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GLOBAL GREEN TRANSITION IN TERMS OF CLIMATE NEUTRALITY AND SUSTAINABLE DIGITALIZATION

ГЛОБАЛЬНИЙ ЗЕЛЕНИЙ ПЕРЕХІД З ТОЧКИ ЗОРУ КЛІМАТИЧНОЇ НЕЙТРАЛЬНОСТІ ТА СТАЛОЇ ДИДЖИТАЛІЗАЦІЇ

ANNOTATION

This article assesses the alignment of the green and digital transitions in the global economy, particularly focusing on EU's strategies for integrating digital technologies to achieve climate neutrality. It discusses how sustainable digitalization principles can boost the green transition and promote climate neutrality. The study reviews digital solutions that reduce business carbon footprints and mitigate climate change impacts, emphasizing digitalization as essential for driving climate neutrality under current geopolitical conditions. The analysis includes a review of digital tools necessary for analytics, blockchain, energy management, and decision-support networks. It proposes creating digital twins of industrial and urban areas to enhance the digital-green transition. Additionally, it explores how the principles of sustainable digitalization act as a booster for both the digital and green transitions, reinforcing each other when aligned correctly. The EU's policy efforts to promote green transitions in technology sectors and the potential rebound effects disrupting these transitions are also examined. The article underscores the importance of a flexible digital approach, global collaboration, and comprehensive educational initiatives as crucial components for effectively synchronizing the transition towards a digitally-enhanced via climate-neutral economy.

Keywords: global economy, European Union, climate-neutral economy, green and digital transition, sustainable digitalization

АНОТАЦІЯ

У статті розглянуто сучасні перспективи зеленого переходу світової економіки з огляду на необхідність забезпечення кліматичної нейтральності та, водночас, можливостей диджиталізації. Проблематику забезпечення синергії та гармонійної узгодженості подвійного зеленого-цифрового переходу досліджено на основі аналітичних матеріалів та стратегічних підходів Європейського Союзу, як флагмана світового зеленого руху. Визначено концептуальні аспекти сталої диджиталізації та її ролі у досягненні кліматичної нейтральності світової економіки. У статті систематизовано досвід ЄС та визначено своєрідний "цифровий скелет", який сприяє фасилітації зеленого переходу та є критично важливим для досягнення "чистого нуля" викидів у різних індустріях. Ключовими складниками такого цифрового скелету кліматично-нейтральної економіки визначено: штучний інтелект, блокчейн, інтернет речей, супутникова навігація, цифрові двійники, квантові обчислення, датчики та мікромережі. У цьому контексті дослідження розглядає цифрові рішення, які сприяють зменшенню вуглецевого сліду бізнесу та пом'якшують наслідки зміни клімату, підкреслюючи важливість диджиталізації як ключового фактору досягнення кліматичної нейтральності в умовах сучасних геополітичних реалій. У статті проаналізовано функціональні можливості цифрових інструментів у сфері аналітики, блокчейну, управління енергією та мереж підтримки прийняття рішень. Обговорюється створення цифрових двійників промислових та міських об'єктів для покращення цифрово-зеленого переходу. Крім того, досліджується, як принципи сталої диджиталізації діють як каталізатори як для цифрового, так і для зеленого переходів, посилюючи один одного за умов гармонійного узгодження. Також розглядаються зусилля політики ЄС зі сприяння зеленому переходу у технологічних секторах та потенційні відскокові ефекти, що порушують ці переходи. Стаття підкреслює важливість гнучкого цифрового підходу та міжнародної співпраці як ключових компонентів для ефективної синхронізації переходу до кліматично-нейтральної економіки на глобальному рівні.

Ключові слова: глобальна економіка, Європейський Союз, кліматично нейтральна економіка, зелений та цифровий перехід, стала диджиталізація

Formulation of the problem. The current world order is characterized by significant geopolitical changes that intensify the formative trends of the global economy. An analysis of the long-term predictors of the russian federation's military aggression against Ukraine reveals their significant impact on critical sectors, including energy, economy, food and national security, defense capabilities, and the overall geopolitical balance of power. Moreover, current developments have the potential to radically change the established approaches of states to the realization of ambitious sustainable development goals for the coming decades. However, in the context of an adequate political response, such challenges can be transformed into drivers that will accelerate the process of achieving the set goals, contributing to strengthening sustainability, achieving global leadership and strategic autonomy in ensuring climate neutrality of global industries.

Harmonizing the processes of digital and green transformation is an important condition for achieving climate neutrality, based on the

comprehensive analytical forecast presented in the Strategic Vision 2023 [1]. The document analyzes the prerequisites for synergies between the green and digital transitions, which are priority areas in the EU's policy agenda. Recognition of the paradigm of mutual reinforcement of these areas seems to be critical for the overall progress in achieving the sustainable development goals. In particular, the implementation of the European Green Deal strategy aimed at achieving climate neutrality of the economy and minimizing eco-degradation by 2050 is an integral part of the green transition. At the same time, the digital transition of the world economy is an objective consequence of the overarching trends of technological determinism, which now requires a more careful approach to global economic policies to minimize potential negative impacts and maximize the positive contribution of digitalization to environmental, social and economic sustainability. This doctrine is reflected in the EU's Digital Compass and Fit for 55 initiatives.

Thus, modern Europe has set a high bar for digital and green development, which requires finding mechanisms to harmonize and systematize these powerful global mainstream trends. In the coming decades, the success of the synergy of digital and green transformation will depend on the ability to implement existing and new technologies on a large scale, as well as on a set of geopolitical, social, economic, and regulatory factors that require systematic research.

Analysis of recent research and publications. The current scientific discourse is represented by a number of international studies that consider digital and green transformation in a certain way. However, the conditions, applied mechanisms, and, most importantly, the consequences of such mutual alignment are not presented in the context of the long-term perspective of ensuring the climate neutrality of the global economy.

A number of applied and fundamental research papers are devoted to the question of how digital technologies can help reduce greenhouse gas emissions in the context of modern economic systems [2–5]. In their academic work, Lange S. and Santarius T. examine the impact of digitalization on sustainable development. They note that digitalization can significantly reduce emissions through the automation and optimization of production processes, reducing energy consumption, and improving resource management via smart grids and the Internet of Things [2]. Authors Rolnick D., Donti P., Kaack L., and Lacoste A. highlight that digital machine learning technologies can play a crucial role in combating climate change if they are directed towards optimizing energy use and enhancing the efficiency of renewable energy sources [3]. In their articles, Hedberg A., Pietryn D., Staab P., and Hofmann F. emphasize the importance of digitalization for developing a circular economy, which contributes to emission reduction by optimizing supply chains, promoting the reuse of materials, and creating sustainable markets [4; 5].

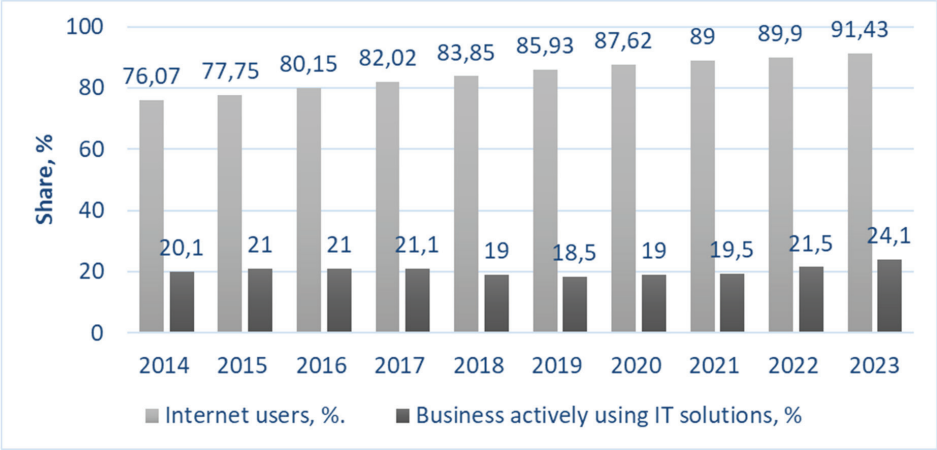
Other researchers, including Santarius T., Pohl J., Lange S., Frick V., Matthies E., Thogersen J., and Matthies E., emphasize the need for societal lifestyle changes towards more environmentally friendly and conscious behaviors. This shift is increasingly recognized as crucial for sustainable development [6–8]. On the other hand, analytical studies conducted by international organizations such as ESC SRIA, EFFRA, and the European Commission, as well as by individual scientists like Vasilescu M., Dimian G., Gradinaru G., Mietule I., et al., focus on the domains of green technological innovation. These innovations are seen as essential for ensuring the long-term competitiveness of European industry [9–12].

It is worth noting that most scientific developments in the area of green and digital transformation are currently focused on the technical aspects of certain sectors of the economy or on certain aspects of the green or digital transition. The issue of their synergy and harmonization remains an open question for scientific research and discussion.

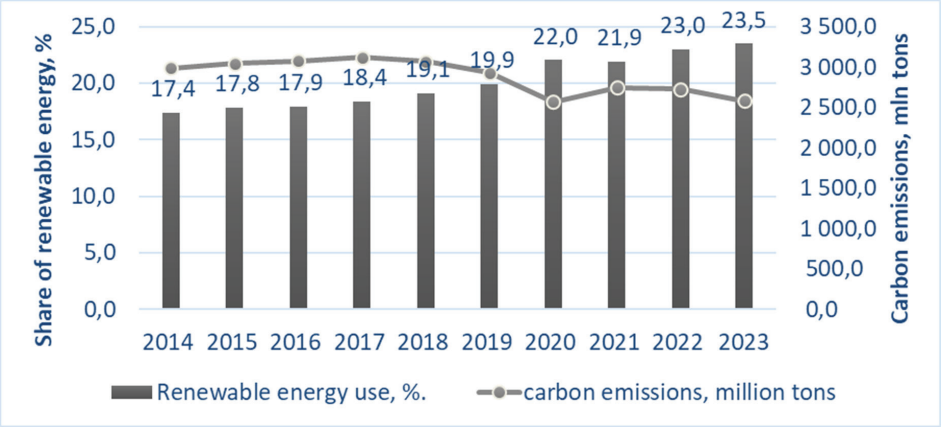
Formulation of the purposes of the article. The study aims to identify the prerequisites and directions for harmonizing the green and digital transformation of the world economy based on the European experience of using digital technologies to achieve climate neutrality in key industries. This involves analyzing the points of contact and mutual reinforcement of digital and green transformation in the context of synergies between them.

Presentation of the main research material. Digital technologies are becoming a fundamental element in achieving climate neutrality of the global economy, actively contributing to the reduction of environmental pollution, decarbonization of production systems and, as a result, the restoration of global biodiversity. The European experience of developing industries in the dual green-digital transition paradigm has opened up broad prospects for digitalization in achieving the environmental goals of business entities. Thanks to information systems for ubiquitous analytics and control over the use of natural resources, as well as through a significant expansion of automation capabilities, advanced technologies ensure increased productivity and adaptability of various systems and network structures.

The use of digital solutions in the field of robotics, the Internet of Things (IoT), and blockchain for energy-efficient data management throughout the entire life cycle of products and services, as well as in their value creation processes, is driving the transition to a sustainable economy. Such an economy is more circular, climate-neutral, and competitive. Given that the share of Internet users is a representative criterion of the intensity of digitalization and a marker of the EU's digital decade, we can see a clear upward trend in this indicator against the background of an overall reduction in emissions and an increase in the share of renewable energy sources (Fig. 1 a, b).



a) digital aspect



b) green aspect

Figure 1. Some metrics of Green and Digital transition in the EU

Source: compiled by the author based on open data from the Eurostat portal

Digitalization also significantly simplifies the procedures for monitoring, reporting and verification of greenhouse gas emissions, which in turn improves the carbon trading system. On the other hand, the introduction of digital product passports provides better tracking of materials, components, and production processes, making information more accessible and paving the way for the development of efficient closed-loop business models [8].

A breakthrough area of the climate-neutral economy, which is currently being actively developed in the EU, is the use of digital twins, which can significantly contribute to innovation and the development of more sustainable production processes, products, or even building structures [1; 3; 13]. At the same time, quantum computing and cloud technologies open up new opportunities for solving problems that remain beyond the reach of classical computers, especially in the context of complex ecosystem modeling [2; 6]. Another important area of technological development policy in Europe is space-based data transmission technologies, which provide real-time access to global information and intensify the processes of monitoring achievements in the field of sustainable development [9]. This opens up new prospects for climate management of the economy at the macro level.

However, the synergy between the green and digital transitions of the economy has some contradictions, as the green transformation not only benefits from modern digitalization solutions, but also directly transforms the digital sector of the modern economy. Resources such as renewable energy sources, renewable hydrogen, nuclear power, and nuclear fusion technology, which are important for the global economy, are important factors in the context of the growing energy needs of the digital sector.

Policies aimed at achieving climate neutrality and improving the energy efficiency of digital data centers and cloud technologies by 2030 directly contribute to the greening of blockchain and IoT technologies by using solar or wind energy to power them [8]. However, potential delays in the development of such green infrastructure could pose a challenge. In this direction, the economic system will require optimal planning, deployment, and adaptation of relevant technologies. On the other hand, sustainable financing is also a significant factor in attracting investment in the climate-neutral digital sector, and the role of demand, consumption, and actions by businesses and the public to reduce e-waste is critical to minimizing the energy consumption of digital technologies [7].

While both transitions are transforming the global socioeconomic system, they differ in nature and dynamics. The Green Transition is driven by the need to achieve climate neutrality and sustainability goals, and to achieve them quickly. Its implementation requires a political and social push. On the other hand, the digital transition is a continuous process of technological change, one of the main drivers of which is the real sector of the economy. Therefore, it is important to ensure the harmonization of digitalization and green transformation processes on the basis of inclusiveness, sustainable governance, and support for public-private partnerships.

If digital technologies do not become more energy efficient, their widespread use will lead to an increase in energy consumption. Already, information and communication technologies (ICT) account for 5–9 % of global electricity consumption and about 3 % of greenhouse gas emissions [1]. Lack of a coherent system for measuring the impact of digitalization on the environment, including predicting possible rebound effects.

The rebound effect in this context describes a possible situation in the economy when improvements in energy efficiency or resource use lead to an increase in the consumption of these resources rather than their saving [13]. This can happen due to a reduction in the cost of operating or using products and services, which encourages consumers to use them more than before. The rebound effect is an important factor in the design and evaluation of energy and climate policies, as it can reduce or offset the environmental and energy benefits of adopting more efficient technologies and practices. Studies show that ICT energy consumption will continue to grow due to increased use and production of consumer devices, demand from networks, data centers, and cryptocurrencies. For example, the electrical footprint of ICT could grow from 1988 terawatt-hours in 2020 to 3,200 in 2030 [14]. Energy consumption and, consequently, the carbon footprint is also growing due to the increased use of online platforms, search engines, virtual reality concepts such as meta-space, and music or video streaming platforms [15]. On the other hand, the deployment of the next generations of low-power chips and more efficient communication technologies (5G and 6G, artificial intelligence-based networks) may reduce the overall environmental impact of ICTs [8]. This will help to somewhat offset the rebound effect and keep the synergy of digital and green transformation in a productive direction.

Additional contradictions arise from e-waste and the environmental impact of digital technologies. A larger carbon footprint is observed from electronics, phones, and computer equipment, which is also accelerating the global production of e-waste, which could reach 75 million tons by 2030 [16]. In the EU, only 17.4 % of this waste is currently properly treated and recycled, and the volume of e-waste generation is growing by 2.5 million tons annually [ibid].

Appropriate economic policy is very important in this area, as each transition to new digital standards will require massive replacement of equipment [17]. For example, the use of the current global 5G and 6G standards require the average European user to replace their equipment to take full advantage of their benefits, as most existing smartphones, tablets, and computers are only compatible with previous generations of wireless systems. On the other hand, advances in digitalization may also lead to an increase in the use of natural resources, such as water for cooling certain digital manufacturing processes, rare earth metals for batteries, etc.

Energy, transportation, industry, construction, and agriculture are the largest sources of greenhouse gas emissions in Europe [1]. Reducing their environmental impact, as is also envisaged by the Fit for 55 package, and strengthening their sustainability are critical to harmonizing the green and digital transition. This requires not only ensuring the availability of technological equipment, but also the adaptation of EU economic, climate, and digital policies. At the global level, the relevance of this request is particularly urgent, as the expected growth of the middle-income population to 9.7 billion by 2050 will require more food, manufactured goods, energy, housing, and environmental safety guarantees [17].

The digitalization of the economy will help to ensure the necessary acceleration of decarbonization by reducing CO2 emissions. However, the achievement of climate neutrality by 2050 will be possible only if the development of new technologies that are currently at the experimental, demonstration or prototype stage is systematically supported [18]. An analysis allows us to outline the components of technological support for the harmonious green and digital transition of the world economy at the present stage of scientific and technological progress (Table 1).

In general, if managed properly, digital technologies can accelerate the achievement of a climate-neutral and resource-efficient economy by reducing energy and resource use in key sectors of modern industries. Stimulating climate neutrality in industries through digital technologies is a very promising area. To achieve climate neutrality in 2050, by 2030, the EU industry will have to reduce its CO2 emissions by 23 % compared to 2015, as industry accounts for about 37 % of total final energy consumption and about 20 % of greenhouse gas emissions [18; 19]. Four energy-intensive industries – steel, cement, chemicals, and pulp and paper – account for about 70 % of total global CO2 emissions. They are also the largest consumers of industrial energy in the EU.

Digital technologies are becoming important for managing the supply and demand of large industrial energy consumers in a system with

Table 1

"Digital backbone" for climate-neutral economy

Digital technology	Examples of application in the area of green policies and climate-neutral economic development
Artificial intelligence	supports connected mobility, helps to improve traffic management, supply chain management, and reduce fuel consumption.
Blockchain	provides greater transparency into the life cycle and value of the product chain, including the production, reuse, recycling, and disposal of batteries.
Internet of things	helps to monitor the condition of agricultural land, geolocation of resources, etc.
Space services, satellite navigation	provide support for precision agriculture to reduce pesticide use and preserve plant health. can optimize electric vehicles and their charging systems, as well as promote the integration of renewable energy sources and maximize their use.
Digital twins	promote innovation, testing and development of more sustainable solutions, for example in construction or urban planning.
Quantum computing	improve understanding of the biological and chemical processes required to reduce the use of pesticides and fertilizers.
Sensors	help measure and control costs to improve the efficiency of resource use in industry
Microgrids and self-organized networks	automatically monitor energy flows and adapt to changes in energy supply and demand, as well as weather conditions

Source: compiled by the author based on EU' foresight [1] and previous findings [12]

diverse sources and raw materials [2; 6]. The main areas are as follows. "Smart meters, including sub-meters, and sensors increase energy efficiency by providing real-time information on energy consumption and feeding it into energy management tools. Supervisory control, big data analytics, and data collection systems drive the efficiency of industrial processes, as well as data processing for smarter decision-making. Digital twins help to improve system design, test new products, monitor and provide preventive maintenance, evaluate the product life cycle, and select optimal materials. Data-driven optimization improves existing materials, develops greener alternatives, and extends their service life. Monitoring and traceability systems provide information about the materials or parts used in products, which can contribute to increased circularity through better maintenance and high-quality closed-loop recycling [4]. The integration of manufacturing, digital and other advanced technologies, such as robotics or 3D and 4D printing, also plays an important role. In general, the implementation of digital solutions in the industrial sector requires a higher level of technological readiness and cybersecurity to protect industrial process data and the integrity of their operation [20].

In view of the above, harmonization of the digital and green transformation of the world economy requires the systematic integration of a number of determinants. An important factor is to strategize the green course taking into account the digital paradigm of the modern economy. For example, the EU is developing integrated strategies that take into account both digitalization and environmental goals. These strategies aim to create a green and smart economy by promoting energy-efficient technologies and digital inclusion. At the same time, digital strategies should be as adaptive as possible, taking into account the intensification of technological progress in the field of digital technologies. The EU is working to expand access to high-speed Internet, develop computing capacity, and promote the introduction of advanced technologies such as artificial intelligence and blockchain to ensure environmental sustainability. On the other hand, the effectiveness of implementing such strategies in the real economy depends on the legislative framework, which should include a legal framework for green standards, decarbonization, energy efficiency, and digital transformation.

To summarize, effective harmonization of digital and green transformation requires multilateral involvement of all international actors, as both world mainstream trends have a global and non-exclusive impact.

Conclusions from the research. Harmonizing digital and green transformation is critical to achieving a climate-neutral global economy. The European Union is leading this process by integrating digital technologies into various areas of modern industry to reduce its carbon footprint and mitigate climate change.

Digitalization as a driver of climate neutrality involves the widespread use of digital technologies for ubiquitous analytics, blockchain, satellite solutions, energy services, micro and macro networks for monitoring and decision support. The creation of digital twins of real industrial facilities, cities, and ecosystem clusters is highlighted as a promising way to strengthen the digital-green transition, enabling innovation and the development of more sustainable solutions. The determinants of harmonizing digital and green transformation are adaptive digital strategies, green course planning, climate education and digital skills, legislative initiatives, sustainable financing, and millennialism in disseminating best practices and engaging international actors in a joint double transition.

An important condition for harmonizing the double transition of the global economy is the need to comply with the principles of sustainable digitalization, where digital technologies should not only be aimed at maintaining climate neutrality,

but also address global green standards. Otherwise, the rebound effect of the economy may offset the environmental and energy benefits of introducing more efficient technologies, which is the subject of discussion and further research by the author in the context of harmonizing the digital-green transition.

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