

STRATEGIC FRAMEWORK OF DIGITAL TRANSFORMATION
TOWARDS CLIMATE-NEUTRAL ECONOMYСТРАТЕГІЧНА РАМКА ЦИФРОВОЇ ТРАНСФОРМАЦІЇ
НА ШЛЯХУ ДО КЛІМАТИЧНО НЕЙТРАЛЬНОЇ ЕКОНОМІКИ

The article presents a strategic framework for digital transformation aimed at achieving a climate-neutral economy. It proposes digitalization as the primary driver of the green-digital transition, essential for reducing greenhouse gas emissions and optimizing energy use. The study identifies potential barriers and risks associated with this transition and offers strategic dimensions to harmonize digital and green initiatives of global economy. This approach emphasizes the need for international cooperation, the development of global standards, and the importance of bridging the digital divide. The article also highlights the critical role of innovation in key industries to support climate neutrality in both the short and long term. The research underscores the necessity of integrating social, economic, and ethical considerations into the green-digital transition, ensuring that sustainable digitalization contributes to long-term economic growth and environmental sustainability.

Keywords: global economy, digital transformation, green strategy, climate neutrality, twin green-digital transition, climate change, innovation, environment and growth.

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Maksymova Iryna¹

PhD in Economics, Associate Professor,
Head of the Department
of International Relations,
State University of Economics
and Technology, doctoral student
at the Department of International Economics,
West Ukrainian National University

Максимова І.І.

Державний університет економіки
і технологій,
Західноукраїнський національний
університет

У статті представлено стратегічні детермінанти цифрової трансформації, спрямовані на досягнення кліматичної нейтральності світової економіки. Пропонується розглядати диджиталізацію як основний рушійний фактор зеленого-цифрового переходу, що є необхідним для зменшення викидів парникових газів і оптимізації використання енергії. У дослідженні визначено потенційні бар'єри та ризики, пов'язані з цим переходом, і запропоновано стратегічні виміри для гармонізації цифрових і зелених ініціатив світової економіки. Цей підхід підкреслює необхідність міжнародного співробітництва, розробки глобальних стандартів і подолання цифрового розриву. У статті також акцентується на критичній ролі стратегічно важливих інновацій у різних світових індустріях, що спрямовані на забезпечення кліматичної нейтральності як у короткостроковій, так і в довгостроковій перспективі. Дослідження підкреслює важливість інтеграції соціальних, економічних і етичних аспектів у зелено-цифровий перехід, забезпечуючи таким чином внесок сталої диджиталізації у довгострокове економічне зростання та екологічну стійкість.

Ключові слова: глобальна економіка, цифрова трансформація, зелена стратегія, кліматична нейтральність, подвійний зелений-цифровий перехід, зміна клімату, інновації, навколишнє середовище та зростання.

Problem statement. The modern global economy is confronted with a plethora of unprecedented challenges in its pursuit of carbon neutrality and sustainable development. Governments, businesses, and society at large are gradually implementing an array of strategies aimed at curbing environmental impact, largely influenced by global initiatives to curtail greenhouse gas emissions and combat climate change. Concurrently, the inception of digital technologies has unveiled novel avenues for attaining this objective, particularly through the optimization of processes, augmentation of resource efficiency, and reduction of energy consumption.

Sustainable digitalization is becoming increasingly important due to the rapid pace of digital development in the world, which significantly affects the nature of energy consumption. On the one hand, digital technologies can contribute to significant emission reductions and energy efficiency, while on the other hand, they put additional stress on ecosystems due to the growing need for energy and materials to produce digital devices and infrastructure. Moreover, there is a significant risk that without a globally implemented regulatory framework and the integration of sustainable principles into digitalization processes, the digital transition could lead to an

increase in negative environmental impacts, such as increased carbon emissions due to energy-intensive ICT services and increased e-waste.

Moreover, it is crucial to address the social implications of the twin transition, as the gap in access to digital technologies between developed and developing countries could exacerbate global inequality and hinder collective efforts to achieve climate neutrality. As a result, digitalization is becoming essential for harmonizing the green-digital transition, ensuring that both economic and environmental aspects of modern economic development are effectively integrated.

Analysis of the latest research and publications. The extant framework of scientific research encompasses a multitude of international studies that examine digital and green transitions, both in isolation and in symbiotic combination. However, there is still a lack of comprehensive exploration into the conditions, mechanisms, and, most importantly, the long-term impacts of aligning these transitions to achieve climate neutrality on a global scale.

Many applied and foundational studies have addressed the role of digital technologies in reducing greenhouse gas emissions within modern economic systems. For instance, Lange S. and Santarius T.

¹ ORCID: <https://orcid.org/0000-0001-9754-0414>

point out that digitalization can play a significant role in cutting emissions by automating and optimizing production processes, reducing energy consumption, and improving resource management through innovations like smart grids and the Internet of Things [1]. Similarly, Donti P., Rolnick D., Lacoste A. and Kaack L. emphasize that digital machine learning technologies could be crucial in the fight against climate change, particularly when applied to optimizing energy use and enhancing the efficiency of renewable energy sources [2]. Hedberg A., Staab P., Pietrón D., and Hofmann F. also highlight the importance of digitalization in advancing a circular economy, which can lower emissions by streamlining supply chains, encouraging material reuse, and fostering sustainable markets [3; 4]. Additionally, researchers such as Santarius T., Lange S., Pohl J., Frick V., Thogersen J. and Matthies E. stress the necessity of shifting societal behaviors toward more environmentally friendly and conscious practices, recognizing this change as vital for sustainable development [5–7]. On the other hand, analytical work by international organizations and the European Commission [8; 9], as well as contributions from scholars like Vasilescu M., Damian G., Gradinaru G., and Mietule I. [10; 11], focus on green technological innovations. These innovations are seen as essential for maintaining long-term competitiveness and achieving climate sustainability.

It's worth noting that much of the existing research on green and digital transformation is currently concentrated on the technical aspects of specific economic sectors or isolated elements of either transition. The challenge of effectively integrating and harmonizing these transitions remains an open and pressing question for further scientific discussion.

Formulation of the purpose of the article. The objective of this article is to provide a comprehensive analysis of the strategic pathways for harmonizing the green-digital transition in order to achieve global climate neutrality. In this regard, the article endeavors to develop a theoretical model and conceptualize sustainable digitization as the fundamental framework for this process.

Research methodology. The study employed a comprehensive approach that integrated both qualitative and quantitative methods of analysis. The principal research method employed was system analysis, which permitted an examination of the interrelationship between digital technologies and environmental initiatives in the pursuit of climate neutrality. System analysis was employed to examine the multifaceted interplay between digital technologies and emission reduction strategies, as well as to ascertain pivotal challenges and prospects that emerge within this domain. To ensure a comprehensive and interdisciplinary approach, the research team collected and analysed the various

perspectives and approaches within the scientific community on the digital-green transition. A significant aspect of the methodology was the utilisation of the findings from the EU foresight analysis to evaluate the potential for the advancement of a climate-neutral economy through the active integration of digital technologies. This facilitated the identification of promising avenues for innovation and the discernment of potential challenges and risks that may emerge on the trajectory towards climate neutrality, as well as the role of sustainable digitalisation in this pivotal process.

The main research results. The twin green-digital transition involves the coordinated implementation of digital and green technologies in the broader discourse of achieving sustainability in industrial, social and economic systems. These two powerful mainstream trends are complementary to achieve common goals, such as reducing greenhouse gas emissions, increasing energy efficiency, and introducing innovative technologies. However, such a twin transition requires some harmonization towards achieving global climate neutrality of the world economy, given the identified groups of negative impact factors (Figure 1).

These factors have a negative impact on the effectiveness of the green-digital transition towards ensuring the climate neutrality of the global economy. The poor level of digital infrastructure can be a serious obstacle to the digital transition, especially in regions with poor Internet coverage and low quality of communication [12]. On the other hand, although digital technologies have significant potential to support green development, they also create a significant energy burden, which may contradict the principles of decarbonization, especially with regard to the use of AI, blockchain, etc. [13]. A critical negative factor is the uncertainty of policies, inadequate regulation, and the lack of specific strategic goals for achieving climate neutrality, taking into account the role of digitalization in this process. This creates uncertainty for businesses and investors, slowing down the transition process [14].

Therefore, the harmonization of the green-digital transition involves, first of all, strengthening the coherence between the green and digital transitions to ensure their better synergy towards achieving widespread emissions reductions and ensuring climate-neutral development of the global economy (Figure 2).

The first dimension of the harmonization of the green-digital transition is aimed at building an international consensus on the vision of climate neutrality of the global economy and the vision of the progressive role of digitalization in this process. This dimension involves several fundamentally important components, which have been identified based on the analysis of a number of scientific studies [5; 12; 15–18]:

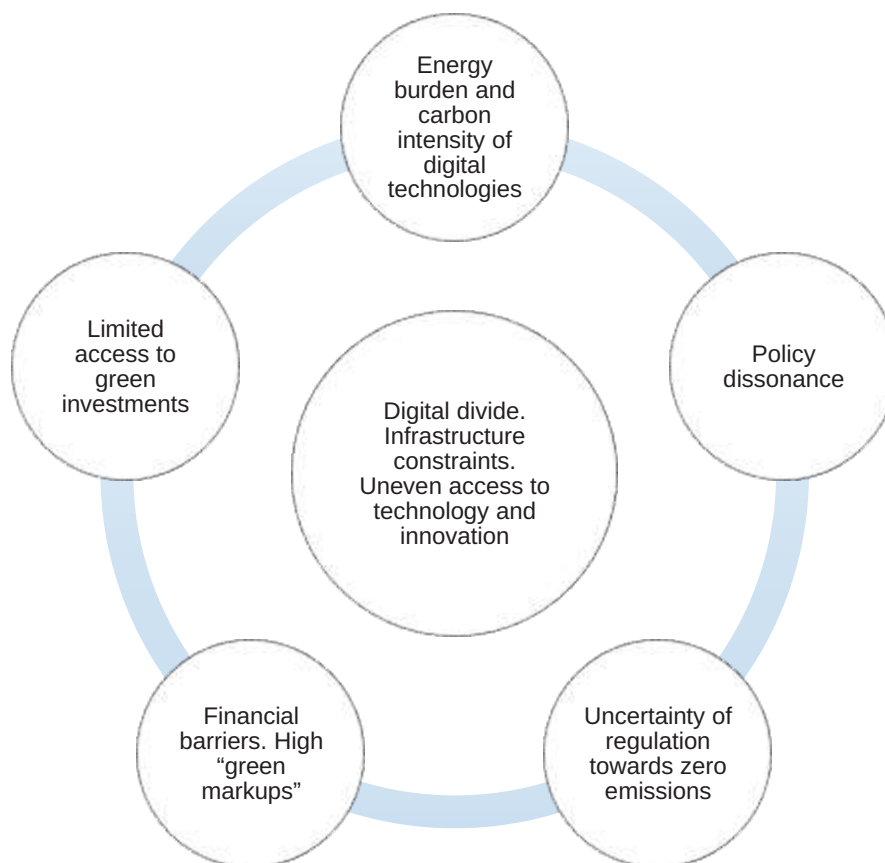


Figure 1. Threat sectors of the climate-neutral development

Source: author's development

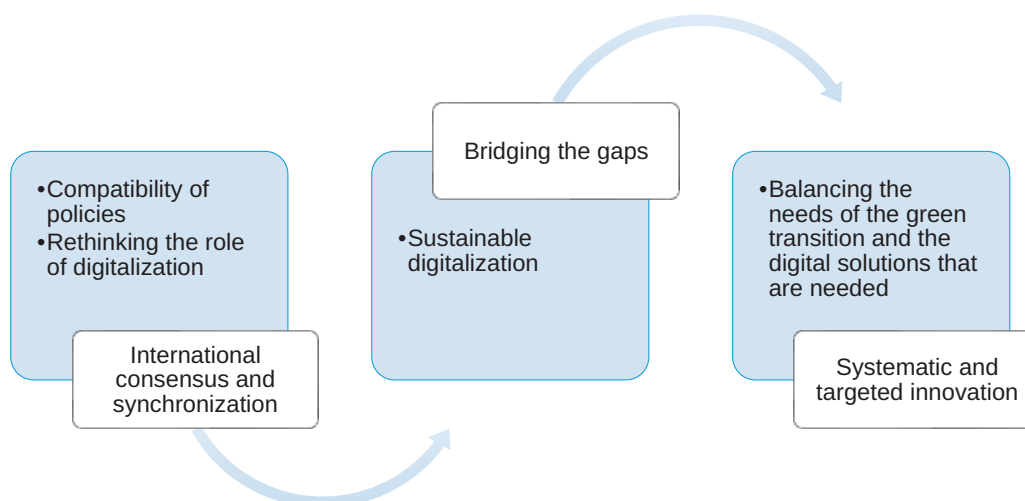


Figure 2. Strategic dimensions for harmonizing the green-digital transition

Source: author's development

- convergence of countries on the way to zero emissions;
- global development of digital competencies and sustainable digitalization;
- science and research (global R&D);
- promoting cross-sectoral innovation ecosystems;

- ubiquity and cross-cutting of norms and standards at the global level;
- coherence of global policies and national interests.

A key condition is to harmonize the vision, values, and goals of achieving climate neutrality of the global economy in the context of the digital era

and sustainable development. Harmonization of the twin transition towards climate neutrality of the global economy requires convergence among all key international actors towards zero emissions. On the other hand, an important aspect of this convergence is the use of the synergy of digitalization as a driver of accelerating environmentally sustainable, socially just and economically responsible development. This requires a rethinking of the purpose of digitalization, taking into account the development of common visions, values, and updated goals for a green transition in the digital age.

Therefore, the goal of digitalization in the context of a climate-neutral economy should be to create a sustainable and innovative infrastructure that minimizes greenhouse gas emissions and efficiently uses resources. This includes the development of digital technologies that automate and optimize production processes, increase energy efficiency, ensure transparency and control over supply chains, and support data-driven decision-making, leading to a reduction in environmental impact. The main goal should be to ensure sustainable economic growth through the integration of environmental and digital solutions that harmonize economic development with climate management goals.

Achieving this goal requires the formation of strong coalitions between public and private organizations, including academia and civil society, who are united in the realization of the dual green-digital transition and understand the importance of ensuring climate neutrality. Harmonization of the green-digital transition implies that local and global awareness of environmental and social values should be systematically integrated by actors with leading positions in existing and emerging digital technologies, innovations, and governance structures. At the same time, commitments to green development and multilateral climate agreements should be periodically reviewed in terms of their implementation through the lens of digitalization.

At the same time, the need to develop digital competencies is critical for the twin transition, as the digital divide directly affects the trajectory of digitalization and the unlocking of all its capabilities to meet the needs of green transformation. Studies show that many business entities currently lack the important digital competencies needed to effectively catalyze the transition to a climate-neutral economy [19]. On the one hand, the public sector and political leaders need to understand the opportunities and risks of digital transformation in supporting decarbonization, building their own digital capabilities to effectively regulate, promote, and implement sustainable policies.

Harmonization of the green-digital transition of the economy at the global level involves the joint development of scientific thought and support for R&D

in this area. In their book, O. Espinoza and J. Walker [20] emphasize that one of the major challenges of modern science is to understand the internal complexity and trade-offs involved in achieving planetary sustainability, which encompasses the complexity and dynamics of processes on Earth, economic and social systems.

Despite a fairly broad discourse on international climate change agreements and arrangements, there remains a significant gap in the regulatory and ethical framework for the green-digital transition and goal-setting towards climate neutrality of the global economy. This primarily concerns the development of standards that would guide the direction of digitalization with social sustainability and climate neutrality in mind. It is also critical to establish a global standard methodology for assessing and measuring the intrinsic impact of digital technologies on climate change. These efforts should include the management of data, which is becoming a new factor of production, alongside land, labor, and capital, and help to develop policies that support digital transformation in line with the goals of the green transition.

The next level of the strategic harmonization is to overcome the main gaps and inequalities of the digital-green transition that slow down the decarbonization of the global economy. These gaps are as follows:

- the digital divide;
- information distortions;
- unequal access to innovation and technology;
- inequalities of rights and obligations;
- capacity to consume “green margins”;
- uneven consumption of energy resources;
- emission reduction gaps: imbalance of adaptation and mitigation.

These gaps require special attention in the context of achieving climate neutrality of the global economy. The first of them is certainly the digital divide, which indicates unequal horizontal access to digital technologies among different regions and, at the same time, unequal vertical access to ICTs for different social groups. This issue is important to ensure that the benefits of the green transformation are distributed fairly. Over the past 20 years, the digital divide in the world as a whole has significantly decreased to 38.4%, but its scale varies significantly depending on the level of economic development of countries [21].

Another important gap is due to the existing dissonance in rights and obligations, which reflects the mismatch between what is required of countries, companies and citizens in the context of environmental initiatives and the resources and capacities they have. This gap often leads to conflicts of interest and delays in the implementation of green policies. Information distortions refer to distorted or insufficient information about environmental challenges and opportunities,

which reduces the effectiveness of decision-making at both the consumer and policy levels.

On the other hand, an important aspect of global inequality in the context of achieving climate neutrality of the global economy is the ability to consume goods and services with "green markups." This indicates the economic ability of the population to bear the higher costs associated with green products and technologies. The gap in this regard is observed not only between individual countries with different levels of economic development, but also between different social groups, which violates the inclusiveness of the digital-green transition and, as a result, its effectiveness in achieving zero emissions of the global economy.

In general, gaps in the dynamics of emission reductions in different countries and industries provoke a certain imbalance of adaptation and mitigation, reflecting the unequal distribution of efforts and resources between measures aimed at mitigating and adapting to the effects of climate change.

The above considerations point to the need to ensure sustainable digitalization as an aspect of harmonizing the green-digital transition of the global economy and minimizing critical gaps.

Sustainable digitalization aims to mitigate the negative environmental and social impacts of digital technologies. These impacts include significant energy and material consumption, which increases the carbon footprint of digital technologies, as well as social challenges related to destabilized consumption patterns, misinformation, unequal access to digital

technologies, and discrimination in the provision of digital skills and opportunities.

Therefore, sustainable digitalization involves the responsible, ethical, and long-term sustainable use of digital technologies based on a set of principles (Figure 3).

The first principle is related to reducing energy consumption and related CO₂ emissions. According to the International Energy Agency, it is projected that the share of ICT in global electricity consumption could range from 3.2% to 7%, while generating 1.8% to 3.9% of the global economy's carbon footprint [22]. Especially the growth of the cryptocurrency sector also leads to an increase in energy consumption and carbon footprint. The carbon footprint of the Bitcoin network alone for the five-year period from 2017 to 2022 was estimated at 114 megatons of carbon [ibid], which is comparable to the carbon footprint generated by some countries in a year (Belgium, Czech Republic, Ukraine). According to a study [23], a record 53.6 million metric tons of e-waste were produced at the beginning of the global pandemic, and 17.4% of this waste was officially collected and recycled, taking into account the fact that only 78 countries currently have legislation on e-waste management. This rapid growth of e-waste requires taking into account the circularity principles of the sustainable digitalization concept.

The second principle of sustainable digitalization is the optimization of the material and technical base required for the functioning of the digital infrastructure. The rapid expansion of the digital

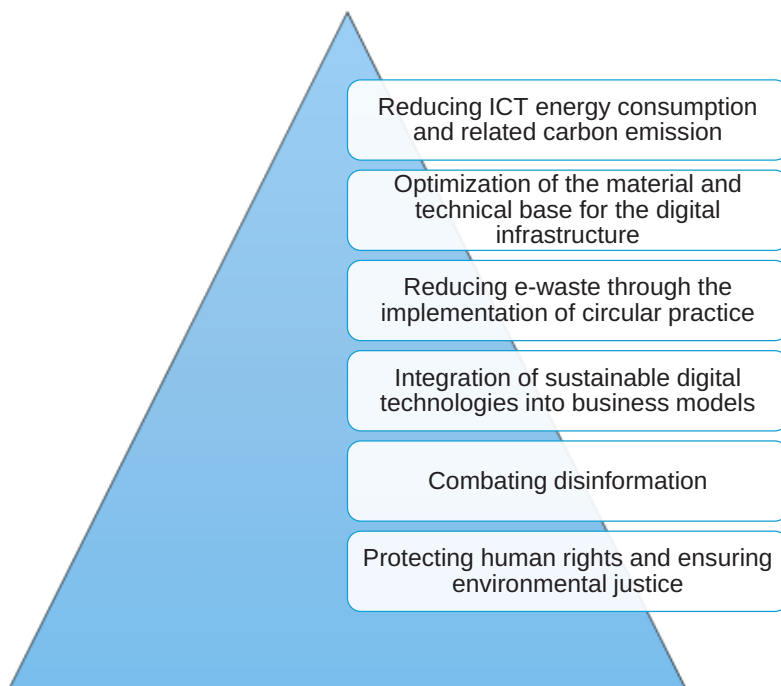


Figure 3. Strategic principles of digital transition as a driver of climate neutrality and sustainability

Source: author's development

economy is significantly increasing the demand for critical materials needed to manufacture ICT devices such as computers, mobile phones, batteries, and other components. Given the growing need for environmentally friendly technologies that support energy transitions, it is projected that the extraction of elements such as graphite, lithium, and cobalt could increase fivefold by 2050 [24]. The exploitation of these resources has various environmental, social, and political impacts, which often depend on the ability of national and local governments to monitor and minimize such impacts.

It is worth noting that sustainable digitalization contributes to the fight against disinformation, which can significantly complicate efforts to promote environmental awareness and action to mitigate climate change. A study by the Massachusetts Institute of Technology found that false news spreads 70 percent faster than true news, and that true information takes six times longer to reach the same audience as false information [25]. The spread of disinformation on topics related to sustainable development, such as climate change, biodiversity loss, and pollution, undermines collective efforts, trust in institutions, and increases polarization and distrust among different groups of people. Establishing effective mechanisms to combat disinformation in the context of a climate-neutral economy requires the use of digital technologies to increase access to accurate and scientifically validated information.

On the other hand, in the context of the transition to a climate-neutral economy, the protection of human rights and environmental justice is becoming an important aspect of sustainable digitalization. With the growing number of people, organizations, and artificial intelligence interacting in the digital space, ensuring human rights in online environments is becoming a key element of sustainable governance

systems. According to research, special attention should be paid to three key aspects [26]:

- human rights violations related to land use conflicts in the extraction of minerals necessary for the development of green digital infrastructure;
- human rights violations in the form of digital surveillance and repression against environmental activists, human rights defenders, journalists and political opponents;
- violations of privacy on the Internet by private companies and government agencies.

Thus, the above considerations form a kind of essential bridge in understanding sustainable digitalization as a factor in minimizing the gaps and inequalities of the twin green-digital transition on the way to climate neutrality of the global economy.

However, a crucial aspect of harmonizing the green-digital transition is meeting the needs and demands of the climate-neutral economy in terms of technology and digital solutions. In many areas, this requires a powerful "innovation leap," as the low-carbon solutions that the global economy needs are often in their embryonic stages of development or have not been sufficiently tested for mass consumption.

Such an innovative "acceleration" of the green-digital transition is an important prerequisite for a harmonious and synchronized movement towards zero emissions. However, it requires significant strategic support.

The analysis of the European Union's foresights in recent years in the areas of the twin transition, climate neutrality, and sustainable future has allowed us to summarize the following critical areas of innovation in the short and long term (Table 1).

The delineated areas serve to illustrate the strategic sectors of innovation that require focused attention and reinforcement in order to achieve climate neutrality of the global economy, particularly in the long term. On the other hand, they show

Table 1

Strategic areas of innovation needed for the green-digital transition

Sector	Current focus and achievements	Long-term strategic focus
Energy	Renewable energy sources, smart grids, lithium-ion batteries	Wave energy, long-term energy storage systems, hydrogen production through pyrolysis, nuclear fusion
Agriculture	Smart farming, integrated sensor systems in the soil	Digital twins for monitoring land plots, genetic editing of plants, selection by design, use of advanced biotechnology
Construction	VR buildings, digital building logs, integrated design tools	Building Information Models (BIM), high-performance buildings with automated control systems
Transportation	Electrification of transport, autonomous vehicles, 3D printing in the production of automotive components	Modularity and virtual coupling in rail transport, coordinated automated road transport, hydrogen airplanes, fully autonomous vehicles
Heavy industry	Electric arc furnaces, water from recycling systems, gas recycling in the mining and metals industry	Improved recycling methods, microbial recycling of plastic waste

Source: compiled by the author based on reports [15; 27]

how digitalization can meet the needs of the green transition, evolving from current solutions to future best practices.

One of the barriers to innovative development in the field of green-digital transition is that digitalization is not yet being laid down at the state level as a cross-cutting and widespread priority in many countries. Despite the existence of a large number of programmatic initiatives, agreements and documents to strengthen the green transition, the lion's share of them do not provide for direct benefits from digital technologies, platforms, programs and SMART systems [28]. Many national legislative frameworks still use traditional approaches to regulating the "physical" world, neglecting the possibilities of using digital tools to achieve sustainable development outcomes and comply with regulatory requirements. This also applies to the lack of adaptation and flexibility of legislation in matters of dual transition. Overcoming this barrier requires the development of at least 3 areas:

- digitalization of national economic systems, taking into account the criteria of climate sustainability.
- transparent monitoring and reporting on the implementation of legislation and achievement of climate goals.
- subsidiarity and decentralized management to stimulate collective action and identify clear needs.

In general, the development of a climate-neutral economy requires prioritizing innovations that catalyze the green-digital transition. It is worth noting that in the current context of digital globalization, countries can gain numerous benefits from the "leap" to smart cities, buildings, transportation, agriculture, smart energy, etc. This effect is cumulative for the economy, as it stimulates progress in various industries, the development of new markets, and the emergence of new opportunities for global leadership.

Conclusions and research prospects. The study highlights that sustainable digitalization is a strategic driver in the global shift toward a climate-neutral economy. By integrating sustainable digital technologies, it's possible to enhance the efficiency of production processes, optimize energy consumption, and reduce greenhouse gas emissions. However, the strategic impact of sustainable digitalization can only be fully realized through close coordination among international stakeholders, social processes, and technological innovation, ensuring that these elements work synergistically.

The proposed strategic dimensions for harmonizing a sustainable digital transition within a climate-neutral economy underscores the importance of international cooperation and the establishment of global standards for digital technology use. Strategically, it is essential to focus on ensuring equal access to technology, bridging the digital divide, and catalyzing innovation

across key industries, which are critical for achieving large-scale impact.

New strategic approaches must consider not just the technical aspects but also the broader social, economic, and ethical challenges that arise during the green-digital transition. Strategic transparency in resource utilization, robust data management, and the mitigation of risks related to disinformation and human rights abuses are vital components of this transition, ensuring that it is both inclusive and ethical. Therefore, the study calls for the strategic development of policies and strategies that support sustainable digitalization as the foundational concept for a climate-neutral economy. This strategic approach will not only accelerate decarbonization efforts but also foster long-term sustainable economic growth.

The author's future research will focus on further examining the impact of sustainable digital technologies on a climate-neutral economy and will develop actionable recommendations for governments, businesses, and civil society to achieve these critical goals.

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