of global climate change and global energy development. This is paid attention to by such scientists as Adrian Rinscheid, Rolf Wüstenhagen, Martin Kittel, Leonard Goeke, Claudia Kemfert, Christian von Hirschhausen, Kamila Svobodova. The researchers' works, in particular, examine the latest trends in energy development from the perspective of decarbonization of the economy and issues of efficiency, and show current problems of the industry.

Previously unsolved parts of the overall problem. Many studies that examine the development of the global economy and modern energy have not examined in detail some issues of decarbonization management, the pace and many areas of development of the complex of energy production and its use, especially taking into account the latest information about the acceleration of negative changes in the planet's climate and the growing economic damage from such changes.

It is necessary to study in more detail the problem of managing the development of global energy in the context of decarbonization, and to consider many related issues comprehensively.

Presentation of the main research material. The most important factor of our time is the increasingly significant change in the earth's climate. This phenomenon has been happening for a relatively long time, but recently there has been a constant acceleration of the negative

manifestations of the impact of human economic activities on nature. The Copernicus Climate Change Service, created by the European Center for Medium-Range Weather Forecasts on behalf of the European Commission with EU funding, provides ample evidence of this. Thus, in the report "Global climate highlights 2023" published in January 2024 [1] it was noted that in 2023 global temperatures on the planet reached an exceptionally high level. In 2023, global temperatures reached exceptionally high levels. The Copernicus Climate Change Service (C3S), set up by the European Center for Medium-Range Weather Forecasts on behalf of the European Commission with EU funding, tracked several key climate indicators throughout the year, reporting record conditions such as the hottest month on record and average daily global temperatures briefly exceeding pre-industrial levels by more than 2°C. Unprecedented global temperatures since June have made 2023 the warmest year on record, beating 2016, the previous warmest year, by a wide margin. Based primarily on the ERA5 reanalysis dataset, the 2023 Global Climate Highlights report provides a high-level summary of the most important climate extremes of 2023 and the main drivers behind them, such as greenhouse gas concentrations, El Niño and others natural changes [1]. As stated in the report fig. 1. The change in global surface air temperature compared to the average for 1850–1900, a period commonly called the pre-industrial reference period, based on several sets of global temperature data, is only increasing, and after about 1970 the increase in temperatures is already pronounced intense character. If in 1970 the excess of the average annual temperature compared to the pre-industrial period was approximately 0.3 °C, in 1990 – approximately 0.6 °C, then from 2015 onwards such an excess was already approximately 1.2 °C.

As Reuters reported in November 2023 [2], with reference to scientists from the University

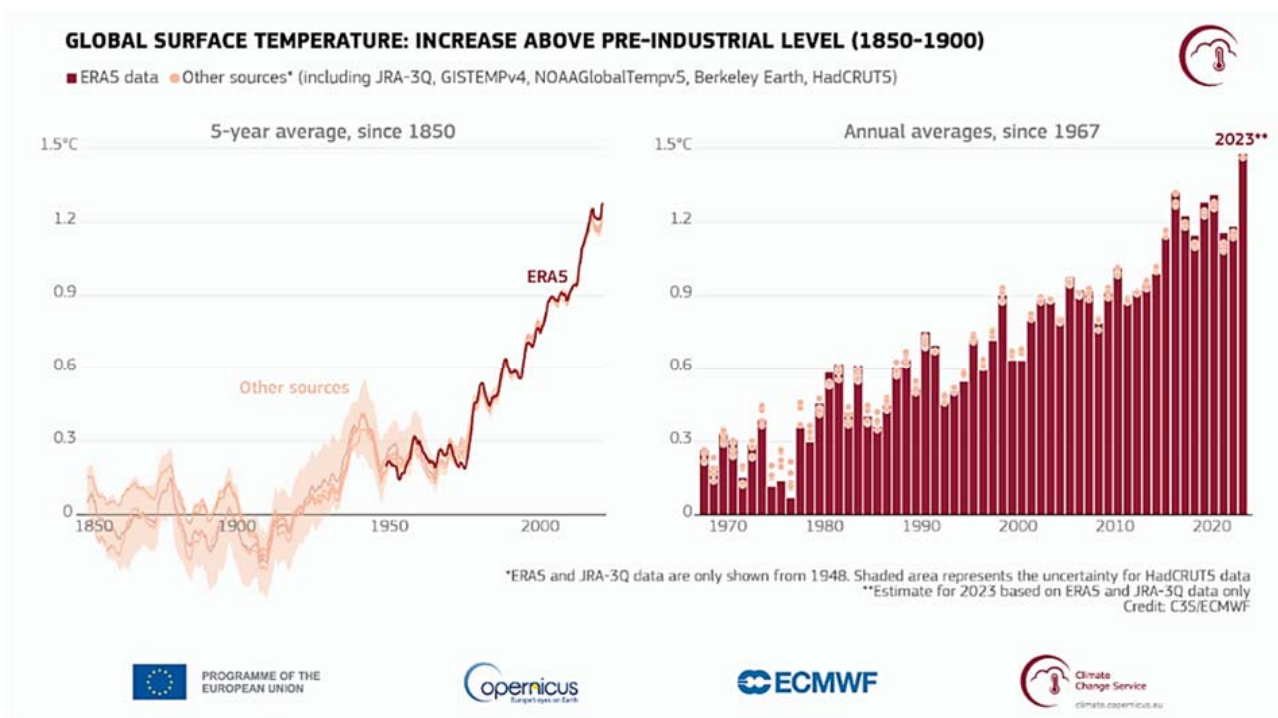


Figure 1. Temperature increases compared to the 1850–1900 average (left) and as annual averages since 1967 (right)

Source: [1]

of Copenhagen, “Global warming has increased the rate of glacier melt in Greenland fivefold over the past 20 years.” According to research by scientists: [2], “melting ice in Greenland is of particular concern, as the ancient ice sheet contains enough water to raise sea levels by at least 20 feet (6 meters) if it melted completely. A study of thousands of glaciers in the area showed that the rate of melting has entered a new phase over the past two decades, Anders Anker Bjork, associate professor in the department of geosciences and natural resource management at the University of Copenhagen, told Reuters.

The National Aeronautics and Space Administration (NASA) has been monitoring the state of the world's oceans from space for 30 years. The information, even for a short period of time, looks very alarming. the following (Fig. 2). According to NASA's Sea Level Change Science Team, "Since satellites began observing sea surface heights in 1993 as part of the U.S.-French TOPEX/Poseidon mission, global average sea level has increased by 3.6 inches (9.1 centimeters). The annual rate of sea level rise – or how quickly sea level rise occurs – that researchers expect to see also increased from 0.08 inches (0.20 centimeters) per year in 1993 to 0.17 inches (0.44 centimeters) per year in 2022. According to satellite measurements,

the projected rate of sea level rise will reach 0.26 inches (0.66 centimeters) per year by 2050" [3]. The rate of rise in sea levels, caused by global warming, will accelerate, so that large areas of land may be flooded in the future.

The UN analyzes the consequences of climate change, indicating that 90% of natural disasters are currently classified as weather and climate related, costing the global economy \$520 billion annually [4].

To decarbonize the global economy, we can propose the following comprehensive management model, the key to which is different types of innovation.

1. Increasingly active and ever-increasing climate change on the planet makes it necessary to constantly and thoroughly inform the widest circles of the public about the severity of the problem and its inevitable consequences. These consequences could affect hundreds of millions of people around the world over the next few years and create very unfavorable living conditions for many of them. Due to the active rise in the level of the World Ocean, in a certain future, which is constantly approaching in time, some very large coastal areas of land may be flooded with water, which contain, among other things, various and very important port infrastructure facilities, berths, dry docks of shipyards, warehouses

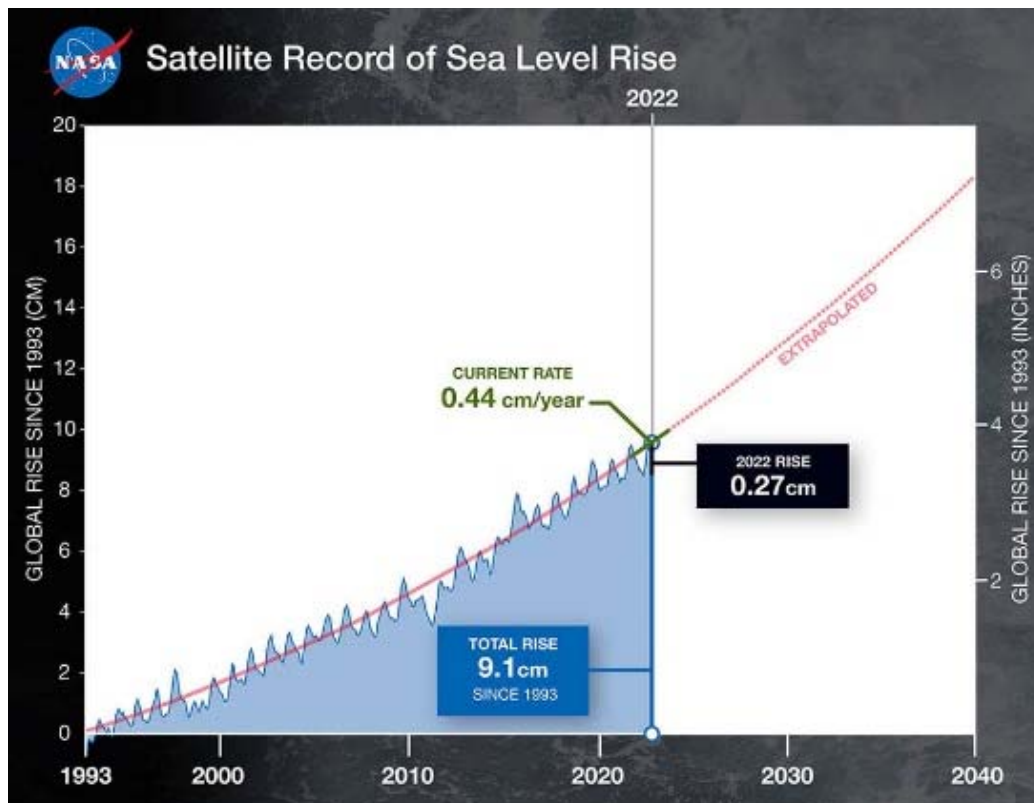


Figure 2. Dynamics of sea level rise

Source: [3]

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and storage facilities, as well as a wide range of residential, resort and tourist facilities, which can lead to large-scale economic damage. Increasing global temperatures are negatively impacting the yields and gross yield of many agricultural crops, which, combined with the growth of the world's population, especially in developing countries with insufficient levels of agricultural production, will lead to increasing food shortages. Such climate changes and their increasingly large-scale negative economic consequences will directly or indirectly affect a significant part of the citizens of many countries around the world. Already now it is necessary to urgently and in detail cover the issues of climate change on the planet, the causes and scale of such changes, possible consequences in the near and long term for specific geographical regions, representatives of certain professional groups. It is necessary to indicate detailed and significant parameters of climate change to form among the general public a real understanding of the situation, the depth of existing and upcoming problems, possible ways to solve climate problems, and the need for decisive and immediate conscious and full responsibility for the fate of the planet actions of all countries of the world and their citizens.

II. Based on the vision of the situation formed on reliable and complete information about the dynamics of global climate change and their possible consequences, adequate actions should be taken. These actions must correspond to the depth and scale of the climate crisis and reflect the existing and future innovative achievements of humanity and attract the necessary investment resources. As narrower and more specific measures within the framework of the decarbonization management system, the following can be identified:

1. The most widespread use of technologies and equipment in various sectors of the global economy of the planet, which ensure the most efficient use of all types of resources at the moment, especially energy resources, which have the greatest negative impact on climate change on the planet. This statement applies to all possible areas of economic activity, but probably the most important in this case will be energy, metallurgy, mining, mechanical engineering, production of building materials, construction, heating of homes and other buildings, chemical industry, transport and other industries.

2. Focus, in addition to the above, on environmentally neutral energy production (Table 1).

Table 1

Properties of different types of power plants

Power plants	CO ₂ emissions	Capacity factor	Global Manufacturing Capabilities	Energy cost
Solar	not available	short	high	average
Wind	not available	average	high	average
Hydro	not available	high	low	low
Gas	average level	high	average	high
Coal	high level	high	average	high
Atomic traditional	not available	high	high	low
Small modular reactor	not available	high	high	low

The traditional producer of electricity in the world today is coal-fired power plants. Such stations are capable of producing large volumes of electricity and have a fairly high capacity factor (Table 1). Coal-fired power plants are characterized by very high CO₂ emissions, according to this criterion they occupy a negative leading position in the world. In addition, the operation of coal-fired power plants is associated with logistical problems: the extraction and transportation of huge quantities of energy raw materials takes place, and coal mining areas are often located long distances from power plants. The quality of hard coal in many cases is low; brown coal has a relatively low energy intensity. The cost of electricity produced at coal-fired power plants is relatively high and will increase as world prices for coal rise and its readily available reserves are depleted. Based on a combination of factors, coal power plants are not promising and will likely lose their global importance within a few decades.

Gas power plants are widespread in the world, they are quite efficient according to the capacity factor criterion (Table 1), they generate electricity with less environmental damage than coal ones, but the cost of electricity depends on the price of natural gas and tends to increase. For a certain period, such power plants can be used on a global scale, until the time when they are replaced by more environmentally friendly and economically feasible ones. They can also be used as backups.

Hydroelectric power plants (Table 1) produce electricity at low cost, they meet the decarbonization criterion and will exist in the future, but a significant increase in their capacity on a global scale does not seem to be at all possible: hydropower resources are already being used to the limit of their capabilities, the

construction of new hydroelectric power stations in many places can cause harm to nature.

Solar power plants (Table 1) have an important global perspective, especially in desert geographical areas and the delivery of electricity to places of consumption, which poses a technical and logistical challenge. Solar power plants are among the key positive ones in terms of decarbonization criterion, but have a relatively low value of the capacity factor criterion, especially in winter and in certain geographical latitudes. Small solar devices for generating electricity can be widely used, for example, on the roofs of buildings and structures, especially in combination with other sources of electricity. Such devices can be effective in the summer even in European conditions.

Wind power plants (Table 1) will most likely become the basis of the global energy sector of the future. They have the most important useful qualities: the absence of a negative impact on the environment, the possibility and even advisability of placement in the coastal waters of the World Ocean or even far from the coast, where there is an increased level of the capacity factor, the ability to generate energy around the clock and at any time of the year, more and more high power of wind turbines. Wind power plants are already widespread in the world, in particular in the USA, Europe, and China. In Denmark, for example, they generate more than 50% of electricity and there is a steady upward trend in this figure. The same trend is global. As one can assume, in the future, wind power plants will take first place in the production of electricity on the planet.

Nuclear power plants (Table 1) play an important role in the global energy sector, especially in countries such as the USA, China, France and many others. France has long

been and remains today the world leader in the share of nuclear power plants in the country's electric power industry. Germany abandoned the use of nuclear power plants in the energy sector, although previously the country had a developed nuclear power system for a long time. This reflects different views in Europe and around the world on the operation and future of nuclear power.

Nuclear power plants have many significant advantages, high efficiency, and relatively low cost of electricity. The disadvantages of nuclear power plants include, in particular, the high cost and long period of their construction, the complexity of design and maintenance, and possible significant environmental risks. Nuclear power plants have the property of climate neutrality and therefore their operation is advisable for at least the next few decades.

Recently, interest in Small Modular Reactors (SMRs) has increased around the world (Table 1). These are small nuclear reactors that are significantly smaller in power than the traditional nuclear reactors typically used in the energy industry. Power plants that use SMRs have many advantages: higher safety, technical excellence, reliability, significantly shorter construction period, significantly lower cost than traditional nuclear reactors, the ability to use a different number of SMRs in a power plant depending on the required total power. Such reactors could well meet the needs of the economies of small and medium-sized cities, which are widespread in Europe. For large cities, multi-module stations with SMRs can be recommended. In addition, it is possible to combine the use of a system that consists of wind, solar power plants, as well as SMRs. At the same time, Small Modular Reactors will quickly compensate for the lack of electricity produced by wind and solar power plants if necessary. This will ensure high reliability and efficiency of the energy system. It is the flexibility of use and relatively low cost of Small Modular Reactors that make them potentially very cost-effective. It appears that SMRs will play an important role in the global economy in the future, together with wind and solar power plants.

3. Efficient energy production must be accompanied by equally efficient use. Electricity is used in various sectors of the economy. Transport is in this case one of the most important areas of energy consumption. In the future, to ensure decarbonization of the global economy and meet transport needs, such types of transport as electric railway transport and

high-speed trains for transporting passengers will be promising. In cases where railway lines are not equipped with electricity, trains can be used that use hydrogen as fuel, which must be produced in an environmentally friendly manner.

The most important area of transport development in the context of decarbonization is the widespread development of electric vehicles. Electric cars have many advantages and, in the future, can almost completely replace traditional cars with internal combustion engines that use gasoline and diesel fuel. Electric buses and trucks will also be used. Currently, the development of electric mobility is hampered by the high cost of electric vehicles, batteries, and the insufficient development of the infrastructure network. The existing problems of electromobility are gradually finding their successful solution.

Aviation transport in the context of decarbonization can switch to hydrogen fuel, which will be produced using wind, solar or other climate-neutral types of power plants.

4. The ideology of moderate consumption and self-restraint. Such an ideology and its practical application to preserve the planet's climate should concern many millions of people on earth, especially in countries with high consumption of various types of resources. This is an urgent need, which is objectively determined in the current conditions.

5. Innovations in energy and energy use. In these areas, which are critical to the global economy and its decarbonization, innovation efforts must be radically increased.

6. Investments and their sizes. The most important areas that are associated with the development of the global economy and its decarbonization should receive investments in amounts that significantly exceed existing ones. To intensify the development of such areas, it is also advisable to use funds from the state budgets of the economically most developed countries of the world.

Conclusions. Thus, as a result of the study, in particular, the following can be stated. Reputable international organizations, which have been studying climate for a long time, point to its rapid change. Climate change was especially noticeable in 2023. This year was recognized as the warmest on record. An increase in temperature and sea level was also noted. The content of carbon dioxide and methane in the atmosphere increased noticeably. High levels of fine dust particles have been reported in Europe, which are particularly harmful to human health. These large-scale climate changes are causing

significant damage and require active, concerted and immediate action by the global community. Measures to decarbonize the global economy include, in particular, comprehensive measures to manage the development of energy generation potential using climate-neutral sources: wind, solar power plants, traditional nuclear power plants and using small modular reactors. The production of environmentally friendly energy must be accompanied by its rational use in all

spheres of the economy, in particular in transport, where electric modes of transport, electric vehicles, hydrogen-powered aircraft and other efficient modes of transport should be actively used. Decarbonization efforts must also include creating a realistic understanding among the general public about global climate change and the necessary actions. There is also a need to significantly increase investment and innovation efforts towards decarbonization.

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