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Digital Transformations: Shaping Green Finance and Sustainable Investment

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ABSTRACT:
The intensive development of digital technologies and their integration into finance and investment necessitate the study of their impact on sustainable development and green finance in the context of the growing importance of environmental financial instruments. The article aims to analyse the impact of digitalisation on green finance and environmental investment. The study used several quantitative methods, including comparative analysis to assess the effectiveness of green financial instruments, analysis of statistical data to identify trends in digitalisation and the development of green finance, forecasting market changes, and correlation analysis to determine the impact of digitalisation on the development of green finance; as well as other general scientific methods of cognition, including synthesis, systematisation, and generalisation. The study's results showed that the Pearson correlation coefficient $r \approx 0.745$ indicates a moderate positive relationship between the level of global digital transformation and the volume of green finance, confirming the primary hypothesis that digitalisation impacts increasing investment in sustainable development. The results of the study indicate that the impact of digital transformations on green finance and environmental investment is mainly characterised by the expansion of opportunities for integrating digital technologies into financial mechanisms, a systemic increase in the size of the green finance market, intensification of public policy and investment promotion, the implementation of strategies for the transition to low-carbon economies.

Keywords: digital economy, digital transformations, green economy, green finance, green trade, sustainable development.

1. Introduction

Currently, the potential of digital transformation goes beyond ensuring social processes, transforming it into a comprehensive approach to sustainable development. For a long time, digitalisation has played the role of an activator of inclusive and accessible services that ensure the integral participation of all social groups, including the most

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vulnerable, in the digital process, thereby helping to minimise social exclusion in the context of globalisation and the digital revolution (Kwilinski *et al.* 2023). Due to the dynamic development of information and communication technologies and digital innovations, new opportunities are emerging to ensure an effective dialogue between governments, businesses, civil society organisations and citizens in a global context aimed at achieving the Sustainable Development Goals, using the mechanisms of interaction characteristic of Industry 4.0 (Carrasco-Farré *et al.* 2022).

In addition, the latest digital solutions have increased the need to expand the environmental investment market, given that green financial instruments have become a priority in the current financial and economic globalisation, where investors' and consumers' interest in environmentally friendly practices and focus on ethical business principles is on the rise. In particular, according to Market.Us (2024), the global environmental finance market is forecast to reach approximately USD 22.8 trillion by 2033, with an average annual growth rate of 21.7%. This is up from the current value of USD 3.2 trillion in 2013. USD in 2023. The projected size of the global green finance market is shown in Figure 1.

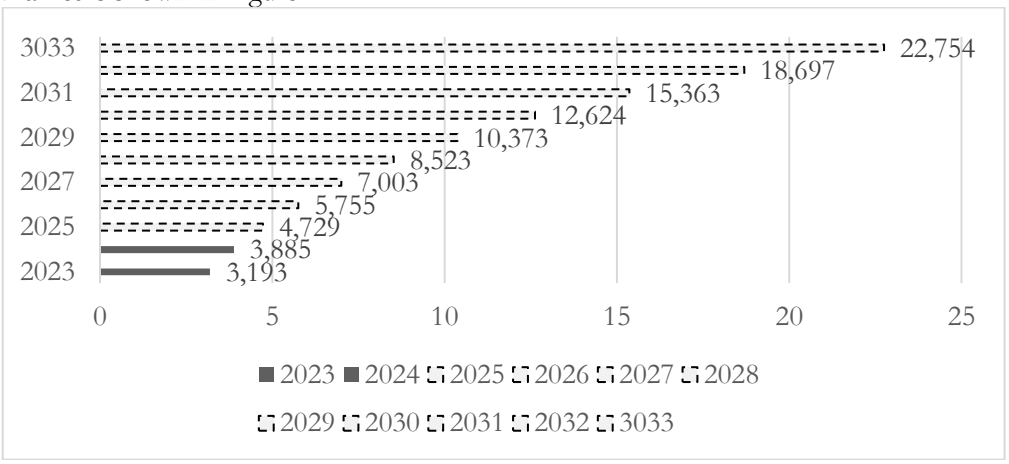

Figure 1: Forecast market size of the global green finance market
Source: Market.Us (2024)
Note: dotted lines indicate forecast values

Given the intensive development of digital technologies and their potential to integrate innovative approaches to finance and investment, it has become necessary to study the impact of digitalisation on sustainable development and green finance, especially given the prospects for further market growth and the overall importance of environmental, financial instruments in today's global climate.

This research article aims to identify sustainable trends in the development of green finance that have emerged against the backdrop of expanding digital transformation. It also seeks to analyse the relationship between the effectiveness of global digitalisation changes and the market for green financial instruments to stimulate sustainable development.

2. Literature review

Given that the traditional model of maximising investment is gradually giving way to the concept of creating long-term sustainable value that takes into account both social and environmental aspects (Zhang & Zhao 2023; Zairis et al. 2024; van Zanten et al. 2023; Popescu et al. 2023), in the context of the rapid development of information and communication and other digital technologies amid the expansion of the global digital transformation process, the potential for integrating digital solutions into environmental management and green trade processes is growing (Yi et al. 2024; Desyatnyuk et al. 2024a). At the same time, there is a significant deepening of environmental problems, environmental pollution (Farooq et al. 2023), increased carbon emissions (Dam et al. 2024), and ecosystem degradation (Chowdhury et al. 2023). Therefore, this situation at the macro level has intensified the process of transition to a green economy, which is the basis for the formation of a socially integrated society, the introduction of energy and resource-saving consumption, and the reduction of harmful environmental impact by stimulating the development of green trade, which promotes the dissemination of environmentally friendly technologies, goods and services, integrating the principles of sustainable development into international economic relations (Bakulina & Ternopilska 2021; Desyatnyuk et al. 2024b).

In addition, as Olasehinde-Williams and Folorunsho (2023) note, the development and support of green trade promotes the integration of environmental standards into international trade, ensuring export and import operations that comply with the principles of sustainable development. In particular, green trade is a financial mechanism that allows markets to achieve the goal of global adoption of new, cleaner technologies to meet the growing demand for electricity, transport, heating and cooling (Fusaro 2005). In this context, green finance is a critical component of modern sustainable development strategies to support environmentally friendly projects, mitigate climate change and facilitate the transition to a low-carbon economy (Ionescu 2021; Krysovatyy et al. 2024).

Recent literature also highlights that the digital divide between developed and developing countries remains a significant challenge (Ojukwu et al., 2024). For example, a study by Arner et al. (2024) shows that limited access to digital payments, lack of financial literacy, and weak digital infrastructure are the main obstacles that limit SMEs' access to finance. Critical assessments by Huang et al. (2024) and Zhang et al. (2024) also point to the risk that digital financial instruments, rather than narrowing the investment gap, could deepen inequality. Nevertheless, Ojukwu et al. (2024) notes that the integration of FinTech into the green bond market presents a pivotal opportunity for advancing sustainable finance. According to Aliano et al. (2024), financial innovations such as green blockchain bonds are mainly available to large institutional investors, while small and medium-sized enterprises in developing countries are often left out of the system. This will lead to a risk of uneven distribution of environmental investments. At the same time, there are promising models that can help equalise access, such as mobile payment platforms and decentralised financial technologies (DeFi), which show the potential to increase participation by less financially integrated actors (Hasan et al. 2024).

However, current research has repeatedly shown that perceived greenwashing practices have a negative impact on behavioural economics, either directly or indirectly. In particular, greenwashing affects consumer purchase intentions and behaviour (Isac et al. 2024) and prevents consumers from making informed purchase decisions, as it increases consumer confusion and reduces their willingness to pay for green products (Santos et al. 2024). This approach integrates financial resources with environmental protection, creating conditions for sustainable economic growth. The main instruments of green finance include green bonds, social bonds, green loans, and transition bonds, which, according to many case studies (Gilchrist et al. 2021; Lin et al. 2024; Park 2018; Zairis et al. 2024), are effective financial instruments for stimulating environmental investments, adapting high-carbon industries to new environmental requirements, and building more sustainable economic systems.

3. Methods

The following methods were used in the research:

- The synthesis method was used to analyse the scientific literature on the prerequisites and prospects for the development of environmental investment and green finance in the context of digitalisation;
- Benchmarking was used to identify the most effective green financial instruments and analyse their market value;
- The analysis of statistical data was used to systematise and identify the trend towards increasing digitalisation in the global context, as well as to study trends in the development of the global green finance market;
- Forecasting conducted using the Excel statistical analysis package (FORECAST.ETS function) was used to identify trends in the further development of the green bond market in 2024-2025;
- The correlation analysis was conducted using the Excel statistical analysis package. The correlation analysis aimed to determine the extent to which digital transformation affects green finance. The central hypothesis of the analysis is the assumption of a relationship between the development of digital technologies and increased investment in sustainable development. To calculate the average values, a base point was established for further analysis of deviations, and, therefore, the stages of this study of relationships are determined by the formula for calculating Pearson's correlation:

$$r = \frac{\sum(X_i - \widehat{X})(Y_i - \widehat{Y})}{\sqrt{\sum(X_i - \widehat{X})^2 * \sum(Y_i - \widehat{Y})^2}} \quad (1)$$

The criteria for the analysis are the Global Digital Transformation Index, which is an indicator of digitalisation, and the volume of green bonds for 2020, 2022 and 2024;

- The systematisation method was used to formulate critical aspects of the multifaceted impact of scaling digital transformation on the development of environmental investments;
- The generalisation method was applied as well.

4. Results

Recently, there has been a significant penetration of digital technologies into all aspects of society. A new stage of innovative development, characterised by the speed of emergence and spread of information and communication technologies and changing requirements for the functioning of business and society, has contributed to the emergence of new forms of economic interaction and knowledge dissemination, which is a characteristic feature of modern reality, closely linked to the processes of digital transformation of various economic systems (Koval & Lyshak 2024). Due to the intensive development of digital tools globally, many developed countries are integrating innovative technologies at all levels of management and production processes, forming the latest strategies to stimulate economic growth and improve social conditions. In particular, digital solutions in public resource management, healthcare, education and finance contribute to the efficiency of information exchange and ensure transparency in relations between citizens and government institutions.

For a comprehensive analysis of digital transformation at the international level, various indices have been developed to classify countries according to their level of digitalisation. One of these aggregate indicators, compiled by Cámara (2020; 2022; 2024) based on the ranking of countries by the level of technological development and integration of digital innovations, is shown in Figure 2. This indicator reflects the dynamics of transformations in different countries and highlights the features of digital development that affect the growth of national economies and the efficiency of public administration.

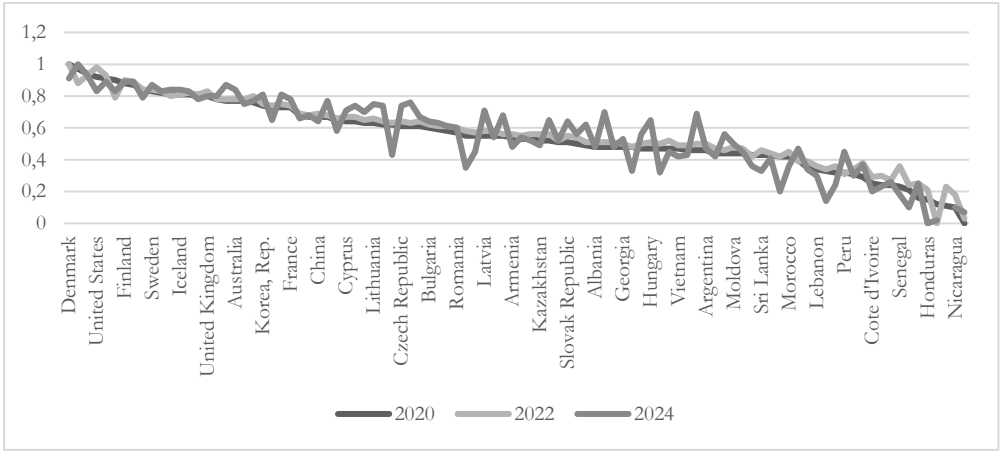

Figure 2: Level of digital transformation by country
Source: Cámara (2020; 2022; 2024)

The gradual transition to a low-carbon development model of national economies is characterised by the need to attract non-traditional sources of financing. Green finance is recognised as one of these sources, and it should be used to support greenhouse gas emission reduction activities and help corporations adapt to the impact of climate change. The main instruments of such financing are:

4.1 Green Bonds

Over the past decade, the green bond market has seen a clear upward trend in its volume. For example, at the initial stage of interest in financing sustainable development projects in 2014, global green bond issuance was USD 37 billion. However, by 2021, this figure reached USD 633 billion (Statista 2024). This indicates the growing attention of society and many countries to climate change and the need to finance environmental initiatives at the international level, which has intensified the activities of governments, multinational corporations, and financial institutions to increase investment in green projects and startups. According to the forecast values calculated using the Excel analysis package (FORECAST.ETS function), it should be noted that the green bond market will continue to grow at the same rate as in previous years, as countries and corporations are undoubtedly striving to meet the requirements of sustainable development and further meet climate goals, thus contributing to the expansion of this segment of the financial markets (Figure 3).

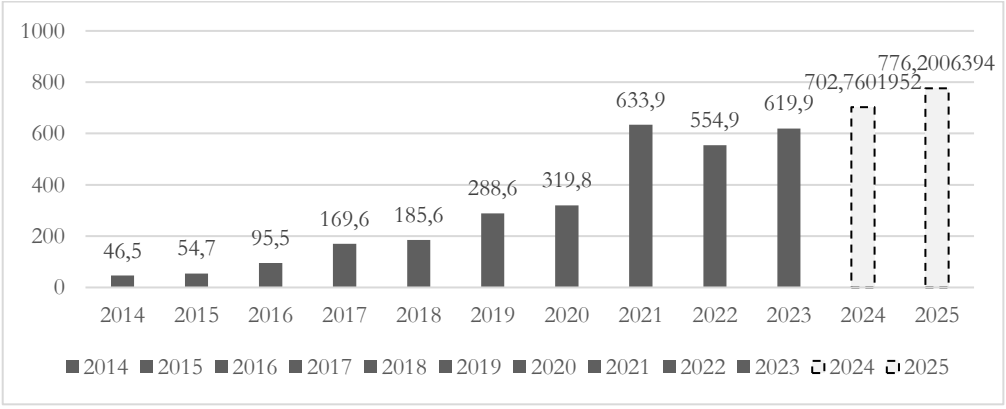

Figure 3: Value of green bonds issued worldwide
Source: compiled by the author based on Statista (2024)
Note: The dotted line indicates the forecast value calculated by the author

Despite a temporary decline in 2022, the overall trend shows the potential for green bonds to develop, which is an essential indicator of the global movement towards sustainable development, including addressing climate change, improving waste management and reducing greenhouse gas emissions.

4.2 Social Bonds

Social bonds play a vital role in transforming modern capital markets, highlighting the need to integrate sustainability principles into investment strategies (van Zanten et al.

2023). International regulatory frameworks that push investors to rethink their strategies and focus on low-carbon technologies significantly contribute to this paradigm's development. In this context, the European taxonomy uniquely facilitates investment in sectors with high sustainability potential. However, it remains an open question to what extent these financial instruments go beyond the traditional neoliberal market model, as there is a view that sustainable development is used mainly to promote without offering natural alternatives (Zairis et al. 2024).

4.3 Green Loans

Green loans represent financial instruments focused on implementing environmentally sustainable projects to ensure the transition to a zero net carbon economy and minimise the effects of climate change. This financing mechanism involves attracting bank investments in areas that promote environmentally responsible business. The historical development of green lending began in 2005, when leading US financial institutions, such as Wells Fargo and Bank of America, started the practice of allocating resources to support sustainable businesses, laying the foundation for the formation of modern environmentally oriented financial policies (Gilchrist et al. 2021). However, green loans are a significant part of the sustainable debt market. According to Environmental Finance (2023), the volume of sustainable loans exceeded USD 860 billion in 2023, with more than USD 8 out of every USD 10 sustainable loans signed as a sustainability-linked loan (SLL).

4.4 Transition Bonds

Transition Bonds are an innovative financial instrument for attracting long-term capital to finance sustainable development projects, particularly in industries with high greenhouse gas emissions, aimed at their gradual decarbonisation. This financial instrument creates conditions for the transformation of enterprises to reduce the carbon intensity of their business activities but does not necessarily imply achieving complete environmental neutrality. Thus, transition bonds play a vital role in the implementation of the strategy of gradual transition of the economy to sustainable models of operation, allowing industries with high emissions to adapt to the new requirements of climate policy (ICMA 2024), which ensures the reduction of the carbon footprint, and, as a result, contributes to the achievement of Sustainable Development Goals 7, 9, 12, and 13, thus ensuring a balance between the economic goals of enterprises and their environmental obligations (Figure 4).

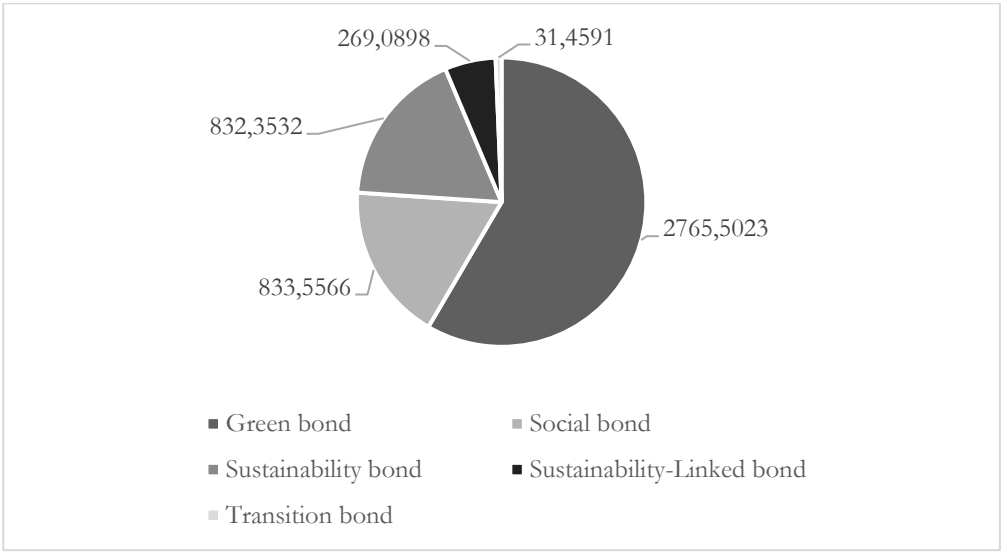

Figure 4: Total market value of green finance instruments
Source: Environmental Finance Data (2024)

Therefore, green bonds provide the most direct positive environmental impact, as their proceeds are allocated exclusively to environmentally friendly projects such as renewable energy, waste management, and energy efficiency. Social bonds, while primarily focused on addressing social issues, can have an indirect environmental impact through improvements to infrastructure, transport, and healthcare facilities, contributing to an overall reduction in the carbon footprint. Transition bonds, in turn, are aimed at the environmental transformation of traditional industries such as metallurgy, energy, and transport, ensuring a gradual reduction in emissions and adaptation of production to environmental standards.

In this context, the perspective of Robeco, an international asset manager, reflects this: in 2023, green bonds were the driving force behind the overall growth of the ESG-labelled bond market, representing a share of more than 60% of ESG bond sales. Issuance of ESG-labelled bonds amounted to USD 311 billion in the first quarter of 2024 exceeding issuance from Q1 2023 by 3%, marking the strongest start to the year ever (Vejarano *et al.* 2024).

Green bonds are the most effective financial instrument for achieving environmental goals in the short and medium term, as they directly finance projects to reduce emissions and transition to sustainable development. In addition, green bonds have demonstrated the greatest impact on reducing CO^2 emissions by financing projects that contribute to the transition to a low-carbon economy (Dam *et al.* 2024). However, improvements to public transport and infrastructure upgrades, often financed by social bonds, can contribute to emissions reductions by improving energy efficiency and reducing fossil fuel use.

It is worth noting that the widespread use of information and communication and other digital technologies as part of the global transition to a new system of economic and

social relations, which includes the digital economy, is currently driving many governments and modern enterprises to intensify their efforts to achieve sustainable development goals. Thus, the scale of digital transformation has a multifaceted impact on the development of environmental investments, which several vital aspects can characterise.

First of all, integrating digital technologies opens new opportunities in the market and contributes to the intensification of government support, which creates optimal conditions for implementing green investments. Given the global trend towards sustainable development, the rapid growth of the green market is becoming increasingly important, allowing businesses to use digital innovations to lead by developing innovative green products and services. In turn, government policies aimed at digitalising traditional industries stimulate the flow of additional resources and provide businesses with the necessary policy support to strengthen their green investment strategies (Fei *et al.* 2021).

Secondly, the latest digital technologies improve the process of analysing the internal and external environment and assessing potential risks for an enterprise, which, preceding the process of financing its eco-initiatives, ensures greater sustainability of green investments. Thus, the development of digital technologies allows the government, investors, businesses and other stakeholders to make more informed investment decisions, reducing uncertainty and increasing the effectiveness of management strategies. In addition, digital transformation facilitates the integration of internal and external information flows, which facilitates cooperation between institutions, businesses and other stakeholders. Such synergies facilitate the development of green initiatives within production chains, ensuring efficient resource allocation and co-creation of added value (Lin *et al.* 2024).

Given that digitalisation is an essential catalyst for increasing green investment by improving cooperation at all stages of environmentally friendly production, it is necessary to conduct a comprehensive analysis of the impact of digital technologies on the effectiveness of green financial instruments, in particular green bonds, taking into account their integration into the overall investment landscape. Therefore, to determine the impact of digital transformation on green finance and environmental investment, a study was conducted by calculating the Pearson correlation coefficient, which allowed us to identify the degree of relationship between the two variables of analysis: the global level of digital transformation and the volume of green bonds. The initial data for the analysis of this relationship are shown in Table 1. The inputs include the Global Digital Transformation Index score and the value of green bonds issued globally over the past five years.

Table 1: Baseline data for analysing the impact of global digital transformation on green finance

Period	Global Digital Transformation Index	The value of green bonds issued worldwide, billion USD US DOLLARS
2020	0,549694	319,8
2022	0,571939	554,9
2024	0,564433	702,8
Average value	0,562022	525,833

Source: compiled by the author

Given that the Global Digital Transformation Index is an indicator of digitalisation, and the volume of green bonds reflects the overall dynamics of green finance, the key indicators were reproduced to determine the relationship between these variables (Figure 2). Correlation analysis requires a more detailed approach to calculating its components. Therefore, to calculate the correlation coefficient to determine the level of impact, it is necessary to calculate the deviation from the average values for each period to assess the variance and degree of variability of the data over time (Table 2).

Table 2: Calculating deviations from the mean

Period	$X_i - \widehat{X}$	$Y_i - \widehat{Y}$	$(X_i - \widehat{X}) * (Y_i - \widehat{Y})$	$(X_i - \widehat{X})^2$	$(Y_i - \widehat{Y})^2$
2020	-0,0123	-206,033	2,539974824	0,000152	42449,59709
2022	0,00992	29,067	0,288257439	9,83469	844,890489
2024	0,00241	176,967	0,426667437	5,81292	31317,31909
Amount	x	x	3,254578	0,000256	74612,586667

Source: compiled by the author

Based on the calculated deviations from the mean value, the Pearson correlation coefficient was directly calculated according to the previously mentioned formula:

$$r = \frac{3,254578}{\sqrt{0,000256 * 74612,586667}} = \frac{3,254578}{\sqrt{19,104822}} = \frac{3,254578}{4,370835} = 0,74455906 \quad (2)$$

The calculations allow us to draw conclusions based on the results of calculating the correlation coefficient. According to the results of the Pearson correlation analysis, it was determined that the coefficient $r \approx 0.745$, which indicates a moderate positive relationship between global digital transformation and green finance; therefore, the primary hypothesis of the study was confirmed, and the development of digital technologies contributes to an increase in investment in sustainable development.

5. Discussion

The results of the study confirmed that the gradual transition of national economies to a low-carbon development model is primarily determined by the need to introduce innovative approaches to financing environmentally oriented projects, which is in line with the general trend towards the integration of digital solutions into environmental management noted in the literature. In particular, Yi et al. (2024) highlights the importance of digital transformation in shaping green trade, while our study highlights the importance of attracting green finance to support such initiatives. The analysis of green bonds confirmed the trend of a steady increase in their issuance identified by Zairis et al. (2024), which indicates an increasing global interest in addressing climate issues. Our study also focuses on the growth of this financial market segment. However, we pay attention to its quantitative characteristics, noting that despite temporary fluctuations caused by macroeconomic challenges, the green bond market has a steady trend towards further development. The results of scientific studies, such as those by Zairis et al. (2024), van

Zanten et al. (2023), and Popescu et al. (2023), confirm the positive impact of social bonds on accelerating the achievement of sustainable development goals which in turn contributes to the transformation of financial markets towards greater responsibility and efficiency. At the same time, we emphasise the open questions about their ability to go beyond the traditional neoliberal model and effectively implement the principles of sustainable development. In addition, the identified aspects of the development of green loans are consistent with the findings of Gilchrist et al. (2021) on the growing integration of environmental standards into bank investments through the spread of modern green lending formats, particularly sustainability-linked loans (SLLs). Instead, transition bonds, which, according to ICMA (2024), are an effective tool for decarbonising high-emission industries, in our opinion, contribute to the achievement of Sustainable Development Goals 7, 9, 12, and 13 and facilitate the implementation of strategies for the gradual transition to a low-carbon economy.

Given the empirical research conducted in this article, it is worth noting the findings of Zhang and Zhao (2023), which aims to analyse the relationship between the coordination of green finance, the digital economy and the environmental environment in China, which demonstrates the importance of optimising the industrial structure for carbon emission reduction ($r = 0.6583$) and the development of green finance. Economic development is identified as a critical factor in the coordination of green finance, the digital economy, and the environmental system (GDE system) ($r = 0.7362$), with the highest impact being in the eastern region ($r = 0.6854$). At the same time, government regulation promotes integrated development ($r = 0.6210$), especially in the central and western regions, through targeted financial and policy support. In this context, our calculated Pearson correlation coefficient ($r \approx 0.745$) indicates a moderate positive relationship between the global level of digitalisation and the volume of green bonds, which is consistent with the findings of Zhang and Zhao (2023) on the interconnectedness of the digital economy, industrial transformation, and carbon reduction. However, our study broadens the context by focusing on global indicators of digitalisation, which complements the regional approach of Zhang and Zhao (2023). Another study by Lin et al. (2025), using instrumental variables such as internet penetration and the number of broadband users, found a significant causal relationship between digitalisation and green investment development (regression coefficients of 0.407 and 0.247, respectively). Instead, our results ($r \approx 0.745$) indicate that the global digital transformation contributes to the expansion of green bonds and acts as a critical factor in strengthening investment activity in environmentally oriented projects. Thus, the identified correlation and consistency with the above studies indicate the complex interaction between technological innovation and environmental sustainability, which confirms our findings' theoretical and practical relevance.

6. Conclusion

According to the study's results, the main aspects of the impact of digital transformations on green finance and environmental investment are, first of all, the integration of digital technologies into financial mechanisms. Currently, the use of digital tools significantly increases the transparency of financial flows, which allows enabling a

clearer assessment of investment effectiveness in sustainable development. In addition, using information and communication technologies will facilitate the development of state support mechanisms that stimulate the implementation of environmental projects through digital platforms, facilitating access to investment for various market participants. Second, digitalisation, including developing extensive data analysis and intelligent systems to predict economic trends, is leading to a significant increase in demand for green bonds, social bonds, and other environmental financial instruments. In this context, using digital platforms allows for adequate investment in environmentally sustainable businesses, contributing to the growth of the global green finance market. In addition, digital technologies facilitate the monitoring and management of financial flows within environmental initiatives, which creates the necessary conditions for supporting sustainable development at the level of governments and international organisations. It should also be noted that the impact of digital transformations on green finance and environmental investment is to expand opportunities for the transition to low-carbon economies and support efforts to achieve global sustainable development goals, in particular, to ensure the effectiveness of decarbonisation strategies at individual enterprises or within industries with high greenhouse gas emissions. Nonetheless, the long-term viability of this transition remains a matter of debate, as the rapid advancement of digital financial technologies may pose unanticipated obstacles. Due to the limited access to digital payments, low financial literacy, weak digital infrastructure, and the dominance of institutional investors in green financial markets, which risk deepening investment inequality, it is essential to integrate inclusive solutions such as mobile payment platforms and decentralized financial technologies. To address these challenges, it is important to ensure synergies between energy-efficient technologies, regulatory frameworks, and sustainable digital infrastructure. Such improvements will be essential for driving digital finance in the context of global decarbonization.

The main limitation of the study lies in its exclusion of the impact of economic fluctuations, policy changes, and regulatory frameworks on the green bond market, which may undermine its predictive power. In addition, the application of Pearson's correlation coefficient did not help to establish different causal relationships. This issue requires further research, as it may lead to an incomplete study of external factors affecting environmental finance.

Future discussion should explore how regulatory frameworks, global economic downturns, and inflation affect green finance, potentially creating instability despite digitalisation's role in mitigating these risks. Particular attention should be paid to the potential of blockchain and artificial intelligence to increase transparency, prevent greenwashing, and ensure effective real-time monitoring of green investments.

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