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DIGITALLY DRIVEN MODEL OF A CLIMATE-NEUTRAL ECONOMY IN TERMS OF GLOBAL FINANCIAL CAPACITY

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ABSTRACT

The article explores the conditions and drivers for the development of a climate-neutral economy model, emphasizing the pivotal role of digital transformation. A crucial lever in deploying this model is the proactive engagement of international financial entities within the realm of global green financing. The study highlights the instrumental role of green funds as key players in shaping global financial capacity and providing multilateral support for climate change adaptation worldwide. It delves into the overarching frameworks and mechanisms of such assistance. Employing a systematic analysis alongside case studies of the Green Climate Fund's projects, the authors aim to identify the most impactful sectors for cultivating a climate-neutral economy. The research identifies four essential segments for achieving climate neutrality: digitalization for climate, strengthening the financial capacity and business sustainability, rethinking ecosystem development, and community empowerment. The investigation draws on extensive data regarding the execution of 240 climate projects across major beneficiaries of climate finance in Eastern Europe, Africa, the Asia-Pacific, and Latin America. It shows that modern climate finance demonstrates signs of geopolitical dependency and polarization in global influence. The findings argue for bolstering the regional presence of climate funds to increase the financial capacity to implement climate-neutral projects at the local level. The article underscores the scale of financial support required across each segment, as well as the leading role of pre-project preparation. The authors substantiate the overarching and twofold role of digitalization in the model of a climate-neutral economy. The digital transformation produces a whole cluster of independent and versatile IT products for green businesses, industries and governance. On the other hand, digitalization creates an informational environment and a powerful digital infrastructure for better efficacy of other crucial segments. Specifically, it provides digital decisions for financial solvency and sustainability of green businesses in terms of green lending, grants and Fintech; strengthens information awareness and involvement of vulnerable communities in green economy processes; promotes digital support for overall ecosystem adaptation.

Keywords: global economy, green finance, digitalization, digital transformation, climate-neutral economy, Green Climate Fund

JEL Classification: F64, F35, F21, L86

INTRODUCTION

Within the prevailing global economic order, the climate issue is escalating in severity, demanding immediate and decisive responses. Despite significant international and regional initiatives aimed at fostering a transition towards a green economy, the extant paradigm for global decarbonization falls short of producing immediate outcomes. The global increase in GHG emissions intensifies adverse impacts on the Earth's ecosystems, thereby complicating the operational landscape for businesses in different aspects ranging from resource allocation, production, network accessibility, food security and human capital. The imperative of achieving climate neutrality of the global economy has gradually turned from consideration about future development into a crucial "condition of survival", particularly in developing countries.

Modern Europe is at the forefront of green initiatives, making significant strides toward climate neutrality. This progress is largely attributed to the concerted efforts of the European Union's programs, positioning the EU as a global leader in environmental sustainability. However, isolated interventions remain inadequate in curbing the global trend of emissions. In addition, the current pace of the EU's decarbonization is deemed too slow to reach net zero by 2050, highlighting the broader challenge for the international community in addressing the climate crisis [1 - 3]. Analyses of various climate policy scenarios delineate that the EU's economy needs to cut GHG emissions at least threefold by 2030 within the Paris Agreement (from 3300 to 1000 megatons annually), while the current average annual rate of EU's decarbonization stands at 0.87 megatons [4].

Given these exigencies, the global economic system needs a transition model that can strike a balance between the demands of global markets and the Earth's ability to withstand environmental pressures. A key concern is the speed at which the economic community can recognize and act upon the essential factors for making this transformation successful.

Global financial capacity plays a pivotal role in achieving climate neutrality goals. Significant investments have traditionally been required for the transition towards renewable energy sources, the reduction of carbon footprint in manufacturing, and the adoption of efficient resource management technologies [5; 6]. This viewpoint requires the mobilization of both public and private capital to support innovations and technological solutions for climate sustainability. The challenge is especially significant in regions like Africa, China, South Asia, and Latin America, where national industries have engaged in practices that heavily impact the climate for many decades [7]. The underlying issue extends beyond the limited regulatory, financial, and technological support for green initiatives. A crucial factor is also the absence of a cohesive vision and awareness among local communities and the business sector, which persists in using production methods harmful to the environment [8; 9]. In this context, establishing a model for shifting to a climate-neutral economy necessitates comprehensive, effective, and widely acceptable drivers. Digitalization appears to be such a driver since it develops a multilateral pro-tech dimension within the modern economic system and the paradigm of international economic relations.

Consequently, digital transformation emerges as a key domain in achieving the climate neutrality of the global economy. Digital technologies such as artificial intelligence, big data, blockchain, and the Internet of Things facilitate to the newest pathways to improve resource use, increase energy efficiency, and cut carbon emissions. These digital innovations offer a deeper insight into climate issues, enabling predictions of its effects and adaptation strategies. Additionally, the rate of digital advancement in national economies is accelerating rapidly. By 2025, it's anticipated that at least a third of European Union countries will achieve the highest levels of digital effectiveness, according to the Digital Economy and Society Index [10]. Thus, the role of digital transformation in the context of a climate-neutral economy is crucial, thereby it contributes to creating a resilient global economic system capable of adapting to climate change, reducing emissions, and ensuring sustainable growth.

Considering these factors, in an era of global geopolitical and environmental shifts, humanity faces an urgent need to rethink conventional approaches to economic development, embrace the integration of digital technologies, reinforce international cooperation, and ensure financial support for all these domains. This article seeks to enrich the scientific discourse on the efficacy and possibilities of digitalization as a key factor in promoting climate resilience worldwide considering the current financial framework.

LITERATURE REVIEW

The current academic discourse on the topic of our study spans two primary areas. First, it explores the role of digital transformation in attaining sustainable development goals, with a particular focus on the green economy. Second, it includes a critical examination of green finance through the framework of international financial entities.

In recent decades, the rapid development of digital technologies has sparked great interest among the scientific community regarding the capacity of digitalization to tackle global challenges with a strong social focus. Scientists R. Pasqualino, M. Demartini, and F. Bagheri, convey the concept that digital transformation and sustainable innovation contribute to systemic transition and global socio-economic scenarios of humanity [11]. These authors present a new dynamic model of sustainability, literally IN4.0-SD, which reflects the interaction of industrial innovation, inequality and inflation, and provides implications for sustainability-oriented businesses and the digital transformation of the economy. Moreover, as the researchers I. Petkovsky, A. Fedajev and J. Bazen point out, that digitalization is closely linked to international competitiveness, i.e. "sustainable competitiveness" [12]. In this study the authors present the pillars of sustainable competitiveness to assess international economic development, showing the strong influence of economic and energy indicators beyond the progress of digitalization. Although these articles consider the impact of digitalization, the focus is more turned to general sustainability and inequality than to the green transition of the economy.

The idea of digitalization as an "accelerator" of green transition is developed in the work by E. Eisner, C. Hsien, and M. Menneng, who substantiate this point using the example of business engineering towards climate-neutral development [13]. The technological nature of climate neutrality is shown in the model of the climate economy developed by the authors [14]. Their paper presents a basic model that simplifies the interaction between economic development and climate change. This allows focusing on the main aspects of the key linkages, such as fossil fuel usage, pollutant accumulation, endogenous growth and climate impacts on financial capital.

Another international team of authors highlights the significant potential of digitalization as a tool for climate change adaptation and sustainable economic development, especially in urban centres [15]. Thus, A. Balogun and D. Marks substantiate those technologies such as Industry 4.0, big data analytics and IoT primarily support global efforts to prepare for climate disasters and enhance food and water security, overall productivity and infrastructure. Digitalization is considered a domain of technological survival for cities in the face of climate change. However, this approach requires international cooperation and joint efforts. A "digital backbone" of a climate-neutral economy is presented in the paper by I. Mietule and I. Maksymova [16]. The study outlines an international framework of eco-digital projects and offers an assessment of digital solutions for the twin green-digital transformation and achieving climate neutrality. However, the authors do not envisage a general model for such a transition.

It is important to note that some researchers argue for an exclusively positive role of digitalization in climate change and deliver the need for a more comprehensive analysis of the green-digital linkages. According to J. Ke and A. Jahanger, digital technologies, including ICTs, play a complex role in shaping environmental change. Their influence on CO2 emissions has been extensively researched, showing both positive and negative effects. For example, digitalization can lead to increased energy efficiency, but the growth of the ICT sector can also raise overall energy consumption [17]. Research on the links between digitalization, financial development, trade and carbon emissions suggests that while digitalization can contribute to economic growth and efficiency, its environmental impacts are nuanced and require careful governance to ensure positive outcomes and further carbon emission reductions.

It is worth mentioning the joint study by D. Haberly, D. MacDonald-Korth, M. Urban and D. Wojcik, which outlines the digital lever for the development of global financial networks [18]. Their article examines the impact of the digital platform model on assets management, highlighting important shifts in market structures due to digitalization. Although the authors do not directly address the issue of climate change, their concept of the integral role of digitalization in the development of general mechanisms for sustainable financial support sounds very promising.

When considering the issue of global financial support for the green economy, scientists tend to focus on global environmental funds and international organisations in this field, as well as the problems of designing financial mechanisms for such support. As noted by S. Ravichandran and M. Roy, global green finance is an important factor in addressing climate change [19]. Moreover, national economies require more financial assistance to achieve Sustainable Development Goals and meet Paris Agreement commitments. Thus, the democratisation of climate finance is an important challenge. A paper by V. Orindi, Y. Elhadi and K. Hesse notes the critical importance of fair access to climate finance and clean technologies, which is especially important for developing countries' transition to a low-carbon economy [20].

Based on the literature review, digitalization can be viewed in the context of transitioning towards a climate-neutral economy. Nevertheless, scientists identify global climate and green funds as the pivotal entities driving this shift.

In particular, the issue of the financial capacity of global financial entities is raised by European and Asian scientists due to the fostering of green transformation and climate adaptation. For example, R. Clark and J. Reed highlight the need for more coordinated efforts to encourage investments in sustainable and low-carbon development, emphasizing fiscal and policy reforms to incentivize private investment in developing and low-income countries [21]. Brechin S. and Espinoza M. suggest that the Green Climate Fund should reconsider the targeted 50:50 ratio between climate mitigation and adaptation finance [22]. Another study conveys the idea of rethinking the co-financing rate of green projects, which varies considerably and affects the long-term sustainability of climate initiatives [8]. S. Bracking, B. Leffel advocates for a return to public-authored finance and governance to effectively address climate finance challenges. They examine the governance of climate finance, suggesting that polycentric systems in climate finance are needed to avoid the concentration of decision-making power with financial fund managers [23]. It is noteworthy that all these studies examine the overall effectiveness of green funds, but do not provide an analysis of the structure of international climate projects. This is essential because such a framework represents the most important directions and requirements for achieving climate neutrality.

Thus, an analysis of the scientific literature on the climate neutrality of the global economy has identified several research areas. Notably, there's a discernible absence of a holistic approach that regards digital transformation as an essential element in promoting sustainability and supporting the global economy's transition to climate neutrality.

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AIMS AND OBJECTIVES

The study aims to provide the determinants for a digitally driven model of a climate-neutral economy, taking into account the current framework of global climate assistance within the overall financial capacity. To achieve this goal, three sub-goals are implemented. First, to identify the key segments of global financial support in the field of green transition as relevant areas for the climate-neutral development of the global economy. Second, to analyze the identified segments in relation to the possibilities of digitalization. Third, to identify the determinants of the climate-neutral model with a focus on digital transformation as a driver of green transition.

METHODS

The methodology involved several stages and combined both fundamental qualitative and quantitative scientific methods. The core of the empirical study focused on 243 projects provided by the Green Climate Fund (GCF). This open data was selected among others due to GCF's leading role as a heavyweight of global green financing. Moreover, it is the premier source, that opens all the projects' details in table format, encompassing data from different countries worldwide. The methodological framework enabled the systematization and classification of complex data to identify key areas for a climate-neutral economy based on international project initiatives. This framework helped recognize the primary components and mechanisms driving the transition towards a climate-neutral economy, particularly in terms of digital transformation, financial support, community engagement and sustainable ecosystem.

Analysis and Synthesis. These methods were applied to comprehend logically the current structure of international climate financing and initiatives, underpinned by financial support from the Global Climate Fund. This process aided in determining the crucial factors influencing the evolution of various segments within international climate initiatives. Through synthesis, we could perceive these segments as interconnected components of a unified climate-neutral economic system, significantly driven by digitalization.

Case Study. This blended approach contributed to the examination of GCF's project portfolio in order to evaluate the unique aspects of various climate initiatives and identify typical features. By employing induction, deduction, and classification techniques, the authors organized the project database, spotlighted key indicators, and delineated four primary segments of projects: digitalization for climate; financial capacity and business strength; ecosystem development; community empowerment. This classification of the GCF's projects served as the foundation for examining the essential needs and main directions of a climate-neutral economy.

Statistical Analysis. This method was employed to analyze samples collected from the four defined segments, with a primary emphasis on the scope of global financing. This approach facilitated an assessment of the financial volumes necessary for driving a climate-neutral economy in different areas.

Empirical Modelling. This approach led to the delineation of a digital-oriented model for the climate-neutral economy involved defining the comprehensive impact of digitalization by establishing logical connections between the key segments of international climate initiatives. Digitalization was established as a cross-cutting driver for the different segments of a climate-neutral economy.

RESULTS

Over the past decade, global financial support for green initiatives has developed a range of strategies and tools to sustain international efforts in climate change mitigation and adaptation. The scheme below illustrates how financial assistance has been organized to facilitate the economy's green transition and enhance climate resilience (Figure 1).

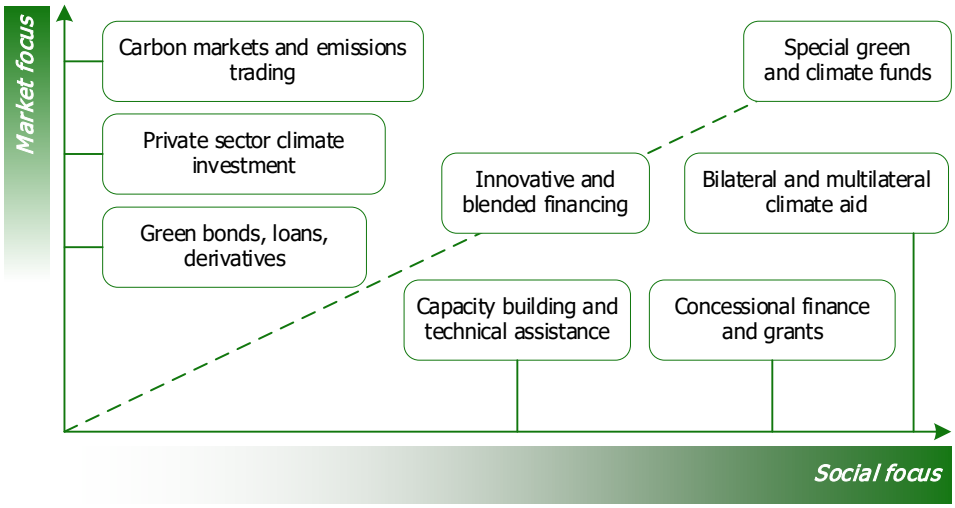

Figure 1. Differentiation of global financial assistance for climate initiatives. *(Source: authors' delineation based on green finance reports by IDFC and GCF [24, 25])*

The scheme presented above showcases the global consensus on the most effective financial mechanisms to bolster climate initiatives. The wide differentiation of financial assistance is rooted in the climate policy-making, asset accessibility and overall economic maturity of international entities. Each kind of assistance strikes a particular balance between market forces and social considerations, harnessing their combined strengths to tackle the complex issues posed by climate change. This balance is pivotal in coordinating effective responses to environmental issues, ensuring both economic viability and social equity [26; 27]. The market-oriented facet of climate financial support highlights the importance of efficiency, innovation, and the mobilization of private investment. Market-based instruments like carbon pricing, green bonds, and investments tied to climate outcomes encourage the private sector to engage in climate-related activities. These mechanisms utilize market dynamics to focus investments in renewable energy, energy efficiency, and sustainable practices by offering financial incentives. Nonetheless, relying solely on market mechanisms can occasionally neglect considerations of social equity and environmental justice [28]. Although these mechanisms are successful in mobilizing capital, they might not fully meet the needs of vulnerable groups or guarantee the equitable distribution of the benefits from climate investments. This is where public policy, governmental interventions, and international cooperation come into play to ensure that climate financial assistance addresses wider social objectives. Actions in this realm include allocating public funds for climate adaptation and mitigation in developing nations, creating regulations and standards for sustainable practices, and offering subsidies or incentives to encourage the adoption of clean energy technologies [29]. This initiative aims to resolve market shortcomings, tackle disparities, and focus investments on communities that are most susceptible to the adverse effects of climate change.

Special green and climate funds contribute to the most effective financial landscape that supports global climate initiatives. By acting as a financial umbrella, these funds help balance the socio-economic narrative, especially in developing countries in the context of their climate endeavours. This facilitates the mobilization of resources for mitigation and adaptation projects. In addition, climate funds focus on both public and private sector engagement, fostering cooperation and innovation in sustainable development. Their inclusive strategy, which involves a broad spectrum of stakeholders, enhances the efficiency of climate finance distribution and ensures a holistic approach to addressing the multifaceted challenges of climate change.

Currently, several of the largest international funds contribute to the global financial capacity for the development of a climate-neutral economy:

1. The Green Climate Fund (GCF) is one of the largest and potentially most effective international funds established to support global GHG emission reduction and climate change adaptation, mostly in developing countries. The GCF was established by the parties to the United Nations Framework Convention on Climate Change with the aim to facilitate a paradigm shift towards low-carbon and sustainable development by responding to the need for substantial financial resources.

2. The Climate Investment Fund (CIF) also supports climate-related projects and offers financing to developing countries for their transition towards a low-carbon and sustainable economy. It comprises various sub-funds, including the Clean Technology Fund and the Forest Investment Programme.

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3. The Global Environment Facility (GEF) conveys projects in the areas of biodiversity, climate change, international waters, the ozone layer, land degradation, and persistent chemicals.
4. The United Nations Development Programme's Small Grants Facility (UNDP GEF SGP) supports local-level projects that promote environmental conservation and sustainable development.
5. The Green Development Fund for Developing Countries (GDF) aims to support developing countries in implementing green development and low-carbon growth practices.

In today's economic environment, the Green Climate Fund stands as an absolute leader in equitably addressing both climate adaptation and mitigation. The GCF achieves remarkable outcomes by eliminating over 265 million tonnes of CO2 with every billion dollars spent on mitigation strategies, while also benefiting more than 155 million individuals for each billion dollars allocated to adaptation projects [24]. The effectiveness of the Global Climate Fund in fostering global climate resilience and sustainability is significantly bolstered by its dedication to encouraging national ownership and ensuring that its projects are in line with the strategic priorities of each country (Figure 2).

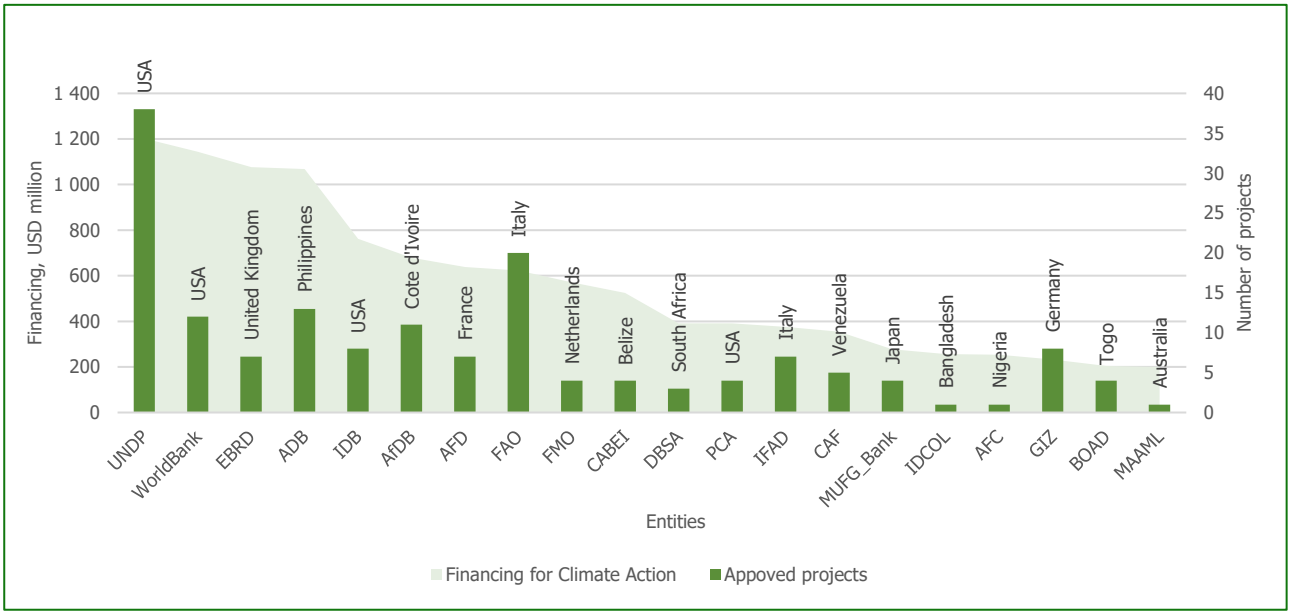

Figure 2. Financial aid for climate action: TOP-20 International entities and countries of residence. *(Source: authors' arrangement based on open data delivered by GCF [31])*

The review of global financial support for climate initiatives indicates that contemporary climate finance could be considered geopolitically dependent, with early signs of global polarization. The USA and the EU are the leading contributors to climate action globally. Nevertheless, a growing number of countries in East Asia and Africa are stepping up by creating local financial institutions aimed at backing climate initiatives. In general, 57 donor organizations are actively working to gather green funds within the framework established by the Green Climate Fund. Furthermore, 60 additional organizations joined the effort to tackle climate issues in 2022-2023. Notably, only 20 financial entities are responsible for 67% of all green projects, providing at least 85% of the total financing dispensed by the Global Climate Fund.

In addition, international donor organizations and their geolocation play a pivotal role in promoting climate finance. The analysis underscores the necessity of local financial entities dedicated to gathering green funds for the successful execution of climate adaptation and mitigation efforts within specific regions. Obviously, international financial support remains crucial for the implementation of climate change programs in Africa, Latin America and Asia. Prominent local donors have emerged to accumulate green funds to address the needs at national and regional levels. This tendency is very important since local green entities are specifically set against the global backdrop of international heavyweights like UNDP, WorldBank, and ERBD that accumulate resources on a global scale and operate at the multilateral level. In particular, this group includes specialized climate programs run by institutions such as the African Development Bank (AfDB), the Asian Development Bank (ADB), the Central American Bank for Economic Integration (CABEI), the Development Bank of Southern Africa (DBSA), the Development Bank of Latin America (CAF), the Africa Finance Corporation (AFC), and the West African Development Bank (BOAD). As shown in Figure 2, these entities are also at the forefront of shaping the global landscape of climate finance.

The Green Climate Fund supports international climate initiatives through various channels, including but not limited to the following channels:

- funding projects and programs that aim to reduce GHG emissions and adapt to climate change. This encompasses initiatives in renewable energy, energy efficiency, forest conservation, and water management;
- providing capacity-building grants to assist developing countries in enhancing their institutional, human, technical, and planning capabilities;
- placing a special emphasis on the private sector by encouraging private investment in climate initiatives;
- offering financial support for technical assistance during the preparation and implementation phases of projects.

In the past decade, funding has risen from USD 10 million to USD 20 million, and the time taken to decision-making has reduced from an average of 15 years to 4 years [24]. This is undeniably a positive indicator, especially considering the global decarbonization timeline established by the Paris Agreement.

However, despite the enhanced overall effectiveness of global green support, the study identified several problematic aspects that require additional attention.

First, uneven distribution of funds and access limitations. While some developing countries effectively access the funding received for climate projects, others face procedural barriers [7]. This calls for better decision-making processes to increase the effectiveness of GCF activities in developing countries. Despite the accreditation of 62 developing country institutions to the GCF, 42 of them have not yet received project funding. Therefore, while the GCF has initiated several financial programs to directly assist institutions in developing and approving projects, these efforts have not yet met the demand [29].

Second, challenges in engaging the private sector. Enhancing effective private-sector participation is considered critical to addressing climate adaptation. A possible solution lies in the aligning private sector in an adaptation by going beyond financing and focusing on market encouragement instead of barriers [28].

Third, common principles of justice and equity. The predominant problems in the implementation and management of the GCF can be seen as symptoms of the shortcomings of the global climate finance architecture [30]. This is reinforced by insufficient financial support provided by developed countries to developing countries and the limited funding allocated to adaptation projects [23].

Additionally, it is important to highlight a problematic aspect concerning the effectiveness and quality of the climate-neutral economy model. The absence of a global vision for a climate-neutral economy hinders the community's ability to present a comprehensive perspective on the necessary efforts, project actions, and required international cooperation.

When developing a model, it is important to consider the organizational and technological readiness of countries for implementing international climate initiatives. This readiness is driven by digital decisions and networking. Thus, financial aid encompasses not only monetary support but also capacity building and technical assistance to enhance the planning, implementation, and management of climate projects. Such support augments the overall efficacy and sustainability of initiatives. The goal of these financial efforts is to accelerate the global shift towards a future where economies emit fewer greenhouse gases (a climate-neutral future) and are better equipped to handle the impacts of climate change (a climate-resilient future).

When devising a model, it's crucial to account for the organizational and technological preparedness of countries to undertake international climate initiatives. This readiness is driven by digital strategies and networking. Consequently, financial assistance extends beyond broad monetary aid, but also includes capacity building and technical support, enhancing the planning, execution and oversight of climate projects. This multifaceted support boosts the effectiveness and sustainability of global climate initiatives. The objective of these financial endeavours is to accelerate the global passage towards a future characterized by lower greenhouse gas emissions (a climate-neutral future) and improved resilience to climate change impacts (a climate-resilient future).

Our research uncovers a compelling narrative regarding the global distribution of climate financial aid among international recipients and their readiness to support it (Table 1).

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Table 1. Recipients of global climate financing. *(Source: authors' calculations based on open data by GCF [31])*

World region	Readiness for climate actions (R)		Climate funded activities (FA)		Balance R to FA	
	Number of grants	Financing, USD million	Number of grants	Financing, USD million	quantitative	financial
Africa	278	166.4	340	5 185.2	1:1.2	1:31.2
Asia-Pacific	239	176.3	162	4 516.3	1:0.7	1:25.6
Latin America and the Caribbean	342	161.4	165	3 311.9	1:0.5	1:20.5
Eastern Europe	41	32.9	27	438.9	1:0.7	1:13.3
Total	900	537.1	694	13 452.3	1:0.8	1:25

The table presents several key insights. Across all regions, except Africa, the number of grants aimed at preparedness surpasses those allocated for specific climate adaptation and mitigation activities. This suggests a significant demand for preliminary activities and strategic planning before the execution of targeted climate projects. Despite the fact that such preparedness requires much less financial resources, the overwhelming majority of grant activities indicate the crucial need for organizational and technological efforts in this area.

The funding ratio between preparedness and actual project funding varies significantly across regions, ranging from 1 to 13.3 in Eastern Europe to 1 to 31.2 in Africa. This highlights a significant disparity in funding between different project stages. Although the overall ratio of grants to activity-ready funding is approximately 1 to 0.8, there are differences between world regions, indicating different approaches to support climate change projects. Although there are more grants available for preparedness, the funding is heavily skewed towards specific adaptation and mitigation actions, with an overall financial ratio of 1 to 25. This demonstrates a general willingness to invest significant resources in implementing projects that address climate change.

Achieving a balance between investments in preparation and direct adaptation and mitigation efforts is crucial. Enhancing transparency in fund utilization and project outcomes can bolster donor confidence and stimulate further investment in climate initiatives. A critical emphasis should be placed on the effectiveness of projects and the capability to assess their climate impact. This involves establishing clear criteria for the evaluation and monitoring of results. Special attention should also be given to engaging local communities, considering their needs and capabilities, as this can significantly improve the effectiveness and acceptance of projects.

Moreover, it is essential to diversify financial instruments to guarantee sufficient funding for climate projects worldwide. This can be accomplished by exploring a range of funding sources, including private investments, grants, loans, and support from international financial institutions. The development and implementation of international legislation and standards to unify efforts against climate change on a global scale are of paramount importance.

On another hand, climate neutrality requires complex dimensions. Facilitating technology transfer between countries is essential for the distribution of innovative digital solutions for sustainable development by offering broader access to cutting-edge technologies. Encouraging sustainable consumption and production patterns minimizes environmental impacts and enhances resource efficiency. Involving citizens through education and raising awareness is pivotal to supporting global sustainability efforts. Moreover, developing a sustainable digital infrastructure is crucial to ensuring that digital transformation benefits, rather than weaken, climate objectives. Therefore, to effectively combat climate change, a holistic approach is essential. This strategy should encompass not just financial elements but also underscore the importance of public involvement, innovation, and international collaboration.

The following analytical findings reflect the need for an integrated approach to the climate-neutral economy model, particularly in terms of incorporating digital solutions. The author's research of the GCF's open project database, which currently covers 243 international climate initiatives from countries around the world, serves as the basis. This study enabled a systematic organization and identification of the four major segments in advancing a climate-neutral economy (Figure 3).

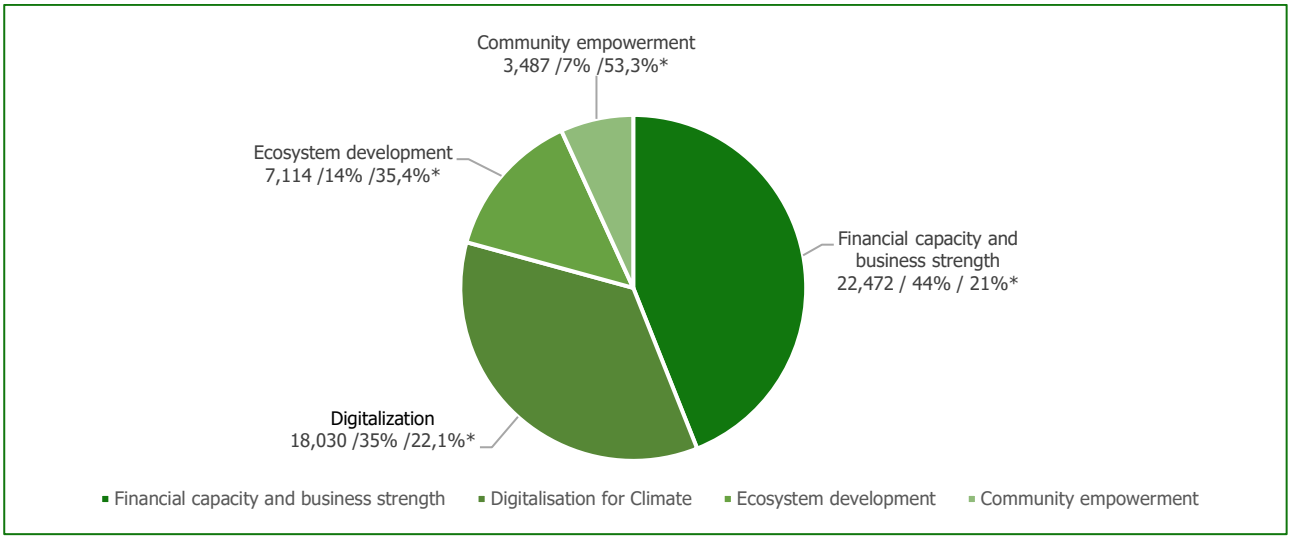

Figure 3. Segments for supporting the climate-neutral economy in the world. Note: *global financing, USD billion / share, % / GCF contribution, %). *(Source: authors' calculations and systematization based on open data by GCF [30])*

The identified segments delineate the foundational directions for advancing a climate-neutral economy, capturing society's most pressing demands. Notably, the main areas include financial capacity building (44% of global funding) and the integration of digital solutions and smart technologies (35% of funding). These initiatives are predominantly implemented through co-financing by the global community, with the Green Climate Fund's (GCF) contribution to these projects being the least, averaging 21% and 22.1%, respectively.

On the other hand, the equally important areas of community strengthening, and ecosystem development have the least financial support in general. They are being conveyed mainly by GCF internal capital. The GCF's share is the largest, amounting to 53.3 and 35.4%, respectively.

Therefore, our findings support the hypothesis that the current level of financial aid for a climate-neutral economy is predominantly directed towards digitalization and financial empowerment components. A comprehensive examination of the GCF's project database allowed to identify the factors and key attributes required to implement each segment of the climate-neutral economy effectively.

Segment 1. Digitalization for Climate. This segment includes global climate initiatives aimed at facilitating a broad transformation to intelligent systems and smart solutions across all sectors of the economy, increasingly integrating physical objects into the digital transformation. Given the climate challenge, a pivotal domain is the establishment of modern digital infrastructure, which forms the basis for the creation of smart architecture, agriculture, and transportation systems. The growth of digital markets, effective communication, and data accessibility, together with the implementation of Industry 4.0 technologies, are essential for enhancing climate resilience.

The case study of GCF's projects in Segment 1 enabled to identify the determinants contributing to the development of the «Digitalization for Climate» segment: digital infrastructure, digital twin, smart architecture, smart agriculture, smart transportation and e-mobility, digital E-services, Industry 4.0 technologies, big data analytics for risk-analysis, monitoring, control, and forecasts.

Segment 2. Financial capacity and business strength. This segment focuses on the financial support and development of the green transition of local businesses. It entails the establishment of specialized funds, the creation of financial instruments, and the exploration of green investment sources. These measures are instrumental in cultivating a sustainable and adaptable economy, highlighting the intersection of finance and environmental sustainability. Through this approach, businesses are encouraged to adopt practices that not only contribute to their economic resilience but also align with global efforts to mitigate climate change.

Key determinants: local funds, climate hubs and business accelerators for a green business transition, development of financial and credit instruments, and the framework of green investment.

Segment 3. Community empowerment. This segment involves the initiatives related to the execution of awareness campaigns enhancing the community's engagement in climate-related issues, the improvement of living standards through infrastructure and service upgrades, and the establishment of community and residential hubs that serve as centres for

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education and action on environmental sustainability. A significant emphasis is placed on ensuring equitable access to essential resources such as clean energy and water, as well as disseminating critical information regarding energy efficiency and climate adaptation techniques. A pivotal aspect of this segment is the promotion of gender equality, recognizing the role of women as key agents in the context of environmental sustainability. Additionally, strengthening the resilience of communities particularly vulnerable to climate impacts is fundamental, involving tailored support to enhance their capacity to respond and adapt to environmental changes. Through these concerted efforts, community empowerment aims to foster a culture of sustainability and resilience, enabling communities to not only withstand climate challenges but also contribute actively to global climate solutions.

Key determinants: informational and communicational campaigns; livelihoods for people from environmentally damaged regions; housing and community centres; new climate behaviour; equitable access (primarily to water, energy and climate information); principle "clean energy for all"; gender equality in environmentally vulnerable communities; adaptive potential of communities.

Segment 4. Rethinking ecosystem development. Most of the initiatives are aimed at implementing the principle of EbA (Ecosystem-based adaptation). This approach uses biodiversity and ecosystem services as part of an overall strategy for helping regions to adapt the adverse effects of climate change [32]. In addition, this segment implies the so-called 3R concept (literally, Reduce-Reuse-Recycle). This principle contributes to sustainable development and the conservation of resources, which are critically important for supporting a climate-neutral economy. Reducing resource consumption decreases pressure on the environment while reusing materials reduces the need for new raw resources, and recycling decreases the volume of waste requiring disposal or storage [33]. By adopting this model, the development of ecosystems can contribute to reducing environmental footprints and promoting the sustainable use of natural resources.

Key determinants: EbA principle (Ecosystem-based adaptation), ecosystem development on 3R-approach (Reduce-Reuse-Recycle), Resilience to change (droughts, floods, glacial melting), restoration of natural patterns and historical landscapes (primarily forest belts, meadows, river valleys), governmental planning of territory development.

The analysis of international financial support for each of the identified segments showed a significant differentiation in the financing of climate-neutral economy projects. This can be seen in the results of the statistical evaluation of the samples (Table 2).

Table 2. Characteristics of financial support for each segment of the climate-neutral economy. *(Source: authors' calculations on open data by GCF [30])*

Segments	Amount of projects	Variation range in financing, USD million		Average cost, USD million	Mode	Median
		min	max			
Digitalization for Climate	74	4.64	1 873.30	253.94	31.00	65.72
Financial capacity and business strength	55	9.88	3 685.00	395.50	200.00	191.82
Ecosystem development	64	8.16	1 497.00	112.92	10.00	50.00
Community empowerment	50	9.39	750.00	87.61	10.00	47.31
Summ	243	32.07	7 805.30	849.97	251.00	354.85

These figures offer a clearer insight into the financial needs of global initiatives across various sectors of the climate-neutral economy. The financial requirements for projects vary significantly, influenced by factors such as the scope of the initiatives, their intended effects, the number of involved parties, and the geographical area of implementation. On average, the cost of current climate projects is pegged at approximately USD 850 million. However, the most frequently observed funding level is USD 251 million, with half of the projects necessitating no more than USD 355 million in financial support. Nonetheless, the distribution of these figures differs across sectors. For instance, initiatives aimed at Enhancing Financial Capacity and Business Resilience demand the most substantial financial backing. About half of these projects manage up to USD 191.8 million, but the rest call for considerably more funding. Notably, ambitious projects like the establishment of green business finance centres and specialized regional climate funds in Africa and Latin America seek substantial investments, ranging between USD 1.5 billion and USD 3.7 billion. This underscores the need for broad participation from international stakeholders in the execution of this critical segment.

On the other hand, projects from the "Digitalization for Climate" segment have an average estimated cost of USD 253.9 million. Since the typical funding amount is around USD 31 million, half of these initiatives need no more than USD 65.7

million for implementation. This affordability makes this segment more accessible and attractive to the private sector, which facilitates the formation of public-private partnerships in the area of green digital transformation.

Noteworthy that international climate initiatives in the "Ecosystem Development" and "Community Empowerment" segments have similar characteristics in terms of funding requirements. The lion's share of projects cost around USD 10 million, and half of the projects in this segment do not exceed USD 50 million and USD 47.3 million, respectively.

For segments that require significant investment, it is important to focus on creating and attracting international financial entities, attracting government funding and large private investors. Thus, public-private partnership mechanisms can be developed to engage private-sector investment while supporting these initiatives at the government level. In segments requiring less funding, attention should be focused on attracting local investment, promoting microfinance, and developing grant programs to engage local communities.

The exploration of all 4 segments of the climate-neutral economy in their logical connection showed the cross-cutting role of segment 2 "Digitalization for climate". Therefore, digitalization serves not just as a distinct and essential component in the advancement of climate initiatives but also reinforces the technological infrastructure crucial for executing other segments. This maintains the concept of a digitally driven model of a climate-neutral economy (Figure 4).

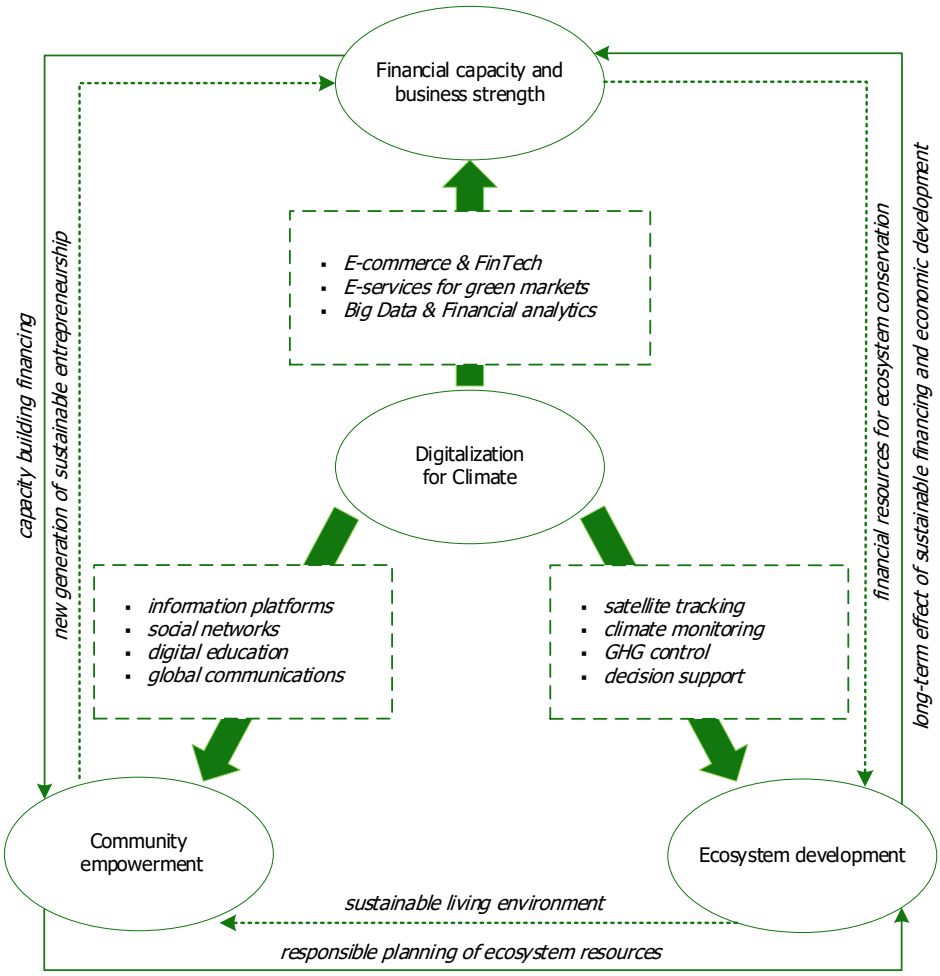

Figure 4. Digitally driven model of a climate-neutral economy.

Specifically, digitalization's impact is twofold. On the one hand, it produces a whole cluster of versatile IT products for green business and governance. On the other hand, digital transformation contributes to an effective information environment and strong digital infrastructure for better efficiency of all formative segments of the climate-neutral model. In summary, digitalization emerges as a pivotal force driving the global conversion to a climate-neutral economy. According to the above model, this essential impact is as follows.

Linkage 1. Community empowerment via Digitalization. Digitalization empowers communities in addressing climate and environmental challenges through better access to climate information, raising awareness and engaging local citizens in

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actions to minimize environmental impact. Such an environment promotes the development of collective initiatives and projects aimed at sustainable development, creating a more informed and proactive society ready to tackle environmental challenges together. Additionally, the connection between digitalization and community empowerment offers indirect benefits to the economy by fostering a green public movement and stimulating growth in green industries. This dynamic leads to job creation and draws investments into sustainable technologies, laying the foundation for a resilient economy.

Linkage 2. Financial capacity and business strength via Digitalization. Digital transformation facilitates business access to innovative financing tools and enables companies to streamline operations and enhance productivity, all of which are crucial in bolstering sustainable growth. Meanwhile, digitalization provides wide opportunities for local small and medium entrepreneurship, in particular, to support its green transition through energy-saving technologies and Industry 4.0 decisions.

Linkage 3. Ecosystem development via Digitalization. Digitalization widely conveys the rethinking of ecosystem development and enhances the decision-making process through transparent data. Technologies like remote sensing and geographic information systems (GIS) are instrumental in monitoring ecosystem health, pinpointing issues, and devising strategies for their restoration and protection. In the agricultural sector, digital advancements such as precision farming and smart irrigation systems are making strides in reducing environmental footprints, boosting productivity, and safeguarding biodiversity.

However, the effective implementation of a digitally driven model of a climate-neutral economy requires the promotion of several support directions.

First, the global integration and adaptation of digital technologies into production cycles plays a crucial role. Moreover, digital transformation has the potential to significantly improve the efficiency of resource use and energy consumption, in particular through supply chain optimization, smart energy management and production automation. This includes introducing innovations that reduce carbon footprints and support the conservation of natural resources.

Second, contemporary climate governance demands decision-making based on transparent data. Consequently, big data and analytics offer precise measurement and monitoring of greenhouse gas emissions and identify avenues to lessen environmental impacts via more efficient resource utilization. Digitalization enhances the transparency of business and governmental actions regarding their climate impact, with blockchain technology enabling the tracking of the carbon footprint of products and services worldwide.

Third, establishing a supportive ecosystem for the emergence and growth of green startups and digital innovations is crucial in addressing environmental challenges. This involves ensuring access to funding, mentorship, and equitable opportunities in the market. Digitalization lays the foundation for breakthroughs in green energy, sustainable agriculture, and water management, thereby facilitating the development and introduction of innovative, more efficient technologies.

Fourth, Bridging the digital divide is imperative to guarantee universal access to digital technologies and the opportunities they present across all countries and regions. This necessitates investments in infrastructure, alongside education and training in digital competencies, ensuring that every community can partake in the digital economy. Crafting educational programs centred on digital transformation and its influence on climate issues is crucial for equipping a new generation of professionals. These individuals will operate at the nexus of technology, ecology, and economics, driving forward the integration of digital solutions into sustainable practices.

Encouraging collaboration across various economic sectors, governments, public entities, and the scientific community is essential for the deployment and expansion of digital solutions aimed at achieving climate neutrality. Digital platforms and tools offer a solid basis for international cooperation, facilitating the exchange of knowledge and best practices among countries, businesses, and civil society. This comprehensive strategy towards utilizing digital means to tackle climate challenges highlights the crucial role of cross-sectoral collaboration.

DISCUSSION

This study continues the international discussion on finding mechanisms for building a climate-neutral economy. This explores the potential of digitalization in this direction. In recent years, the concept of a twin green and digital transformation of the economy has been actively raised in many regulations, strategies and papers, especially in the European Union. Our study develops the idea of the potential of digitalization for the development of green initiatives but from a more applied perspective of global financial support. Undoubtedly, climate-neutral financing is an important condition for the green transition of the economy.

This issue is actively addressed in the scientific discourse. Unlike previous studies, we analyzed the structure of GCF projects and systematized and grouped them. This allowed us to identify 4 self-sufficient segments of applied implementation of climate-neutral economy initiatives: Digitization for Climate; Financial Capacity and Business Strength; Ecosystem Development; Community Empowerment. The case study of projects in these segments allowed us to identify the determinants of each and to reveal the cross-cutting role of digitalization in achieving climate neutrality in the global economy.

A limitation of the study is the choice of an open database of a single GCF, among others. However, this fund is the largest in green finance and covers the climate needs of all regions and countries of the world. In addition, the datasets presented cover more than 240 climate projects, which allows us to build relevant samples and speak about the validity of the conclusions.

Another controversial point is that the presented digital-oriented model of a climate-neutral economy is based on the current state of the technological process in the field of climate action. However, we believe that the identified conceptual segments of the climate-neutral economy will remain the basis for the coming decades. However, the role of digitalization in their development may be adjusted over time as new digital solutions are introduced. Therefore, the cost estimates of the projects presented in this article are relevant for the coming years.

In addition, even though we have mentioned the contradictory opinions of some scientists regarding the positive and negative role of digitalization, we have focused on the strength of digitalization as a driver of climate neutrality. Despite the digital sector producing some greenhouse gas emissions, its role in achieving climate neutrality is irreversible and cross-cutting for the global economy.

CONCLUSIONS

This study leads to several conclusions and suggests directions for future research.

Digitalization is identified as a key driver in the shift towards a climate-neutral economy, delivering innovative IT solutions for green businesses, industries, and governance while enhancing digital infrastructure to boost green performance. However, this transformation must consider the global financial landscape. The support of international financial institutions, particularly in green finance, is crucial for facilitating climate-neutral projects globally. These institutions help to balance the socio-economic narrative, especially aiding developing countries in their climate efforts. Furthermore, climate funds engage both the public and private sectors, encouraging collaboration and innovation in sustainable development. Despite a broad array of international participants, the Green Climate Fund stands out as a leader in equitably addressing climate issues.

The geographical location and role of international donor organizations are vital in advancing climate finance, reflecting the geopolitical dependencies and emerging global divisions. The USA and the EU are primary contributors to global climate action, with 20 financial entities accounting for 67% of all green projects and providing at least 85% of the Global Climate Fund's financing. Thus, significant local donors have arisen, gathering green funds to meet national and regional needs.

The climate funds' portfolio reflects the contemporary economy's demand for climate-neutral initiatives across four main segments: Digitalization for Climate (35% of global funding); Financial Capacity and Business Strength (44%); Community Empowerment (7%); and Rethinking Ecosystem Development (14%).

While the concept model of a climate-neutral economy is based on these segments, digitalization is considered a core pillar. On the one hand, it produces a whole cluster of versatile IT products for green business and governance. On the other hand, digital transformation contributes to an effective information environment and strong digital infrastructure for better efficiency of all formative segments of the climate-neutral model. Thus, digitalization impacts climate neutrality across main linkages. Digital technologies facilitate access to climate information, encourage public participation in sustainability efforts, and enhance the efficiency of green initiatives. By enabling better access to innovative financing and operational tools, digitalization supports the economic viability of green transitions for businesses, especially small and medium-sized enterprises. Additionally, it offers advanced solutions for ecosystem management, improving monitoring, and conservation strategies. Collectively, these linkages illustrate digitalization's role as a cornerstone for sustainable development, fostering a resilient economy and healthier ecosystems through informed decision-making, community engagement, and economic growth in green sectors.

Strategic recommendations for deploying a digitally driven model of climate neutrality emphasize the importance of improving digital integration, adopting data-driven climate governance, supporting green startups, bridging the digital divide, and fostering cross-sector collaboration.

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CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest.

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ЦИФРОВО ОРІЄНТОВАНА МОДЕЛЬ КЛІМАТИЧНО НЕЙТРАЛЬНОЇ ЕКОНОМІКИ В КОНТЕКСТІ ГЛОБАЛЬНОЇ ФІНАНСОВОЇ СПРОМОЖНОСТІ

Робота досліджує умови та драйвери розвитку моделі кліматично нейтральної економіки, акцентуючи увагу на ключовій ролі цифрової трансформації. Вагомим важелем упровадження цієї моделі є проактивна участь міжнародних фінансових інституцій у глобальному зеленому фінансуванні. Дослідження звертає увагу на інструментальну роль зелених фондів як ключових гравців у формуванні глобальної фінансової спроможності задля забезпечення багатосторонньої підтримки адаптації до змін клімату по всьому світу. У статті узагальнено всеохоплюючі рамкові механізми такої допомоги. Використовуючи системну аналітику та кейс-стаді проєктів Зеленого Кліматичного Фонду, автори обґрунтовують визначальні сегменти для розбудови кліматично нейтральної економіки. Отож, у дослідженні

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визначено чотири ключові сегменти досягнення кліматичної нейтральності світової економіки: диджиталізація для клімату, зміцнення фінансової спроможності та стійкості бізнесу, переосмислення розвитку екосистем і розширення можливостей громад. Дослідження спирається на відкриті великі дані щодо реалізації 240 кліматичних проєктів за участі основних бенефіціарів кліматичного фінансування в Східній Європі, Африці, Азійсько-Тихоокеанському регіоні та Латинській Америці. Автори акцентують увагу, що сучасне кліматичне фінансування демонструє ознаки геополітичної залежності та поляризації глобального впливу. Отримані дані свідчать на користь необхідності посилення регіональної присутності кліматичних фондів із метою зростання фінансової спроможності для реалізації кліматично нейтральних проєктів на місцевому рівні. У статті окреслено розмах фінансування, необхідного для кожного сегмента, а також важливість допроєктної підготовки країн. Автори обґрунтовують наскрізну та водночас подвійну роль диджиталізації в моделі кліматично нейтральної економіки. Цифровий перехід генерує цілий кластер незалежних та універсальних IT-продуктів для зеленого бізнесу, промисловості й управління. З іншого боку, диджиталізація формує інформаційне середовище та потужну цифрову інфраструктуру задля підвищення ефективності інших важливих сегментів. Зокрема, вона забезпечує цифрові рішення для фінансової спроможності та стійкості зеленого бізнесу з погляду зеленого кредитування, грантів і фінтех; посилює інформаційну обізнаність і залучення вразливих громад до процесів зеленої економіки; сприяє цифровій підтримці загальної адаптації екосистеми.

Ключові слова: глобальна економіка, зелені фінанси, диджиталізація, цифрова трансформація, кліматично нейтральна економіка, Зелений Кліматичний Фонд

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