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Convergence of Digital and Climate-Neutral Economic Development: Evidence From Global Indices

Abstract. Introduction*. The article examines the convergent aspects of global digital and green development on the way to building a global climate-neutral economy through the lens of global indices. Given the urgency of overcoming the climate challenge and achieving "net zero" emissions, the role of the digital transition in this process is shown.*

Purpose. *The purpose of the article is to analyze the general aspects of the convergence of green and digital development of the world economy based on the analysis of a number of global indices. The research aims to identify irregularities, lags and general patterns of the international movement towards a climate-neutral economy.*

Results. *The study is based on the analysis of global indices such as the Green Future Index, the Climate Change Index, the Energy Trilemma Index, the Global Digital Competitiveness Index, the Digital Economy and Society Index, and the Digital Quality of Life Index. This allows for a fairly comprehensive assessment of the development of green and digital currents in various countries of the world in view of the development of a climate-neutral economy. The obtained results show significant differences between countries and individual regions in the levels of digital and green development, in particular in the part of the energy transition. Countries with a high level of digital competitiveness are usually leaders in implementing green initiatives, confirming the synergy between digital transformation and environmental sustainability. At the same time, there is a significant gap between developed and developing countries in their progress towards climate neutrality, highlighting the need for additional targeted support, investment and international coordination.*

Conclusions*. The study showed the importance of integrating digital and green development to achieve climate neutrality. Countries that successfully combine these areas achieve greater success in reducing emissions, implementing innovations and increasing the sustainability of their economies. To overcome global disparities and accelerate progress, coordinated international efforts, increased financial support and increased technological potential are needed.*

Keywords*: global economy, climate neutrality; digital transformation; green growth global indicies; energy trilemma; green index; climate change index; Global Digital Competitiveness Index; Digital Economy and Society Index.*

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Конвергенція цифрового та кліматично-нейтрального розвитку економіки: репрезентація глобальних індексів

Анотація. *У статті розглядається глобальна конвергенція цифрового та зеленого розвитку з точки зору глобальних індексів. Він аналізує перетин цифрової конкурентоспроможності та екологічної стійкості, демонструючи, як країни просуваються до кліматично нейтрального майбутнього, використовуючи цифрові технології. Дослідження представляє аналіз кількох глобальних індексів, включаючи індекс зеленого майбутнього, індекс ефективності зміни клімату (CCPI), індекс енергетичної трилеми, індекс глобальної цифрової конкурентоспроможності та індекс цифрової економіки та суспільства. Додаткова увага приділяється енергетичному переходу в регіонах світу як важливій частині низьковуглецевої економіки. Висновки вказують на критичні прогалини та можливості зміцнення як цифрових, так і зелених ініціатив. Отримані дані підкреслюють значні відмінності між розвиненими країнами та країнами, що розвиваються, на шляху до кліматичної нейтральності, підкреслюючи важливість скоординованих міжнародних зусиль, надійної політики та цільових інвестицій для прискорення сталого розвитку в усьому світі.*

Ключові слова*: глобальна економіка; кліматична нейтральність; цифрова трансформація; зелене зростання; глобальні індекси; енергетична трилема; зелений індекс; індекс зміни клімату; індекс глобальної цифрової конкурентоспроможності; індекс цифрової економіки та суспільства.*

JEL Classification: *F01, Q55, Q56, O33, R11.*

Formulation of the problem. At the current stage of global economic development, climate change is emerging as one of the most pressing challenges requiring immediate action by the international community. The climate crisis, characterized by extreme weather events, loss of biodiversity, and rising greenhouse gas emissions, is already causing significant economic damage, affecting all sectors of the economy. Over the past 20 years,

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climate-related disasters have cost the global economy more than $3 trillion, and this figure is expected to rise as extreme weather events become more frequent and severe [1]. At the same time, there is growing recognition of the need to transition to a low-carbon economy that ensures sustainable economic growth without exacerbating environmental degradation. The International Energy Agency projects that achieving net-zero emissions by 2050 will require an annual investment of $4 trillion in clean energy technologies by 2030 [2].

In this context, digital technologies are becoming critical tools that can accelerate the achievement of climate neutrality. The digitization of economic processes, the implementation of green energy innovations, the development of renewable energy infrastructure, and the improvement of energy efficiency are key elements of this transition. For example, the global market for smart grid technologies that improve energy efficiency is expected to reach $61 billion by 2025, driven by the need to reduce emissions and optimize energy consumption [3]. However, to effectively implement these technologies, it is essential to understand global trends and differences in the pace of digital and green initiatives across countries.

The problem lies in the lack of synergy between digital development and environmental strategies at the global level. While some countries have made significant progress in adopting digital technologies, this progress has not always been matched by adequate efforts in environmental policies. In addition, there are significant inequalities in the development of digital and environmental infrastructure across countries and regions, slowing overall progress towards climate neutrality [4]. While EU countries lead in both digital competitiveness and green energy adoption, many developing countries lag behind due to a lack of infrastructure and investment.

Analysis of recent research and publications. The question of coherent green growth and the convergent movement of countries towards "zero emissions" is a topic of discussion in numerous academic discourses. However, this movement is mostly assessed from the perspective of climate policy and global regulation. For example, in their article, Mecklin J. and Alan B. focused on the transition of economic ideas from neoclassical to green industrial policy, emphasizing its significant impact on global climate policy [5]. Another team of researchers led by Pasmeni F. emphasized the need for continued global efforts to ensure international cooperation and technological development in climate change, as well as the role of Europe, China, Japan and the United States [6]. A similar conclusion, with an emphasis on the role of bilateral climate agreements between leading countries, is presented in a number of studies [7, 8]. Interesting is the concept of Joselli L., who emphasizes the role of transnational climate initiatives that cover both mitigation and adaptation. He notes that the global climate regime has evolved from simple agreements to a complex network of initiatives [9]. The role of regional climate leadership is considered by Zhu L. et al. who emphasize that in Asia, China can act as a locomotive in the implementation of green agreements, similar to the EU [10]. However, as the work of McLaren D. and Marcuson N. [11] shows, the nature and formulation of climate goals in international politics has changed significantly since the 1980s, co-evolving with broader climate policies, modeling methodologies and technological promises. This has led to negative policy procrastination and international divergence that limits climate change mitigation at the global level.

Formulation of research goals. The goal of the research is to propose an analytical canvas for assessing the convergent intersection between digital and green economic development across countries. This is done by analyzing a set of global indices. The goal is to identify critical gaps and assess the global path to a carbon neutral economy.

Research results. Global indices can be seen as an appropriate representation for examining green and digital development. They provide a comprehensive and consistent assessment of relevant factors, including environmental sustainability, digital infrastructure, innovation, and policy implementation. In the context of research on the low-carbon economy, global indices provide valuable insights for scholarly discourse, as they encapsulate sophisticated perspectives on the evaluation of collected evidence. In addition, global indices highlight critical gaps and opportunities, guiding policymakers in aligning digital progress with environmental goals to promote a climate-sustainable future.

A number of different global indices were selected to assess the green and digital development of countries as they converge towards climate neutrality (Figure 1).

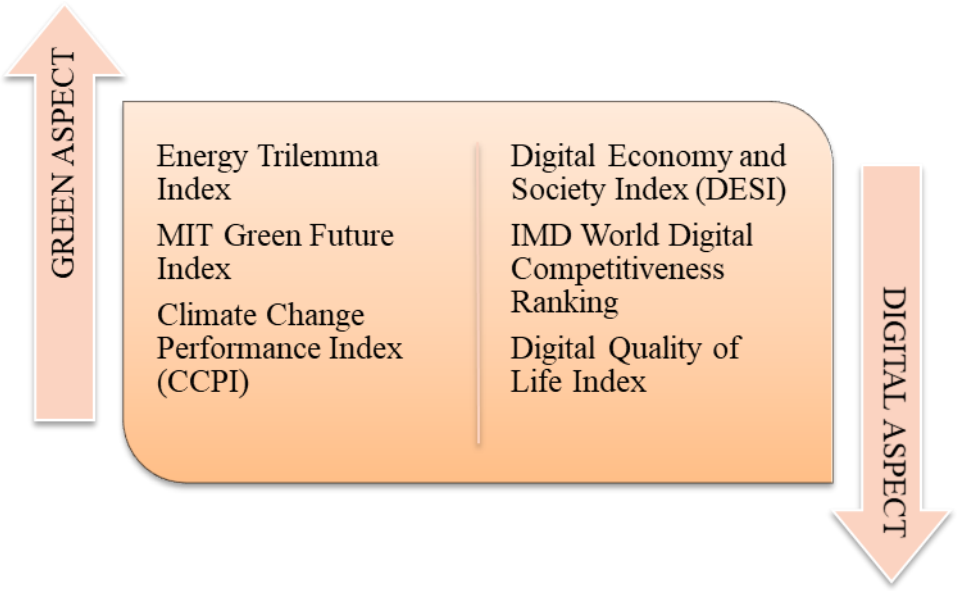

Figure 1 – **Overview of global indices for assessing the climate-neutral economy in terms of green development and digitalization**

Source: compiled by the author

This scheme illustrates a certain balance in assessing the climate neutrality of the global economy in terms of environmental green indices and digital development. It should be noted that the selected green indices are comprehensive in content, covering cross-cutting environmental, economic, innovation, technological, infrastructural and political criteria.

The analysis of these indices has led to remarkable results.

The Green Future Index is a research initiative of MIT Technology Review Insights [12]. At present, the index measures how 76 countries are moving towards a greener future in 5 dimensions: carbon emissions dynamics, energy transition, green society, pure innovation, climate policy. Currently, there are striking contrasts in the differentiation of countries by the Green Future Index (Figure 2).

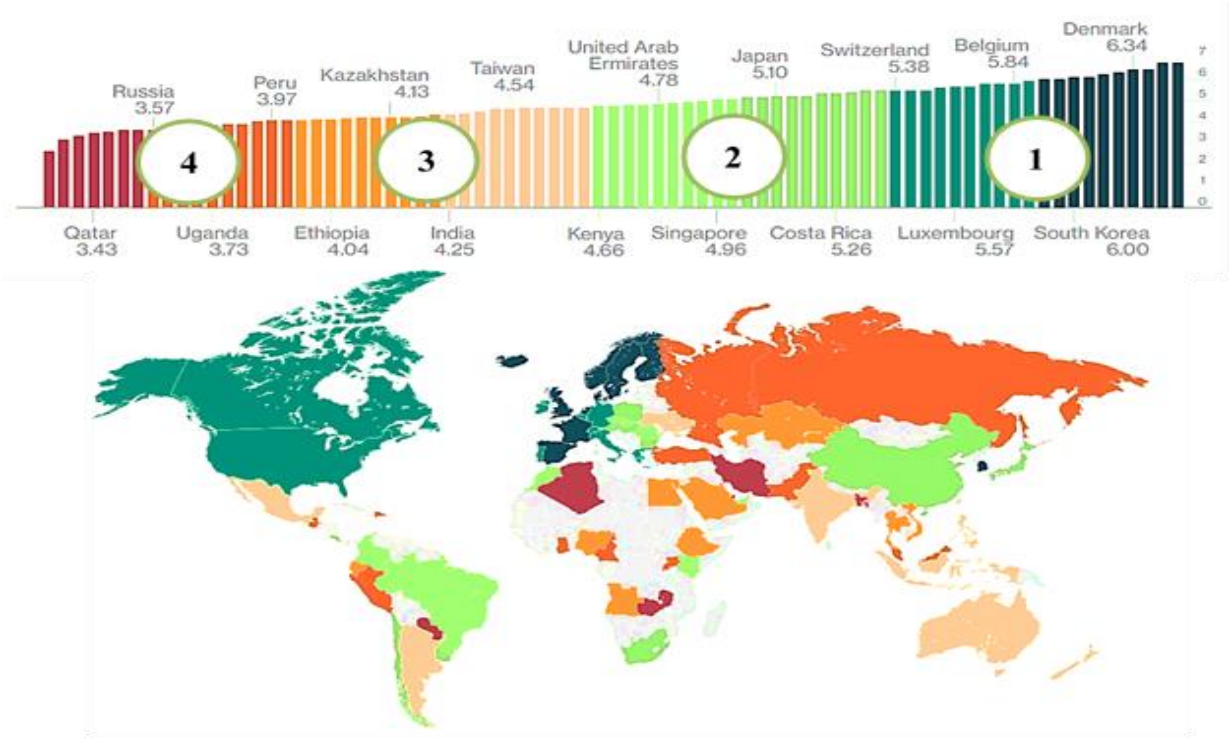

Figure 2 – **MIT Green Future Index, 2023**

Source: Compounded from MIT Technology Review Insights [12]

The given index conveys 4 clusters of countries: (1) Green Leaders. Countries with the greatest progress and political will to develop a climate-neutral economy; (2) Countries with an average level of green development and implementation of low-carbon practices; (3) Climate Laggards. Countries with extremely slow or insignificant progress towards building a green future, which may be due to low levels of climate policy implementation; (4) Countries that are not in favor of implementing global agreements and policies, mainly for two main reasons: their own inability to implement green transition practices, or lack of awareness of the importance of the problem and low political will. The latter reason allows us to refer to the countries in this group as "climate evaders". Currently, there are 16 countries that remain outside the green trend due to a number of factors, including lack of progress towards green economic growth, low development of innovation and clean technologies, and weak climate policies. These are countries that are underperforming in meeting greenhouse gas emission reduction targets or failing to comply with international climate change agreements.

The cluster of green leaders is expected to be represented by the European Union. However, in 2023, Canada and South Korea are added. It is worth noting that the main emitters, namely China and India (cluster 3) and russia (cluster 4), are in clusters 3 and 4, which are the most critical in terms of ensuring a climate-neutral economy. This position of countries is a rather negative marker, which definitely slows down the global movement towards net zero emissions. It is worth highlighting the promising assessment of China's climate policies and efforts, which fell into the second cluster of economies, despite its primacy in terms of greenhouse gas generation.

An alternative but more focused assessment is provided by the Climate Change Performance Index (CCPI), which aims to increase transparency in national and international climate policies. The CCPI uses a standardized framework to compare the climate performance of 63 countries and the EU, which together account for more than 90% of global greenhouse gas emissions. The effectiveness of climate change mitigation is assessed in four categories: greenhouse gas emissions, renewable energy, total energy use, and climate policy (Fig. 3).

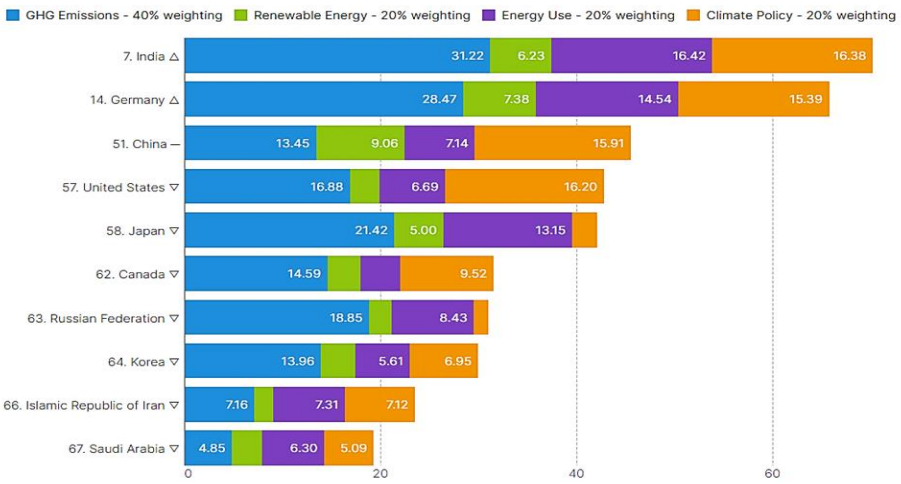

Figure 3 – **CCPI for the economies with the largest carbon generation**

Source: Compounded from CCPI platform [13]

It should be noted that climate change mitigation involves transforming the economic system to reduce emissions. Adaptation, on the other hand, involves promoting partial or complete "adaptation" practices in various sectors to the effects of climate change. Both the MIT Green Future Index and the CCPI Climate Change Index include aspects of emissions reduction, climate policy, and decarbonization, which allows them to be used to assess the climate neutrality of the global economy. However, the Green Future Index covers the broader discourse of the climate challenge (both adaptation and mitigation), while the CCPI focuses on the effectiveness of climate policies. This explains why countries that are currently making some progress in adapting to the existing impacts of climate change (the United States, Canada and China) received significantly lower scores in the mitigation efficiency assessment.

At the same time, the Energy Trilemma Index is interesting for a deeper understanding of the problem of achieving net zero in the context of the green transition of the energy sector. The Energy Trilemma Index includes 3 assessments [14]: energy security; equitable access to energy; environmental sustainability. It shows a certain distribution pattern that correlates with the results of the previous indices (Table 1).

Table 1 **Balancing the energy transition by region**

Region.	**Problem. in the context of the energy trilemma**	**Steps and goals**	**Development in the context of a climate-neutral economy**
1	**2**	**3**	**4**
Asia	Coal dependence and infrastructure challenges	Expanding renewable energy, sustainable development	Focus on sustainable growth and regional cooperation
Middle East	Energy security and geopolitical changes	Investments in diverse sources, sustainable markets	Navigating complexity to achieve sustainability and security amid regional tensions
Africa	Infrastructure and investment constraints	Renewable energy development, institutional leadership	The need for a strategic approach to overcome challenges and achieve sustainability
North America	Investments in energy transmission, market vulnerabilities	Policies that promote clean energy, strengthening grids	The importance of innovative policies and technologies to protect against the effects of climate change
Europe	Dependence on gas, the need for energy sustainability	Development of renewable energy, energy reforms	Transitioning to renewable sources and reducing dependence on natural gas contributes to sustainability

Source: author's resume based on the analysis of the digital platform of the energy trilemma www.imd.org [14]

Europe is currently rethinking its energy policy, with a focus on increasing the affordability and resilience of its energy systems. In the context of increased reliance on gas, the rapid development of renewable energy sources is creating tensions between current needs and long-term goals. At the same time, North America is actively addressing the problem of balancing the energy trilemma, focusing on strengthening infrastructure resilience, energy equity at the local community level, and environmental sustainability. The transition to clean energy is supported by current government policies, such as the Inflation Reduction Act, but faces challenges related to the need for investment in energy transmission systems and market vulnerabilities.

Latin American and Caribbean countries face a more acute manifestation of problems related to climate change and general political instability, which in turn affect the energy sector. Energy subsidies play a key role in ensuring energy affordability in the region, but they also create economic disparities and increase the cost of decarbonization [15]. The dependence of some regions on hydropower underscores the need for overall diversification of energy sources, including a rapid transition to alternative green solutions [16]. The pursuit of a sustainable energy system in the future requires a more decisive balance between economic and environmental aspects, which is crucial for structural change in the region.

Asia's energy transition is characterized by a rapid increase in energy demand, driven by overall economic growth and the region's participation in numerous green transition programs supported by international climate funds. However, the impacts of climate change are most devastating to energy infrastructure, business processes, and loss of human capital [17, 18]. As a result, the region is striving to become energy independent and gradually overcome its dependence on coal. Efforts are primarily aimed at overcoming market difficulties, expanding renewable energy sources, and introducing electric vehicles.

In contrast, the countries of the Middle East are the most illustrative in terms of the possible scale of energy sector transformation and the gradual change in the paradigm of environmental management. Countries in the region are currently undergoing an important period of transition from traditional dependence on oil and gas to the introduction of innovations in renewable energy and even nuclear fusion, which is an important factor in ensuring global energy security. The region, which scores high on the Energy Trilemma Index, is investing in a variety of energy sources and global initiatives to ensure sustainable access.

It should be noted that Africa is also at a critical stage in its energy development due to growing energy demand and energy security challenges amidst the transition to cleaner energy sources. Despite some constraints on access to quality infrastructure and investment, efforts to introduce renewable energy are gaining momentum [19]. The continent faces a delicate balancing act between ensuring energy equity, creating new opportunities for economic growth, and addressing climate challenges, especially in rural areas [20]. The urgent challenge for

Africa is to develop institutional leadership, education, and private sector capacity in the green transition and in attracting investment.

The analysis of global differences in all of the above-mentioned green indices confirms the existence of a rather significant gap between countries, which is slowing down the achievement of climate neutrality at the global level. Bridging the gap will require joint coordinated efforts, additional financial support, strengthening of national climate policies, and improved technological capacity.

As digitalization is seen as a driver of climate neutrality in the global economy, it is of particular interest to assess digital indices in addition to environmental indices.

Currently, one of the most representative indices of the digital economy is the Global Digital Competitiveness Index calculated by the International Institute for Management Development (IMD) [21]. This index annually assesses the ability of economies to adopt and explore new digital technologies that can change government practices, business models, and society as a whole.

The analysis reveals the following differences.

Firstly, digital leadership is becoming more multinational. The United States, the Netherlands and Singapore take the top positions in the 2023 ranking. This is largely due to their strong performance in three key areas: knowledge, technology and future readiness. The US demonstrates a robust digital infrastructure, high levels of innovation, and significant investments in technology and AI, which are critical to maintaining its competitive edge. The Netherlands and Singapore, ranked second and third respectively, highlight the strong digital presence in Europe and Asia. The Netherlands' significant leap in the rankings is attributed to improvements in cybersecurity, public education spending, and higher education outcomes. Singapore's consistent performance reflects its strategic focus on technology and innovation as key drivers of economic growth.

Secondly, there is a notable gap between developed and developing countries in terms of digital competitiveness. While countries such as South Korea, Sweden and Finland are among the top performers due to their advanced digital ecosystems, developing countries such as India (ranked 49th) and Turkey (ranked 54th) are lagging behind, mainly due to challenges in technology adoption and future readiness. This disparity underscores the need for more targeted investments in digital infrastructure and education initiatives in developing regions.

Finally, the top-ranked countries often correlate with strong economic indicators, such as high GDP per capita and significant investment in R&D. These countries are not only digitally competitive, but also show strong economic resilience and growth potential. For example, Switzerland, Denmark and South Korea, which rank high in digital competitiveness, also perform well in global economic rankings, suggesting a synergistic relationship between digital readiness and economic prosperity.

On the other hand, most EU countries are in the top half of the global ranking, with digital competitiveness scores ranging from 70 to 98 points (20 countries). The largest gap is observed in Greece (54.7 points), Romania and Hungary (both 58.2 points). It should be noted that about 100 countries are not yet ready to provide adequate information support for the assessment of this score.

It is reasonable to hypothesize that a high ranking on the Global Digital Competitiveness Index can significantly enhance a country's technological capacity to achieve climate neutrality. A comparative analysis of the digital competitiveness and green future rankings generally confirms the logic of the above assumptions, especially for EU countries. For example, Denmark, Sweden, Norway, Finland and the Netherlands are in the top clusters of both the Green Future and Digital Competitiveness rankings. However, a similar coincidence of high positions is typical for the United States and Canada. At the same time, countries with low green policy scores (India, Turkey and russia) occupy mediocre positions in the digital competitiveness ranking. In this context, China deserves attention, as its case was discussed earlier in the context of a kind of green leap from unsatisfactory positions to an average level of green development. It should be noted that China's economy also shows stable growth in the digital competitiveness ranking.

The EU-initiated Digital Economy and Society Index (DESI) allows a more detailed examination of the conditions for digital growth in the context of promoting a low-carbon economy. The index tracks the performance of Member States in the areas of digital connectivity, digital skills, online activity and digital public services to assess each Member State's state of digitalization and identify areas that require priority investment and action.

The DESI 2022 methodology covers four dimensions: Human capital (Internet literacy, advanced skills and development); Connectivity (fixed and mobile broadband, broadband prices); Integration of digital technologies (digital intensity, digital technologies for business, e-commerce); Digital public services (e-government).

The ranking of EU countries according to the DESI is as follows (Fig.4).

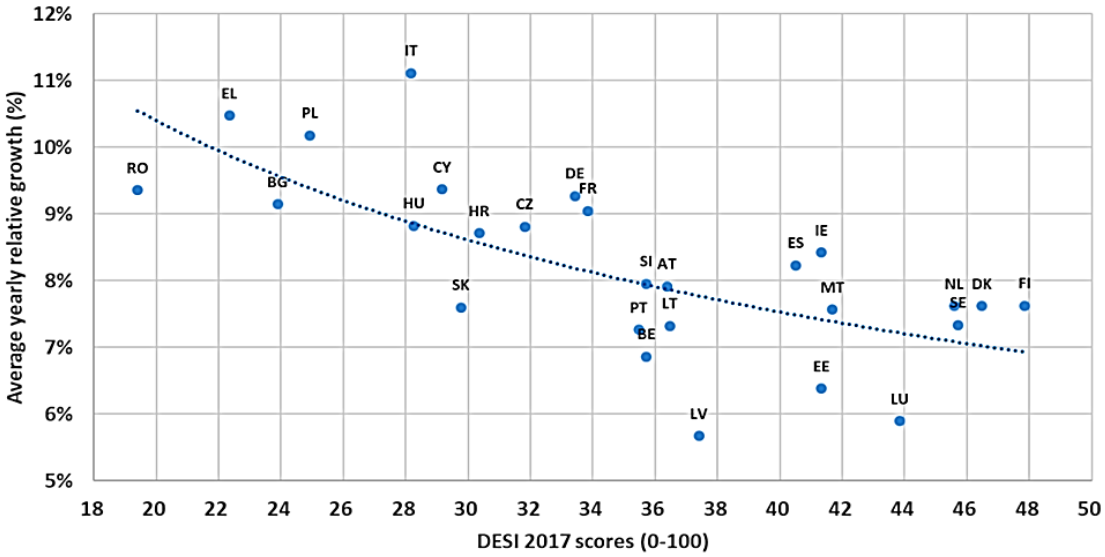

Figure 4 – **Convergence of EU according to the DESI (2017-2022)**

Source: Compounded from DESI report [22]

The graph shows the leap in the overall level of digitalization of the economy and society in the Member States over the last 5 years.

The analysis of the DESI index in the EU in recent years allows us to identify several areas of increasing digital trends, which are presented below [23, 24, 25]:

1) Development of digital infrastructure..
2) Digital public services.
3) Development of human capital and digital literacy.
4) High digital intensity in the economy.

These statistics show not only a significant increase in digital trends in the EU, but also an increase in the quality of digital services provided, their ubiquity and public acceptance. This is also confirmed by the more global DQL Index, which examines the level of digital well-being in different countries. The DQL Index covers 117 countries with available data, representing 92% of the world's population (Fig. 5).

	DOL	Internet accessibility	Quality of the Internet	Electronic infrastructure	Electronic security	E-government
DOL	1					
Internet accessibility	0,67	1				
Quality of the Internet	0,78	0,42	1			
Electronic infrastructure	0,91	0,48	0,76	1		
Electronic security	0,89	0,5	0,54	0,72	1	
E-government	0,94	0,53	0,77	0,89	0,75	1

Figure 5 – **Correlation in DQL's parameters**

Source: compounded from DOL platform [26]

The above dependency is due to the fact that the indicators of Internet accessibility and quality are no longer a "super-advantage", but are perceived as basic conditions for organizing the life of a modern person. It should be noted that in 2023 the top 10 countries in the digital quality of life ranking are France, Finland, Denmark, Germany, Luxembourg, Spain, Estonia, Austria, Switzerland and Singapore.

This assessment differs from the distribution according to the Global Digital Competitiveness Index. Therefore, it is appropriate to consider the DOL index in the context of ensuring the social component of digital transformation (quality of digital services for citizens, e-security, e-

government, etc.), while the IMD index reflects the country's potential for digitizing the economy, transforming industries, and creating digital innovations to a greater extent.

However, all of the digital development indices discussed above are useful for understanding the role of digitalization as a driver of a low-carbon economy. These indices represent the actual overall readiness of countries to adopt and widely integrate digital technologies that can help reduce environmental impacts and optimize resource use. Currently, such areas of digitalization include digital solutions for energy efficiency, smart technologies and smart grids, green innovations, environmental monitoring and climate management.

The assumptions about the points of such mutual reinforcement are as follows:

1. Technological readiness for the green transition. Countries that score high on the Digital Competitiveness Index tend to be leaders in the adoption and use of the latest technologies. This includes green energy and energy efficiency technologies that are critical to the transition to a low-carbon economy.

2. Innovation capacity. High digital competitiveness of a country is impossible without an innovative infrastructure, which usually includes the latest solutions for sustainable development [27]. This means that countries can more effectively develop and implement innovative solutions to reduce their carbon footprint.

3. Business processes. Digital competitiveness indicates the efficiency of business processes related to direct production, logistics and energy management. Therefore, countries with a high level of digital competitiveness are able to optimize these processes to reduce their environmental impact.

4. Skills and education development. A country's high level of digital competitiveness is also linked to the level of education and skills of its workforce, which can direct them to sectors related to climate technologies and the ecological transformation of businesses.

Thus, countries that rank high on the Digital Index have more resources, technologies, and opportunities to effectively transition to a low-carbon economy. They can adapt more swiftly to new technological standards and respond more effectively to climate challenges. In general, the assessment of a set of green and digital development indices allows a deeper understanding of the global differentiation of countries in achieving climate neutrality of the global economy.

Conclusions. Analysis of global indices such as the MIT Green Future Index, the Climate Change Performance Index (CCPI), the Energy Trilemma Index, the Global Digital Competitiveness Index (IMD), and the Digital Economy and Society Index (DESI) reveals significant patterns among countries in their pursuit of climate neutrality and digital transformation.

There is a clear synergy between digital and green development, with countries demonstrating high levels of digital competitiveness often leading the way in green initiatives. European Union countries such as Denmark, Sweden, Finland and the Netherlands exemplify this trend, demonstrating that advanced digital readiness facilitates a more efficient transition to climate neutrality through the implementation of cutting-edge technologies in the green sector.

Innovation potential, supported by digital technologies, is emerging as a critical factor in reducing emissions and achieving climate neutrality. Countries that rank high in the Global Digital Competitiveness Index have greater capacity to develop and adopt innovative solutions to minimize carbon footprints, underscoring the importance of technological progress in efforts to achieve environmental sustainability.

However, there is a significant gap between developed and developing countries in terms of digital and green progress. Countries such as India, Turkey and russia rank in the middle of the digital league table and receive low scores on green indices, highlighting slower progress towards climate neutrality due to limited infrastructure and investment. This gap underscores the need for targeted support and resources to accelerate sustainable development globally.

The impact of political will and effective climate policies is evident in the progress towards climate neutrality. Countries that are making significant progress in green transitions despite economic challenges often do so through proactive and robust climate strategies. This observation underscores the role of governance and policymaking in facilitating and sustaining environmental and digital development.

Overall, the global indices underscore the critical importance of integrating digital and green strategies to achieve climate neutrality. Nations that successfully merge these approaches tend to achieve greater emissions reductions, foster innovation, and improve the resilience of their economies. To address global disparities and accelerate progress, coordinated international efforts, increased financial support, and strengthened technological capacity are essential, particularly in developing regions.

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