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WORLD INDUSTRY DIGITIZATION IN THE CONTEXT OF ENSURING CLIMATE NEUTRALITY

Abstract

The article examines the connection between digitalization and climate neutrality of economy, which is an obvious mainstream in the modern world. Global development programs aimed at solving climate problems and digital transformation of the industry are analyzed. Strategic directions of climate neutrality achievement are considered in accordance with the EU 2050 Strategy, aimed at reducing the greenhouse effect and CO2 emissions. Comparative analysis of the volumes of greenhouse gases emissions generated by the economy of different countries of the world related to ratios of their GDP is carried out. Critical limit of greenhouse gas emissions per 1 million dollars of the country's GDP is determined, which is an indicator of necessity to implement environmentally friendly approach. Relying on the experience of the world heavyweights of modern industry (USA, China, Germany, etc.), it is emphasised that the modern economic system has the potential to achieve climate neutrality, introducing innovative practices and digital tools The capacity for such implementation is as-

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sessed on the basis of global digital competitiveness indicator, indicating general technological readiness of most countries for digitization. A list of tasks and projects of digital transformation in the field of climate problems and environmental protection is defined on the example of Ukraine. The conclusion is made about synergistic implementation of digital and environmental initiatives as a great contribution to the sustainable reconstruction of the domestic industry in the nearest future.

Key Words:

digitalization; climate neutrality; global industry; Industry 4.0; digital competitiveness index; sustainable development; EU strategy.

JEL: F29, O14, O57.

3 figures, 30 references.

Problem Statement and Literature Review

In recent decades, digitalization has become a powerful global mainstream, which covered almost all branches of the world economic system and quickly transformed the information and communication processes of people's social life.

However, while in the social sphere the strengthening of digital trends is mostly connected with the general growth of society loyalty to the digital, such a transformation is due to numerical digital dividends for business in the field of production. According to the World Bank analysts, the unconditional benifits of the world industry digitalization primarily refer to growth in companies labor productivity and competitiveness both in local markets and in the international arena, cutting current production costs, creation of fundamentally new products and new workplaces, and meeting needs of a wider range of consumers in different market segments (World Bank Group, 2016). However, technology in a broad sense

should serve the higher needs of the human community, and therefore the possibilities of the digital transformations should also be considered in view of solving climate problems and ensuring sustainable development, especially considering the significant negative environmental consequences of industrial expansion. In this context, digitization requires the world community to define priorities for political and institutional reforms, creation of digital mechanisms, which is becoming an increasingly urgent task, especially for countries that have already faced significant climatic changes (Hanna, 2020).

Digitization is seen as a creative force in ensuring sustainable development of the planet, ensuring high innovation of the ecology-economy-social sphere triad through the stimulation of innovative activity, development of human capital, support of high-tech sectors of the economy and improvement in energy efficiency (Kosovych, 2021).

The synergy between digitization and greening is emphasized by developers of national strategies and policies of industry digital transformation in different countries of the world. For the recent decade, such examples are as follows:

- The *US National Strategic Plan for the Development of Smart Manufacturing* (Interagency working group on Advanced Manufacturing, 2012);
- British foresight project for future of manufacturing (More et al., 2013), which is currently laid as a basis for the development of a national strategy for a climate-neutral society;
- German plan for the development of Industry 4.0 (Kagermann et al., 2013);
- China digitalization program *Made in China 2025* (Li, 2018);
- *EU Digital Compass 2030*, presented by the European Commission with a call for the implementation of the «digital decade» in Europe (European Commission, 2021) and others.

All these documents focus on solving problematic issues of industry digital transformation in context of implementing smart production technologies. Therefore, digitization should work for the benefit of people, in particular, helping to achieve climate stability of the economy.

The world scientific community and representatives of international organizations are increasingly calling for the coordinated development of digital capabilities and environmental initiatives. For example, in a meaningful report delivered by representatives of the German Advisory Council on Global Change (2019), it was noted that the global digitalization policy should be formed in such a way as to become a lever and support for a large-scale transformation of the world in the direction of sustainable development and solving climate problems.

Based on the previous strategies of the European Union, in particular, the policy of the European Green Deal, the strategic vector of the EU economy development directed to achieving climate neutrality was outlined. Thus, presenting the New Industrial Strategy of Europe until 2050, its developers noted that «Europe is beginning the transition to climate neutrality and digital leadership ... such a double environmental and digital transition will affect every part of the economy, society and industry» (Brouwer, & Bergkamp, 2021). The implementation of such strategies requires new technologies, innovations and investment mechanisms, as it contributes to the creation of new products and the transformation of existing business models and markets (Paoli & Geoffron, 2019).

Another important task is the harmonization of policies and standards for the regulation of the transition processes to a climate-neutral economy of the EU together with other countries participating in the energy market (Pimonenko, 2021).

Currently the key issue is still to determine the mechanism of integration of ecologically oriented policies and international practices at the level of national industries and individual agglomerations, which traditionally see digitization primarily as a source of internal optimization of production processes and company revenue growth. On the other hand, it is necessary to systematize the international experience regarding digitization tools in the context of solving climate problems of modern industry.

Despite the ultimate importance of climate issues and the environmental consequences of human industrial activity, the issue of using digitization tools in the context of climate neutrality is revealed in a fairly general way. In modern scientific journalism, two angles of coverage of this problem can be distinguished.

The first is the examination of the environmental consequences of industrial expansion through the prism of sustainable development. Here, we might note the scientific works of M. van der Velden (2018), C. Gensch et al. (2017), S. Kunkel and D. Tyfield (2021), B. Kosovych (2021), A. Niñerola et al. (2020), L. Filho et al. (2022) and others. The analysis of scientific works shows that climate issues are considered among other global goals, and digitalization is considered to be a global trend which must be taken into account when solving environmental issues. Climate change is mentioned mostly among the problems of sustainable development. To be more concrete, SDG 13 *Take urgent action to combat climate change and its impacts* is dedicated to its solution. However, scientists emphasize the lack of road maps for achieving this goal in terms of individual types of economic activity in countries, as well as the lack of clear criteria for assessing acceptable limits of the global industry impact on the climate change.

The second emphasis in scientific opinion is made on the issues of forming a smart and green industry, and general directions of economy digitalization. Thus, scientists consider digitization as an irreversible stage of the global indus-

trial transformation, while climate effects are proposed to be taken as a selection criterion for choosing the right digital model for the manufacturing. These questions are considered in the studies of Borysiak and Ivanechko (2021), Galtsova et al. (2021), Duch-Brown and Rossetti (2020), Kagermann et al. (2013), Murthy et al. (2021), German Advisory Council on Global Change (2019), Hanna (2020) and others.

At the same time, there is no semantic bridge between considerations of the role of digitalization in overcoming climate effects and their prevention by ensuring the climate neutrality of the world industry. A study provided by a group of German scientists (Pauliuk et al., 2022) is worth mentioning, since it indicated that despite general proclamations of the necessity for the inseparable development of digital technologies and climate initiatives, there is currently a conceptual and categorical gap in identifying the opportunities of digitalization and its tools in the direction of solving problems of climate neutrality.

The main aim of the research is to determine the background for synergistic development of the processes of digitization and greening of the world industry towards achieving its climate neutrality.

Methodology

Fulfillment of the purpose of this study requires a combination of qualitative and quantitative approaches. Firstly, an empirical study was conducted in order to determine the features of industrial digitalization as a global trend, and its opportunities to address the climate problems. The problematic issue led to revealing the logical coherence between the global industry, as a research object, climate neutrality, as a strategic criterion for its development, and digitalization, as a tool for achieving climate neutrality of the industry. Thus, the qualitative analysis focused on the current trends of digital transformation of the industry in the context of solving environmental problems. Then, modern scientific findings regarding the concept of climate neutrality of the economy were theoretically summarized, while strategic directions for its achievement were systematized on the basis of regulatory documents of the EU, the UN and countries with relevant programs.

Secondly, we put forward a hypothesis about the different nature of dependence between the volume of greenhouse gases as a trigger of climate change and the country's GDP as a result of its industrial activity. The prefetching covered quite different countries, from the world's leading producers (the US, China, Germany, the UK) to countries with huge deposits of fuel and energy resources that are global leaders in some industries average by GDP level (Ukraine, Uzbekistan, Iran, UAE, Australia, Canada). It was suggested that coun-

tries from these groups have the greatest impact on the environment due to the active industrial expansion of available resources. The EU leader-countries in socio-economic indicators that are currently actively promoting the idea of clean industry (Denmark, Luxembourg) were also added to the sample. The main idea of such country grouping was to check the relevance of the proposed assumptions and to determine the direction of further research. The volume of greenhouse gas emissions as a ratio to the country's GDP was chosen as the criterion. It should be noted that the proposed quantitative approach was used to generally outline the problem and justify further research in the direction of confirming the specified hypothesis. On the other hand, the determination of trends in the ecological impact by various countries logically requires setting a mechanism for solving the problem of climate neutrality. Therefore, considering digitalization as a tool for achieving climate neutrality, the indicator of global digital competitiveness was investigated for selected countries. This allowed us to illustrate the existing gap in the states' readiness for independent digital transformation of the manufacturing.

Research Results

Digitization of world industry involves the widespread introduction of information technologies and computer systems such as automated design, computer modeling, industrial Internet of Things, big data analysis, etc. These digital technologies have developed so much in recent years that they formed a separate digital industry market which is currently experiencing rapid growth. The capitalization of the global market of digitized production is expected to grow at least five times in the next 8-10 years from 276.5 billion dollars to 1.37 trillion dollars in 2030 (Murthy et al., 2021). The greatest growth can be seen in the sectors of industrial engineering, automation and electronics, which are necessary for the implementation of the production cycle in many industries. On the one hand, this growth is caused by the wide implementation of the results of technological progress in mass production, and, on the other hand, the powerful opportunities that digitalization opens up for the owners of international companies. They lie in the area of optimizing production processes, increasing product quality, increasing productivity while simultaneously reducing production costs, and communicating with consumers around the world.

It could be assumed that technical and economic effects of digital transformation arouse the greatest interest of international players. However, in recent years there has been an increasingly noticeable tendency to shift the focus of international attention from material needs to socially significant goals. As the concepts of eco-thinking spread, the creation of climate hubs and eco-laboratories, the implementation of socially conscious business practices, in particular, the im-

plementation of UN strategies for achieving the 2030 sustainable development goals, attention to the role of technology in this process is growing.

Modern new technologies should serve as a tool for solving the problems of greening production, preventing climate crisis, and preserving the planet's natural landscape. In the era of the digital economy and the burst of innovation, it is appropriate to review climate change management policies due to the emergence of a large number of useful digital solutions.

This problem is especially relevant for the global industry, which is one of the most significant factors influencing the climate changes. There is peculiarity to digitization of the industrial sphere in that the main focus of digitization projects is directed precisely at the optimization of company complex production processes, but not at shaping customer experience, as, for example, in the field of electronic commerce. For instance, 55% of all vendors' offers in the field of the Internet of Things fall into the sector of industrial production and construction of smart cities, 21% are involved in energy sector, and 14% participate in trade and customer service (UNCTAD, 2021). Less than 9% refers to «other projects», which include digital projects to combat climate change and environmental consequences. However, they are more local and not suffienciently frequent.

Positive developments in this direction were set against the background of the large-scale COVID-19 pandemic, which acted as a trigger for digitalization. Thus, the transfer of the companies' activities to the online space served as an impetus for active digitalization, development of information and communication infrastructure, and increased time for developing qualitatively new foresight projects of «life after COVID», which include digitization projects in the field of climate change.

Climate neutrality of the economy is the chief goal of the European economic modernization. Moreover, more and more scientists, politicians and public figures emphasize that the country's competitiveness on the world stage and its welfare should not be measured by economically oriented indicators. Instead, success of the country should be considered in the context of its aspiration to achieve climate neutrality of the economy.

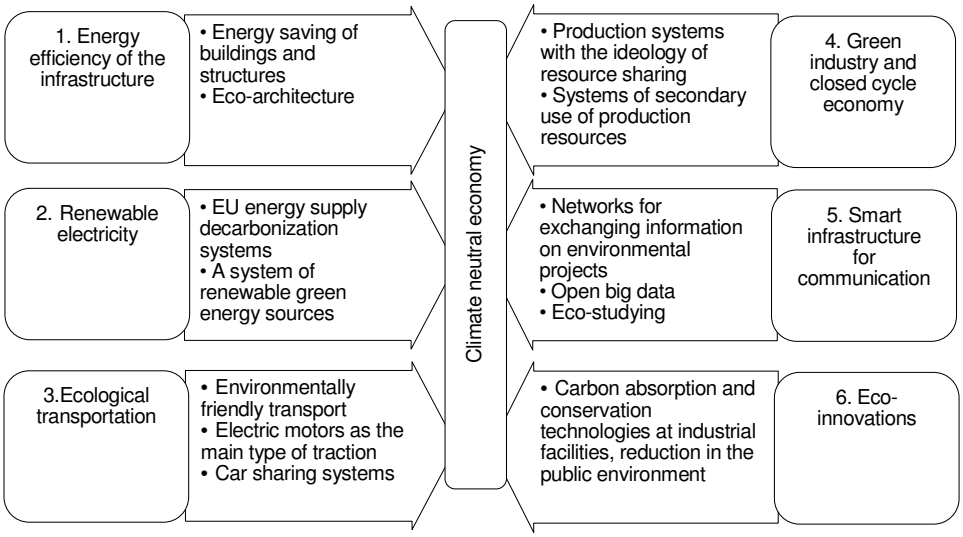
The above-mentioned thesis is confirmed by the report of the Commissioner for Climate and Energy of the European Commission, Miguel Cañete, and its head at the time, Jean-Claude Juncker. Presenting the first strategy for a climate-neutral economy until 2050 for the European Union, the speakers claimed that «the very provision of climate neutrality is necessary, possible and of great interest to the EU, which is a key region of the world» (Delbeke & Vis, 2019). It is worth noting that the EU member states signing the Paris Agreement back in 2015 contributed to the development of the strategy. Accordingly, a number of unique regulatory documents were put forth in five years, the main of which are the *Long-Term Environmental Strategy 2050*, *Road Map of EU Climate Neutrality until 2050* and the first in the world *European Climate Law*.

According to these documents, a climate-neutral economy is an economy with zero greenhouse gas emissions. It should be mentioned that this very notion regarding the maximum neutralization of the greenhouse effect and CO2 emissions is the major idea in the European Green Deal. However, such a simple and, at first glance, obvious definition has a complex nature. Establishment of a climate-neutral economy involves the study of technological, institutional and financial mechanisms for ensuring climate neutrality in all key sectors of the economy: industry, energy, transport and agriculture.

Currently, the strategy for ensuring a climate-neutral economy of the EU is based on seven key components (Figure 1).

Figure 1

Strategic directions for achieving climate neutrality of the EU economy



Source: compiled by the author based on European Commission (2021); Brouwer & Bergkamp (2021).

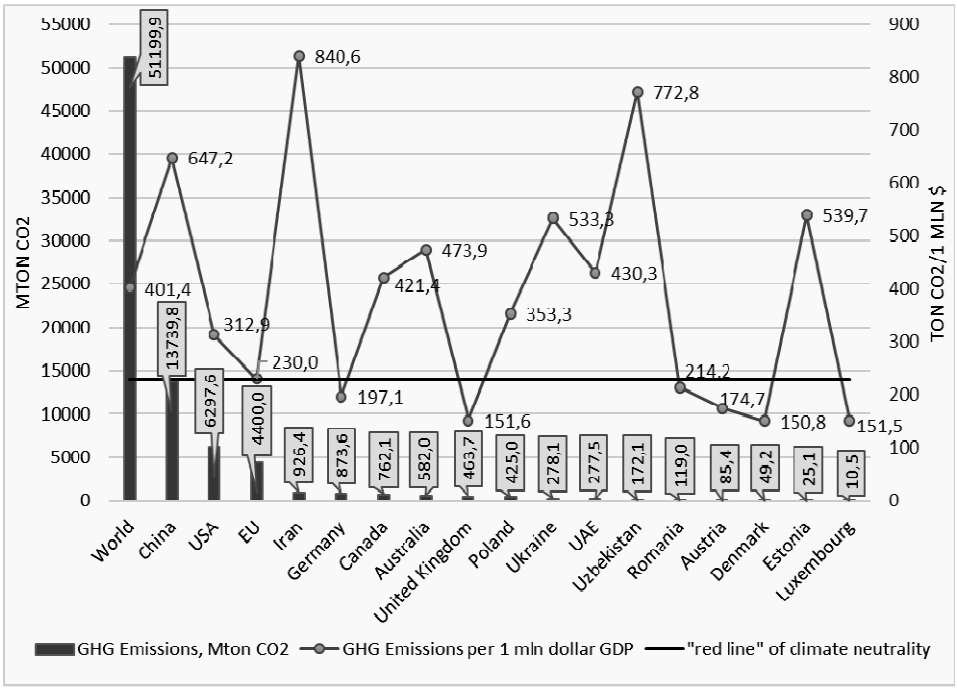
In current conditions, digital technologies help significantly in the implementation of the outlined strategic directions. It should be noted that in the context of the industrial development of the planet, the greatest potential of digitalization is considered precisely in the direction of achieving climate neutrality by re-

ducing the negative consequences of the greenhouse effect, in particular through the neutralization of carbon emissions. The idea of achieving exactly «zero level» of CO2 emissions looks quite utopian, considering the scale and climate aggressiveness of modern industry. However, the development of all six components of the EU Climate Neutrality Strategy will allow the countries to significantly reduce emissions and promote their gradual absorption from the environment. As the head of the European Commission, Ursula von der Leyen, notes, «if today the company is unable to implement transformation measures to achieve climate neutrality directly in its sector, then it should still contribute to their reduction by participating in other projects where it is possible».

Currently, the amount of greenhouse gases produced by the economies of individual countries varies significantly (Fig. 2).

Figure 2

Greenhouse gas emissions relative to the GDP of some countries (as of 2019)



Source: based on data of statista.com, worldbank.org.

As we can observe, the biggest polluters of the planet in the context of climate change due to CO2 emissions are China, whose economy forms up to 26.8% of global greenhouse gas emissions, the USA (12.3%) and the EU countries, which together produce 8.5% of the global greenhouse effect.

The conducted research made it possible to reach an important conclusion: currently the amount of gross domestic product produced by a country does not necessarily correlate with the amount of CO2 emissions. Until now, belief prevailed that the industrial activity of the country, aimed at the production of the gross domestic product in the sectors of energy, industry, agriculture and tourism, is the main negative factor of climate change influence (Niñerola et al., 2020; Krishna & Srikanth, 2021). However, as shown graphically in Fig. 2, there are obvious gaps between the total level of emissions and their volume relative to the country's GDP. It is a rather important aspect in determining the economic paradigm of climate neutrality.

First, it is reasonable to assume that the lower the level of CO2 emissions in the formation of a country's GDP, the more climate neutral its economy is. Considering the fact that the *EU Climate Neutrality Strategy until 2050* began to be implemented in 2018-2019, the average level of CO2 emissions in the EU for this period (230 tons of CO2 per 1 million GDP) can be taken as a critical level or a kind of «red line» of climate neutrality of the EU economy and a benchmark for other countries of the world. Accordingly, countries that have crossed this limit should first of all pay attention to the utmost necessity for active implementation of economic greening programs. The identified trend determines the expediency of determining the limits of fluctuation of the established red line of climate neutrality for the industries of different groups of countries using mathematical modeling, which is the direction of the author's further research.

Second, the tendency towards a climate-aggressive economy is observed in many countries which are the leaders in world production and countries which are rich in fuel and energy resources. For example, the United States, which is the undisputed world leader in terms of gross domestic product, shows an inflated level of greenhouse gas emissions by EU standards, amounting to 312.9 tons of CO2 for every million dollars of GDP. The situation is even more severe in China as its economy, often compared to a «big factory», has the second largest global GDP after the USA and is even more climate-aggressive. The creation of every $1 million of GDP is accompanied by emissions of more than 630 tons of CO2 in China, which is almost three times as high as the average level of EU countries. A similar negative situation can be observed in some EU member states, as well as Iran, Australia, Canada, Uzbekistan, the UAE, and Ukraine (Fig. 2). Here, it is important to dwell upon the example of Estonia. Although the level of emissions in the country is one of the lowest in the EU, every million dollars of Estonia's GDP is accompanied by 550 tons of greenhouse gas emissions, which is almost twice as much as the red line level in the EU and indicates the climate-exhausting economic activity of the state despite the country not specializing in heavy industries.

The trends of Germany and Great Britain are opposite to this, which can be considered indicative from the point of view creating climate-neutral production. The economies of Germany and the UK are among the most industrially and technologically powerful in the world, respectively having the fourth and fifth largest GDPs in the world. However, they produce a much smaller amount of greenhouse gas emissions compared to other world countries and are below the red line for the EU countries (197 tons and 150 tons of CO2 per 1 million dollars of GDP, respectively). These figures suggest the possibility of improving the climate situation and achieving neutrality even in those countries that specialize in heavy industries and the extraction of energy resources.

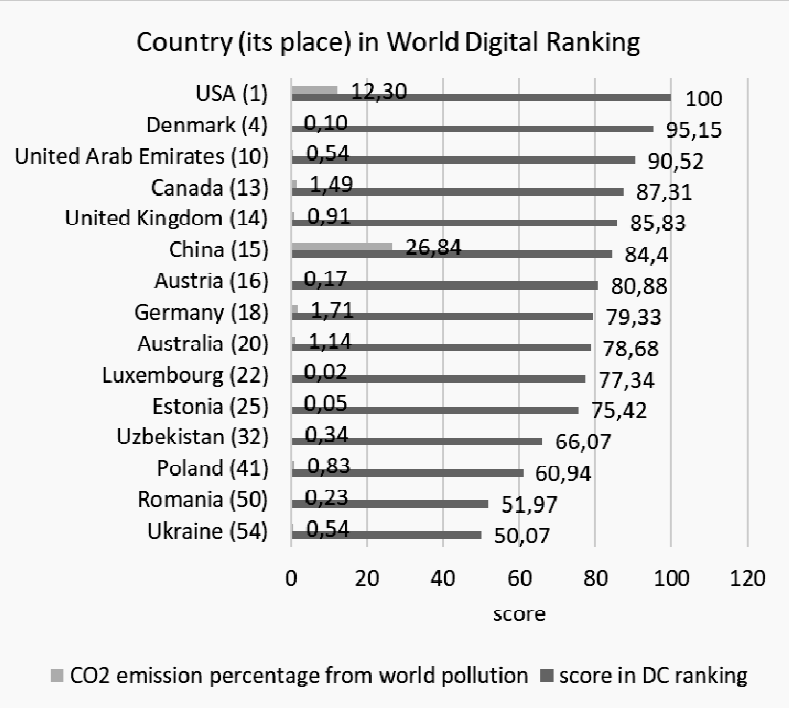
Third, the volume of carbon emissions in each individual country is determined by the directions of development of the national economy, its specialization. The following statistics prove this thesis. The largest sources of the greenhouse effect in the country due to CO2 emissions can be transport, electricity production, industrial production, consumption of fuel and energy resources, and consumption of resources by households. Generally, one of these prevails in each country, but a combination can also occur, forming an individual map of CO2 accumulation factors (Maris & Flouros, 2021). Thus, in China, up to 70% of all carbon emissions are due to intensive consumption of solid fuel and energy resources by industries. The same factor is relevant for Ukraine (52%). Meanwhile in Luxembourg, up to 68% of CO2 is due to the activity of the country's transport system; a similar situation is typical for the countries of South America. At the same time, up to 80% of Estonia's CO2 emissions are caused by electricity production. In contrast to previous production reasons, in Uzbekistan, Armenia and Switzerland up to 33% of CO2 emissions are a result of household activities (private and commercial residential buildings, public services).

Taking into account the outlined observations, we come to the conclusion that climate neutrality or, on the contrary, climate change is determined not so much by the quantitative component of production, as by the qualitative component, as well as by the desire for such an approach. That is, under modern conditions, achieving climate neutrality is possible not by reducing the volume of environmentally harmful production in the country, but by its gradual, step by step transformation.

In this direction, digitalization should become an effective tool for such transformation. The potential for digital transformation of the industrial sphere can be assessed using the digital competitiveness indicator. This indicator was presented by the IMD Global Competitiveness Research Institute for 65 countries of the world (IMD World Competitiveness Center, 2021). Its calculation is based on a complex system of 52 criteria, which are studied in the following directions: knowledge and scientific research, technological assessment, flexibility and adaptability to the future. The study of the indicator of digital competitiveness for some countries of the world is shown in the chart (Fig. 3).

Figure 3

Digital competitiveness of countries (as of 2021)



Source: compiled by the author based on IMD World Competitiveness Center (2021).

More than 25 countries of the world demonstrated high indicators of the digital competitiveness of their economies (more than 75 points), which testifies to a fairly significant potential for the digital transformation of national industries. It is of great interest that the countries that are currently the greatest polluters of the planet in terms of the amount of emissions have a favorable digital environment for the implementation of digitization projects in the field of climate neutrality. However, many countries, including Ukraine, need external technological and investment support in this matter.

It is worth bearing in mind that digital projects in the field of climate neutrality are currently being considered at the state level in many countries of the world. For example, in Ukraine, the *State Digital Transformation Plan* includes 94 general digitization projects, which were presented by the Ministry of Digital

Transformation of Ukraine in 2021. Along with others, we can identify 12 individual digitization projects specifically in the field of nature management and environmental sustainability, which were developed on the basis of the integration of international experience and presented together with the Ministry of Environmental Protection and Natural Resources of Ukraine. Among them are the following digitization projects (Ministry of Digital Transformation of Ukraine, 2021):

1. State supervision in the field of environmental protection (e-Control);
2. Rational subsoil use (e-Subsoil use);
3. General environmental monitoring (e-Environment);
4. Environmental impact assessment (e-EIA);
5. Controlling and protection of atmospheric air (e-Air);
6. Strategic environmental assessment (e-SEO);
7. Pesticides and agrochemicals management (e-Pesticides);
8. Biological and landscape diversity monitoring (e-PZF);
9. Water management (e-Water);
10. Forestry (e-Forest);
11. Fisheries (e-Fishing);
12. Wastes management (e-Waste).

The above mentioned projects are aimed at digitizing the key processes of monitoring and controlling climate changes caused by human economic activity. Despite the fact that digitization projects were developed in the wake of economic recovery after the global pandemic of COVID-19, they can now be used in synergy with sustainable industrial recovery programs in the context of Ukraine's post-war reconstruction. To achieve this purpose, a number of problematic issues should be urgently addressed. It is necessary to, firstly, summarize information flows regarding the climate situation, which are currently generated by various entities of economic activity (state institutions in the field of environmental protection, business, public organizations); secondly, develop an electronic environmental control system with automated notification of participants about exceeding pollution indicators in certain regions of the country due to the activities of domestic industry heavyweights; thirdly, work out a mechanism for the integration of digital technologies in order to solve the problems of climate neutrality of the economy, in particular, the digitalization of the processes of negative impact of industry on the environment.

In the field of green energy, an important task is the creation of digital communication platforms for the exchange of information between consumers and providers of energy services (Borysiak & Ivanechko, 2021).

Positive trends can be identified regarding the intentions of implementing international digitalization experience as an effective approach to solving these issues in Ukraine. Effective projects for digital solutions are the following (Williges et al., 2022; Duch-Brown & Rossetti, 2020):

- Open data and access to information in all areas related to the use of natural resources, subsoil and environmental impacts of production;
- Constantly updated electronic registers of the country's natural wealth that track changes caused by greenhouse gas emissions;
- Open and transparent digital auctions related to the sale or lease of natural resources;
- Digital integrated mineral maps;
- Digital investment atlases for various industries;
- Digital permits for the use of subsoil, which make it possible to speed up the process and to create a single transparent register of subsoil use;
- Electronic tickets for individuals as permissions for hunting, fishing, logging, etc.;
- Electronic systems for monitoring emissions in industrial zones and the public sector with automatic generation of protocols for violation of established environmental norms.

The specified digital solutions are summarized from the international experience of digitization projects in the field of environmental protection. Mechanisms for their implementation in Ukraine should be established now, because in the nearest future they will contribute to the permanent and ecologically sustainable reconstruction of the domestic industry.

Conclusions

Taking into consideration the dynamic and, unfortunately, often climate-unfriendly growth of world production, digital and ecological development strategies should be developed and integrated into synergies at the level of individual states, regions and, finally, the whole world.

Digitalization is a powerful tool for solving the problems of modern industry greening. Positive influence is observed in several areas simultaneously. First area is the reduction of greenhouse gas emissions through the digital optimization of production processes at the stages of manufacturing, resource consump-

tion and transport logistics regulation. The second one is the use of eco-innovations to absorb harmful substances in the urban ecosystem and reduce the existing consequences of the greenhouse effect. The third area concerns general regulation of the industry climate neutrality by creating and implementing digital platforms for monitoring environmental impacts, whether adverse or beneficial, and participants' involvement in this process.

Currently, most of the developed countries of the world have quite high indicators of digital competitiveness, which demonstrates the technological and infrastructural readiness of the states to implement modern projects of industry digitization, which are aimed at achieving climate neutrality. However, national industry remains climate-unfriendly in many countries of the world. This is evidenced by the large volumes of greenhouse gas emissions that accompany every million dollars of the country's GDP. For EU countries, the calculated average level of 230 tons of CO2 per 1 million GDP, from which the implementation of the *EU Climate Neutrality Strategy until 2050* began, can be considered a point of reference or a critical emission limit. Of all the world leaders in industrial production, only Germany and Great Britain managed to cross and lower this limit, while maintaining their positions as top five most powerful economies in the world by the volume of national production. The USA and China are currently the leaders of this rating and at the same time the biggest polluters of the planet, which makes it necessary to adjust their development programs to the climate neutrality strategy of the EU. This task is relevant for all countries with powerful resource potential, including Ukraine.

The experience of EU countries proves that achieving climate-neutral economy is quite possible. Digitalization acts as a kind of accelerator of this process. Modern digital tools in the field of greening the industry cover a wide range of areas of environmental protection and pollution monitoring. Currently, their implementation requires the development of national mechanisms in accordance with the *Climate Neutrality Strategy*, in particular, the creation of single digital platforms to unite all participants at the level of community, business, state and regional associations.

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