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Effects of digital transformation on green investment: Evidence from developing economies

Assel Kozhakhmetova
Business School, Kazakh British Technical University, Kazakhstan
a.kozhakhmetova@kbtu.kz
ORCID 0000-0002-3077-2023

Zhanar Tazhiyeva
Department of Business Technologies, Al-Farabi Kazakh National University, Kazakhstan
zhanzari@gmail.com
ORCID 0000-0002-1730-6490

Aknur Zhidebekkyzy *
School of Management, Almaty Management University, Kazakhstan
a.zhidebekkyzy@almau.edu.kz
ORCID 0000-0003-3543-547X
** Corresponding author*

Zoltán Bács
Faculty of Economics and Business, University of Debrecen, Hungary
bacs.zoltan@econ.unideb.hu
ORCID 0000-0003-0612-658X

Abstract. This study examines the impact of digital transformation on green investments in Kazakhstan from 2014 to 2022. The analysis is grounded in the Green Digital Transformation Theory, which posits that digital enablers such as high-tech manufacturing, E-participation, Big Data analytics, and ICT infrastructure foster environmentally sustainable business practices. The study employs linear regression modelling to assess the influence of five independent variables reflecting digitalisation on green investment, serving as the dependent variable. The dataset combines indicators from IMD, WIPO, and Kazakhstan's Bureau of National Statistics. Before modelling, variables were logarithmically transformed, and internal consistency was verified using Cronbach's alpha, which

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yielded a coefficient of 0.989, indicating excellent reliability. The results suggest that digital and technological skills (β = 1.88, p = 0.008) and E-participation (β = 1.63, p = 0.023) have a positive and statistically significant effect on green investment, while digital transformation (β = -0.72, p = 0.041) in companies unexpectedly exerts a negative effect. The findings reveal sector-specific trade-offs in digital modernisation and underscore the need for better alignment between digital and sustainability policies in developing economies.

Keywords: digital technologies, green business, green investment, e-participation, Big Data, ICT costs, Kazakhstan.

JEL Classification: Q01, O33, M15

1. INTRODUCTION

Modernisation worldwide is going faster as humans' needs increase, pushing the level of consumption of natural resources and energy (Swathisri & Kumar, 2014). At the end of this century, the world's temperature is expected to increase by up to 3–6° Celsius (Agudelo, 2013). Therefore, countries are actively searching for solutions to mitigate and slow down the effects of climate change (Satpayeva et al., 2025). They understand the growing demand for more environmentally friendly consumption items (Haleem, 2022; Lyeonov et al., 2023).

In order to meet the above-mentioned needs, the industrial sectors of many countries follow modern manufacturing techniques (Swathisri & Kumar, 2014) and business models that prioritise the ecosystem (Kangalakova et al., 2025). Given the enormous energy consumption and environmental pollution worldwide, many industries are adopting green technologies to mitigate their negative impact (Bianchini et al., 2023; Swathisri & Kumar, 2014). Thus, practical environmental protection efforts through green initiatives by these respective sectors are arguably considered a critical measure for tackling environmental pollution (Liu et al., 2022). In this regard, green business serves as a key driver for economic growth, emphasising the importance of renewable resources and social responsibility (Megawati et al., 2024).

Due to the seriousness and urgency of this problem, developed and developing countries try to looking for any ways of enhancing the efficiency of green business through government support (Kontautienė et al., 2024; Oláh et al, 2024), green investment (Kwiliński, 2023; Kubalek et al., 2024), advanced technology (Widiatami et al., 2023; Megawati et al., 2024; Szwajlik, 2023), digital technologies (Wang et al., 2022; Zhang & Li, 2024; Slingerland et al., 2024), and artificial intelligence (Haleem et al., 2022; Gladden et al., 2022).

Thus, greening businesses has become central to the global sustainable development agenda in recent decades (Kangalakova et al., 2025). Therefore, digitalisation and green transition are two of the most important trends characterising the European economy nowadays (Cimini & Kalantzis, 2024; Streimikiene et al., 2024). By contrast, despite the advantages and opportunities that digital technologies offer, there are increasing concerns about their effects on green business in developing countries (Lindgren et al., 2021). Existing knowledge on the relationship between digital technologies and green business has a gap in understanding, as exemplified by a developing country with relatively low technological development (Lin & Zhou, 2024; Akhmetova et al., 2022).

Kazakhstan is an upper-middle-income country located in the Central Asian region whose development pathway can hardly be considered "green" in any area (Sitenko et al., 2023; Sansyzbayeva et al., 2020; Gassim et al., 2025). There is a lack of empirical research on the impact of digital technologies on green business in Central Asian developing countries (Bekbosinova et al., 2023; Olzhebayeva et al., 2023).

Therefore, this study aims to assess the impact of digital technologies on green business in the Republic of Kazakhstan.

This study uses the Theory of Green Digital Transformation (Perez, 2002), which is relatively new but widely presented in modern scientific literature. It is based on the integration of digital technologies with the principles of sustainable development to address environmental issues and enhance the efficiency of environmental investments in business. This study contributes to the existing literature in several ways. Firstly, while most existing literature on green digital transformation primarily focuses on advanced economies, this study fills a significant geographical and contextual gap, offering new insights into how digital tools foster green business in the developing Central Asian economy, specifically in Kazakhstan. Secondly, it reveals unique barriers and facilitators in Kazakhstan's institutional, economic, and technological landscapes, enriching the theoretical understanding of how green digital strategies can be adapted and scaled in similar developing economies. Thirdly, the study significantly advances the Green Digital Transformation Theory by integrating diverse digital factors (high-tech manufacturing, E-Participation, Big Data analytics, digital transformation, and ICT costs) into a unified analytical framework. This comprehensive approach provides clarity on how different digitalisation dimensions collectively or individually impact green investments.

The structure of the study is organised as follows: Section 1 presents the relevance and goal of the study, and Section 2 contains a literature review on green digital transformation theory, its components, and practical applications. Section 3 describes the methodology, which involves using linear regression to assess the relationship between variables. In Section 4, a regression analysis was performed on the results to determine the role of digital technologies in green investment. Section 5 summarises and compares the earlier findings with the results of this study. Section 6 concludes the study by highlighting the main findings, research limitations, and proposing recommendations for further research.

2. LITERATURE REVIEW

The literature review covers key theoretical concepts of the Green Digital Transformation theory, its components and empirical evidence of the application of this theory.

The term "Green Digital Transformation" arises from the merger of two key areas: digital transformation and sustainable development (Perez, 2002). This concept is actively developing in the scientific literature, especially in the context of implementing digital technologies to achieve environmental goals. Figure 1 presents a structured and detailed description of the components of this theory.

As depicted in Figure 1, according to this theory, digital technologies and infrastructure are independent factors that directly affect the development of the dependent factor, green business. The theory provides a deep theoretical justification for the relationship between the introduction of digital solutions and increased investment in sustainable development. According to the theory, digital technologies facilitate the development of green business and investment. The input variables of this theory include Big Data and analytics, E-participation, digital skills, ICT costs, digital transformation in companies, and digitalisation of manufacturing. Output variables are sustainable business factors, such as green investment, green production, and waste minimisation, considering that greening a business involves integrating environmentally sustainable principles and practices into a company's activities to minimise its negative impact on the environment (Kangalakova et al., 2025; Németh et a., 2023). Green business practices encompass all stages of the business process, from product design and raw material selection to waste management, aiming to sustain economic growth while reducing environmental impact (Mubeen et al., 2024; Zhidebekkyzy et al., 2022; Sabden et al., 2020). Therefore, green practices such as green investment, green products, pollution elimination, environmental innovations, renewable energy utilisation, and sustainable product design are considered key green business factors (Fineman, 2000; Ma et al., 2020; Kozhakhmetova et al., 2024).

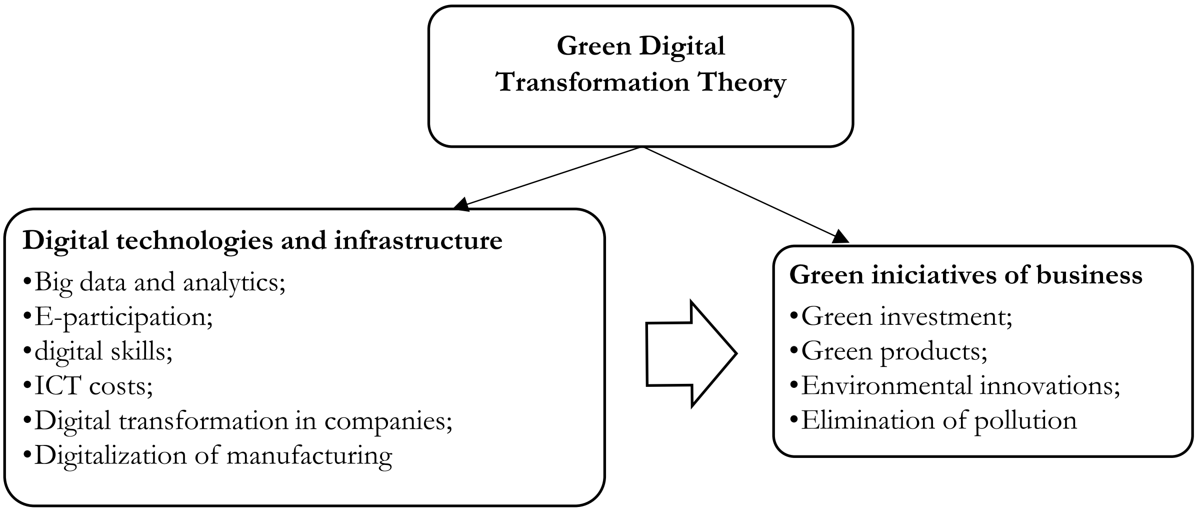

Figure 1. Green digital transformation theory

One of the first references to green digital technologies can be found in Perez's (2002) book, Technological Revolutions and Financial Capital, where she describes how technological revolutions lead to changes in the economy and society. Although she does not use the term "green digital transformation", her work provides a theoretical basis for understanding how digital technologies can contribute to sustainable development. According to this theory, firms can use different digital technologies within a mature digital infrastructure to enhance the factors of green business.

The World Bank also publishes research on the relationship between digital technologies and green business in its reports and annual publications, concluding how digital technologies can help countries adapt to climate change and create more sustainable development paths (WB, 2023).

As the results of the literature review indicate, Chinese scientists have frequently employed this theory. As the world's largest manufacturing nation (Qu et al., 2020; Lukács & Völgyi, 2021), China has actively committed itself on the international stage to achieving 'carbon neutrality' and a comprehensive 'green transformation' in response to global climate change, thereby clearly demonstrating its dedication to advancing green development (Yu et al., 2024). For example, Zhang & Li (2024) collect relevant data at the enterprise level and construct an econometric model for empirical testing. They examine the impact mechanism of digital transformation on enterprises' green technology innovation capability. Using 20,283 datasets from 2049 listed manufacturing firms from China from 2007 to 2020 as the study sample, the mechanism of digital transformation's impact on firms' green technological innovation capability is empirically examined, and the mediating role of firms' green dynamic capabilities is verified. This study finds that digital transformation significantly enhances enterprises' level of green technology innovation.

A recent study by Sun et al. (2025) empirically examines the impact of digital transformation on corporate green innovation from an affordance perspective using data from firms from 2013 to 2022 as the research sample. The findings suggest that the higher the level of digital transformation, backed by accumulative and variational affordances, in a firm, the more conducive it is to corporate green innovation as it enables the homogenization, recombination, and transformation of existing information related to green environmental protection and low-carbon energy efficiency, facilitating firms to achieve targeted and breakthrough green innovations. Moreover, a similar study was conducted by Jiang (2025), who examined the relationship between digital transformation and green innovation using examples from Chinese companies. Using panel data covering 3,021 firms across 75 industries listed on China's A-share stock market from 2011 to 2021, the study applied a fixed effects model and found a positive relationship between digital transformation and green innovation.

These studies' limitations lie in their focus on mature industrial sectors, such as manufacturing and high-tech industries, where digital transformation is already advanced and enjoys substantial governmental backing. In contrast, many developing economies are only starting to adopt digital technologies, making it challenging to capture the unique characteristics and barriers in these less digitally mature contexts. Moreover, these studies focus exclusively on "green technological innovations" without considering the broader "green investments" and "green business" as holistic economic and social processes.

On the other hand, even though the literature points to the existence of important mutual implications between investments in green and digital technologies (Ortega-Gras et al., 2021; Husain et al., 2022; Fouquet & Hippe, 2022), some scholars tend to adopt pessimistic stance arguing that the digitalisation of the economy may encourage the adoption of environmentally unsustainable practices (Andersen et al., 2021; Strubell, 2019). For example, Strubell (2019) argues that despite digital superiority, data centres consume a significant amount of energy, hindering businesses from going green. In addition, Needhidasan et al. (2014) note the problem of the disposal of technological devices in organisations that contain many elements that are not recyclable, which in turn does not comply with the principles of green business. This research gap justifies the need to assess the relationship between digital transformation and green business and significantly expand its theoretical and empirical boundaries.

Hypothesis development

Banda and Plessis (2024) found that E-participation improves environmental performance through indirect effects such as increased human capital and reduced corruption, stimulating investment in sustainable projects. Empirical studies by Sun et al. (2025) support this idea and confirm that E-participation positively impacts green energy investment, primarily through reduced corruption and increased institutional accountability. Additionally, E-participation enhances citizen engagement, resulting in a more sustainable allocation of public funds, including funding for environmental projects (Merhi & Ahluwalia, 2024). Thus, the more actively citizens engage in digital interactions with the government (through electronic surveys, petitions, online discussions), the more investment is directed towards "green" goals. These facts allow us to put forward the following hypothesis (H_1):

H_1: Increasing the level of E-Participation has a positive impact on green investments.

Empirical studies show that the introduction of Big Data stimulates the development of a green economy, as Big Data processing can optimize production processes and resource allocation, reducing losses and damage to the environment (Wang & Li, 2024). Companies actively using Big Data are more likely to invest in new green technologies (e.g., emission monitoring systems, smart grids) for long-term efficiency (Alyahya & Agag, 2025). A study using a difference-in-differences (DID) model found that introducing Big Data in pilot areas in China significantly reduces urban carbon emissions, attracting green investment and raising public awareness of environmental issues (Liu et al., 2024). Thus, the existing literature shows that the expansion of Big Data in the business environment has a positive impact on the volume of green investment, allowing us to put forward the following hypothesis (H_2):

H_2: The active use of Big Data in the economy contributes to the growth of green investments.

Digital transformation (implementation of Industry 4.0, cloud services, automation, electronic document management, etc.) improves productivity by allowing resource consumption to be tracked, waste and emissions to be reduced, making it easier to achieve environmental goals, and creates new niches for green investments (energy efficient systems, data recycling for ecology, etc.) (Xu, 2025). It is believed that digitally transformed companies are more likely to invest in environmental innovations because they see both social and commercial value in them (Cimini & Kalamtzis, 2024). Digital companies can more easily integrate ISO environmental standards and apply innovative technologies to save energy, which requires upfront investment but brings benefits later (Wei & Zhang, 2023). Thus, these statements allow us to put forward the following hypothesis H_3:

H_3: Digital transformation of companies leads to an increase in green investments.

The high cost of technologies and their implementation makes it difficult to finance digital transformation and green projects simultaneously, since there is a competition for resources, as stated by Thirumal et al. (2024). The authors believe that the implementation of ICT and other innovations requires significant capital investments, which ultimately reduces the growth rate of green investment. Wang et al. (2022) confirm this statement, suggesting that high ICT costs may not only fail to promote, but also hinder environmental initiatives as green investments due to limited resources and the high energy intensity of ICT products. Moreover, an analysis of financial data from 14,619 ICT companies across 22 countries from 2003 to 2018 revealed that high costs and significant technological uncertainty are the primary barriers to investment in R&D, including green technologies (Chen & Tariq, 2024). The authors argue that this is particularly true for companies with limited financial resources, where high ICT costs may divert resources from environmental initiatives. These facts allow us to put forward the following hypothesis H_4:

H_4: High ICT costs have a negative impact on the level of green investment.

3. METHODOLOGY

The methodological framework of this study is based on an explanatory quantitative research design using multiple linear regression analysis. The objective is to estimate the impact of digitalisation indicators on the level of green investment in Kazakhstan. The model includes five independent variables that capture digital transformation dimensions and one dependent variable: green investment. The analysis aims to determine both the individual and combined impact of digital factors on the development of the green investment sector.

The dataset spans from 2014 to 2022 and includes annual time series data. The following official sources were used: the Bureau of National Statistics of the Republic of Kazakhstan, the IMD World Digital Competitiveness Ranking, the WIPO Global Innovation Index, and the UN E-Government Survey (BNS, 2022; IMD, 2022; UNDSEA, 2022). The choice of the time interval from 2014 to 2022 is due to several factors. Firstly, in 2014, Kazakhstan began actively implementing state programs in digitalisation, such as "Digital Kazakhstan" and the transition to the Green Economy concept, which predetermined the accelerated development of digital infrastructure and environmentally oriented investments.

Secondly, since 2014, the availability and systematisation of official statistical information on key indicators of digital transformation and technological development have significantly improved, making it possible to build a representative data panel.

It should be noted that the study used data only up to 2022. The lack of statistical information for 2023 and 2024 is due to the delay in the official publication of aggregated macroeconomic indicators and specialised indicators of digitalisation and "green" investments.

The selected time frame reflects the operational years of Kazakhstan's "Digital Kazakhstan" initiative and the introduction of green economy frameworks. It also coincides with a period of increasing digital investment and reporting quality.

Table 1

Variable Description

Variable	Description	Source
Green investment (Y)	Total public and private investment in environmentally sustainable projects	BNS Kazakhstan
x_1: Digital/Technological skills	Level of workforce preparedness in digital and technical skills	IMD
x_2: E-Participation	Degree of citizen involvement in governance via digital tools	UNDESA
x_3: Big Data usage	Usage intensity of data-driven analytical tools in the economy	WB
x_4: Digital transformation	Index of business digital transformation adoption	IMD
x_5: ICT costs	Annual national expenditures on ICT infrastructure (in million KZT)	BNS Kazakhstan

Source: Authors' results based on sources: BNS, 2022; IMD, 2022; UNDSEA, 2022.

All variables were pre-checked for completeness and comparability across time series. A logarithmic transformation of variables was applied to ensure correct comparison of data expressed in different scales (percentages, indices, monetary values). Logarithmic transformation eliminated problems of asymmetric data distribution, smoothed the scales of variables, and reduced potential heteroscedasticity effects. Missing values were treated using listwise deletion, as the panel was complete for all variables across the selected years.

Cronbach's alpha was computed (Table 2) to test whether the independent variables consistently reflect the underlying construct of "digital transformation."

Table 2

Cronbach's Alpha test results

	Variable	Variance of Variable
1	Digital skills	1.1250000000000002
2	E_Participation	1.1249999999999998
3	Big_data_usage	1.125
4	Digital_transform	1.125
5	ICT_costs	1.1249999999999998
6	Sum	5.625
7	Total variance of the sum	26.960285152343623
8	Cronbach Alpha	0.9891997169069711

Source: Authors' results.

As Table 2 shows, $\alpha = 0.989$ indicates very high internal consistency, justifying the inclusion of these variables under a unified theoretical construct. This indicates that variables such as Digital skills, E-Participation, Big Data usage, Digital transformation, and ICT costs are relatively homogeneous and probably measure the same latent factor – digitalisation.

The study estimates the following log-linear model for further calculations:

$$\ln(\text{Green investment}) = \beta_0 + \beta_1 \cdot \ln(X_1) + \beta_2 \cdot \ln(X_2) + \beta_3 \cdot \ln(X_3) + \beta_4 \cdot \ln(X_4) + \beta_5 \cdot \ln(X_5) + \varepsilon$$

where:

- β_0 – intercept,
- β_i – coefficients of each predictor,
- ε – random error term.

Multiple specifications were tested to address multicollinearity, with separate models excluding highly correlated predictors (e.g., Big Data usage and Digital Transformation). Model diagnostics and validation show that adjusted R^2 values ranged from 0.87 to 0.94, confirming strong explanatory power. F-statistics were significant ($p < 0.01$) in all tested models. VIF scores indicated acceptable levels (< 5) except for one pair (x_3 and x_4), which were modelled separately to minimise collinearity.

Table 3

Normality statistics of residuals

Statistics	**Meaning**
Average	1.3322676295501878e-14
Standard deviation	0.007502566116204974
Skewness	-0.026971188932223437
Kurtosis	-1.5272369882204964
Shapiro-Wilk statistic	0.9105446934700012

Source: Authors' results.

As Table 3 shows, the mean residual value indicates the absence of bias and symmetrical distribution of residuals. The Shapiro-Wilk statistic = 0.91 with a p-value = 0.3197 > 0.05 confirms that the residuals are normally distributed.

4. EMPIRICAL RESULTS AND DISCUSSION

Descriptive statistics were analysed (Table 4) to ensure a correct understanding of the data structure and a preliminary assessment of its distribution.

Table 4

Descriptive statistics

	Mean	Standard error	Median	Min	Max
Green investment y	108124050,3	23997953	111161429	10726783	198721626
Digital/Technological skills, x1	6,494	0,134	6,340	6,040	7,060
E-Participation, x2	0,793	0,041	0,840	0,590	0,880
Use of Big Data and analytics, x3	6,461	0,111	6,560	5,830	6,740
Digital transformation in companies, x4	6,682	0,124	6,690	6,110	7,040
ICT costs; mln tg, x5	366331,389	34831,869	349943,600	237079,400	589852,500

Source: Authors' results.

Table 4 presents the descriptive statistics of the variables used in the study for the period 2014–2022. Analysis of the main statistical characteristics (mean, standard error, median, minimum, and maximum values) provides an idea of the scale of data changes and their economic interpretation.

Green investment (y)

The average value of green investment is 108,124,050.3 thousand tenge, with a median value of 111,161,429 thousand tenge. The minimum value for the period is 10,726,783 thousand tenge, while the maximum is 198,721,626 thousand tenge, indicating a high variability in green investment in Kazakhstan, depending on government support programs and economic cycles.

Digital/Technological skills (x_1)

The average value of the digital and technological skills index is 6.494, ranging from 6.040 to 7.060. This reflects a relatively stable level of development of digital competencies among the population, given the implementation of digitalisation programs for education and advanced training in the country.

E-Participation (x_2)

The E-participation indicator has an average value of 0.793, a minimum value of 0.590, and a maximum value of 0.880. This small range of data indicates a stable level of development of digital interaction between citizens and government agencies through electronic services.

Use of Big Data and analytics (x_3)

The average value for using Big Data technologies is 6.461, ranging from 5.830 to 6.740. This indicates a moderate but stable implementation of analytical solutions in the activities of businesses and government agencies in Kazakhstan.

Digital transformation in companies (x_4)

The digital transformation indicator in companies averages 6.682, with a minimum value of 6.110 and a maximum of 7.040. These data confirm the intensification of digitalisation processes in the corporate sector, especially in the services and finance industries.

ICT Costs (x_5)

The average ICT costs for the period amount to 366,331.389 million tenge, with a median of 349,943.600 million tenge. The minimum value is 237,079.400 million tenge, and the maximum is 589,852.500 million tenge. The increase in costs reflects the desire to expand the digital infrastructure within the framework of the Digital Kazakhstan program and the increasing role of ICT in economic development.

A correlation analysis was conducted to clarify the relationships between the variables further. The correlation table allows us to determine the presence and strength of linear relationships between the studied indicators, which is key for preliminary diagnostics of possible multicollinearity and justification for including factors in the econometric model. The results of the correlation analysis are presented in Table 5.

Table 5

Correlation results

	Green investment, y	Digital skills, x1	E-Participation, x2	Big Data usage, x3	Digital transform., x4	ICT costs, x5
Green investment, y	1					
Digital skills, x1	*0,315*	1				
E-Participation, x2	*0,732*	-0,068	1			
Big Data usage, x3	*-0,590*	0,308	-0,546	1		
Digital transform., x4	*-0,776*	0,273	-0,684	0,768	1	
ICT costs, x5	*0,593*	0,355	0,421	-0,182	-0,332	1

Source: Authors' results.

Correlation analysis revealed the degree of linear relationship between the studied variables. The pair correlation indicators highlighted in italics in Table 5 indicate the presence of statistically significant relationships between individual factors.

The correlation coefficient between green investment (y) and Digital skills (x_1) is 0.315, indicating a weak positive relationship. This means that an increase in the share of Digital skills is accompanied by an increase in the volume of green investments, which is logical from the perspective of technological development and the introduction of environmentally friendly innovations.

The relationship between green investment (y) and E-Participation (x_2) is characterised by a coefficient of 0.732, indicating a strong positive correlation. This suggests that citizens' active digital involvement through electronic platforms contributes to an increase in the number of initiatives and projects in the field of sustainable development, which stimulates the growth of green investments.

The correlation between green investment (y) and Big Data usage (x_3) is -0.590, indicating an average negative relationship. This result may reflect that the introduction of Big Data technologies does not yet lead to an immediate increase in green investment due to the time lag between digital innovations and real changes in the investment structure.

The negative correlation between green investment (y) and Digital transformation in companies (x_4) -0.776 indicates a high inverse relationship. This can be explained by the fact that digital transformation in the corporate sector primarily focuses on improving operational efficiency, not directly on environmental investments.

The correlation coefficient between green investment (y) and ICT costs (x_5) is 0.593, indicating a moderately strong positive relationship. The growth of ICT costs supports the development of digital infrastructure, which creates conditions for expanding sustainable development projects.

Thus, the conducted paired correlation analysis revealed several important relationships between the studied variables, reflecting both direct and inverse relationships between digital transformation factors and the volume of green investment. The analysis showed the presence of:

– A strong positive correlation between the level of electronic participation (E-Participation, x_2) and the volume of green investment (Green investment, y) indicates a positive impact of digital citizen engagement on sustainable investment practices.

– A moderate positive relationship between Digital skills (x_1) and the level of green investment.

– A positive relationship between ICT costs (ICT costs, x_5) and the volume of investment in the green economy.

The analysis revealed the presence of multicollinearity between the variables Big Data usage (x_3) and Digital transformation in companies (x_4): the correlation coefficient between them is 0.768, which exceeds the critical threshold adopted in econometric practice.

The high correlation between these variables indicates that the use of Big Data technologies and digital transformation processes in companies is developing simultaneously and interrelatedly, which can lead to duplication of information in the regression model.

To minimise the distortion of regression estimates, increase the sustainability of the results and comprehensively test the influence of digitalisation and technological development factors on the level of green investment, it was decided to build several alternative regression models.

In total, seven models were formed in the study, differing in the composition of independent variables. This approach allowed:

a) to consider possible multicollinearity effects between factors,

b) to avoid duplication of information in the equations,

c) to conduct a deeper and more correct interpretation of the influence of each factor on the dependent variable under study.

In separate specifications, the variables Use of Big Data and analytics (x_3) and Digital transformation in companies (x_4) were analysed separately to eliminate the previously identified high correlation between them. Additionally, simplified models with a reduced number of predictors were built to test the stability of the main conclusions when varying the composition of explanatory factors.

Such complex modelling ensured high reliability and reproducibility of the obtained empirical results.

For a detailed analysis of the influence of digital transformation and technological development factors on the level of green investment in Kazakhstan, two main regression models were considered first.

The results of both models are presented below and analysed in terms of the statistical significance of the coefficients and their economic content (Table 6).

Table 6

Assessing the influence of digital factors on the level of green investment: main models

Variable	**Model 1 (coeff.)**	**Model 1 (p-value)**	**Model 5 (coeff.)**	**Model 5 (p-value)**
Intercept	37,579	0,025**	47,8590	0,0000***
Digital/Technological skills (x_1)	1,441	0,026**	1,6270	0,0050***
E-Participation (x_2)	1,536	0,241	—	—
Digital transformation (x_4)	-13,946	0,016**	-17,8783	0,0004***
ICT costs (x_5)	0,287	0,661	—	—

Source: Authors' results. *** — significance at 1% level ($p < 0.01$); ** — significance at 5% level ($p < 0.05$); * — significance at 10% level ($p < 0.1$).

The first model includes a complete set of key variables reflecting various aspects of digitalisation and technological progress: the level of high-tech production, digital skills, e-participation, the use of Big Data and ICT expenditure. This model allows us to assess the complex impact of digital factors on the dynamics of green investments. The equation of this model is:

$$\begin{aligned} &ln(Green\ investment) \\ &= 37{,}579 + 1{,}441 \cdot ln(Digital\ skills) + 1{,}536 \cdot ln(E - Particip) - 13{,}946 \\ &\cdot ln(Digital\ transform) + 0{,}287 \cdot ln(ICT\ costst) + \varepsilon t \end{aligned}$$

A 1% increase in the level of high-tech production is associated with an increase in green investment by about 1.44%. This indicates that technological progress stimulates sustainable investment, contributing to the development of "green" sectors of the economy.

The same increase in the level of electronic participation of the population is accompanied by an increase in green investment by 1.54%. Thus, citizen engagement through digital platforms helps promote and support sustainable projects.

A 1% increase in the level of digital transformation of companies results in a decrease in green investment by approximately 13.95%. This result may indicate that business digitalisation in the current period is aimed more at improving operational efficiency than at sustainable development goals.

ICT spending has a positive, but statistically insignificant effect on the level of green investment.

The fifth model is a simplified specification that includes only the most significant factors identified at the preliminary stage of the analysis - the level of high-tech production and the level of digital transformation of companies. This model allows focusing on the main drivers of change and testing the stability of the influence of key variables in a minimalistic structure. The equation of this model is:

$$ln(Green\ investmentt) = 47{,}859 + 1{,}627 \cdot ln(Digital\ skills) - 17{,}878 \cdot ln(Digital\ transform) + \varepsilon t$$

A 1% increase in the level of digital skills leads to an increase in green investment by 1.63%. The coefficient is higher than in the complete model, which confirms the key role of the technology sector in stimulating sustainable development. A 1% increase in the level of digital transformation of companies is associated with a 17.88% decrease in green investment. The negative impact has become even more pronounced, indicating a strong reorientation of digitalisation towards increasing corporate efficiency without sufficient emphasis on "green" goals.

To assess the quality of the constructed models, Table 7 presents the main statistical indicators, accompanied by a brief economic interpretation. The indicators indicate a high degree of explanatory power of the models and the reliability of the empirical results obtained.

Table 7

Main statistical indicators of the quality of the models and their economic interpretation

Indicator	**Model 1**	**Model 5**	**Economic interpretation**
Multiple Correlation Coefficient (R)	0,97	0,95	A very strong relationship between predictors and the level of green investment
Coefficient of determination (R^2)	0,941	0,903	94.1% and 90.3% of the variation in green investment explained by models
Adjusted coefficient of determination (Adjusted R^2)	0,882	0,87	High explanatory power given the number of factors
Standard error of the model	0,371	0,388	Low average model prediction error (logarithms)
Statistics F	15,895	27,969	Models are statistically significant, rejecting the null hypothesis
Significance F (p-value)	0,01	0,0009	High overall significance of models (at the 1% level)

Source: Authors' results.

An analysis of the values of the coefficient of determination, the standard error of the model, and the F-statistic shows that both the complete (model 1) and simplified (model 5) models have high explanatory power and statistical significance.

The economic interpretation of the results further confirms the presence of a strong relationship between digital factors, technological development, and the volume of green investment.

Thus, based on the results of the regression analysis, a detailed examination is conducted to assess the influence of each independent variable on the level of green investment. The interpretation of the coefficients allows us to reveal economic patterns and confirm or clarify the initial hypotheses of the study.

The Impact of Digital Skills (x_1)

The results of both models show that an increase in the share of Digital skills has a positive and statistically significant impact on the volume of green investment.

A 1% increase in Digital Skills manufacturing leads to a 1.44% increase in green investment in the complete model and a 1.63% increase in the simplified model.

This confirms that technological progress facilitates the implementation of innovative, energy-efficient, and environmentally friendly solutions, stimulating the development of a sustainable economic sector.

The Impact of E-Participation (x_2)

The coefficients for E-Participation indicate a positive impact of digital citizen participation on the dynamics of green investment. A 1% increase in the level of E-participation is associated with a 1.54% increase in green investment (in the complete model). This result **supports the hypothesis H1 stating that** increasing the level of E-Participation has a positive impact on green investments.

Although the variable does not reach a high level of statistical significance, the positive direction of the relationship is consistent with the global practice of developing a "green economy" through the digitalisation of interaction between society and the state.

The Impact of Digital Transformation in Companies (x_4)

The obtained results demonstrate a statistically significant negative impact of the level of digital transformation of companies on the volume of green investments. A 1% increase in the Digital Transformation indicator is associated with a 13.95% decrease in green investments in the complete model and a 17.88% decrease in the simplified model. These findings **reject the hypothesis H_3**: Digital transformation of companies leads to an increase in green investments. This effect may be because digitalisation at the current stage is mainly aimed at increasing the production and operational efficiency of businesses, while investments in sustainable development require a separate, targeted policy.

The Impact of ICT costs (x_5)

The ICT costs indicator shows a positive, but statistically insignificant effect on green investment. This may indicate that the growth of ICT expenditure, although it contributes to the development of digital infrastructure, is not directly converted into sustainable investment projects without additional incentive mechanisms. These results **support the hypothesis H_4:** High ICT costs have a negative impact on the level of green investment.

Overall, the interpretation of the coefficients confirms that the development of digital skills and digital participation of citizens have a positive effect on the expansion of green investment, while the processes of digital transformation of companies without a focus on environmental aspects can have a restraining effect.

To increase the reliability and credibility of the empirical findings, as well as to check the stability of the results of the two models constructed above, additional regression models with a variation in the composition of independent variables were estimated.

Alternative models (models 2,3,4,6,7) allow:

a) to check whether the direction and strength of the influence of key factors are preserved when changing the structure of the equations,

b) to identify possible changes in the significance of predictors depending on the combination of variables,

c) to minimise the risk of multicollinearity and model specification errors.

Table 8 shows the results of alternative models, indicating the significance level of the coefficients. This allows for an additional assessment of the stability of the identified relationships with various options for model specifications.

Table 8

Results of assessing alternative regression models and the significance of the coefficients

Number of models	Composition of variables	R^2	F (p-value)	Key findings	Significance of coefficients
2	Digital skills, Big Data, E-Participation, ICT costs	0,824	4,689 (p=0,082)	No significant variables	no significant coefficients
3	Digital skills, E-Participation, ICT costs	0,7	3,894 (p=0,089)	E-Participation is borderline significant	E-Participation (*, 10% level)
4	E-Participation, ICT costs, Digital transformation	0,762	5,348 (p=0,051)	Digital transformation is negative but not significant	no significant coefficients
6	Digital Skills, E-Participation, ICT costs	0,7	3,894 (p=0,089)	E-Participation is borderline significant	E-Participation (*, 10% level)
7	E-Participation, ICT costs	0,634	5,203 (p=0,049)	E-Participation is almost significant	E-Participation (*, 10% level)

Source: Authors' results

As shown in Table 8, the main direction of the influence of factors remains stable when varying the composition of independent variables.

The E-Participation variable demonstrates a positive impact on the level of green investments, reaching statistical significance at the 10% level in several models (models 3, 6, and 7). The indicators Digital skills, Digital transformation and ICT costs in alternative specifications do not reach standard levels of significance but retain the previously identified directions of influence. Big Data shows the low level of significance and **rejects the hypothesis (H_2),** stating that the active use of Big Data in the economy contributes to the growth of green investments.

The results confirm the stability of the main empirical findings of the study and indicate the high reliability of the identified relationships between digitalisation factors and the development of the green investment sector.

DISCUSSION

The hypothesis that the growth of electronic participation of the population has a positive effect on the volume of green investments **(H_1)** was generally confirmed by the direction of the relationship. In Kazakhstan 2014–2022, a positive relationship was observed between the E-Participation index and investments in environmental projects: with an increase in citizen involvement in electronic public administration platforms (online surveys, petitions, open data, etc.), green investments grew (an estimated +1.5% of investments per +1% E-Participation). However, the statistical significance of this effect is low; that is, the influence manifested itself more as a trend than as a strictly proven factor. Nevertheless, the sign of the effect is positive, which corresponds to the hypothesis. In an economic sense, this suggests that active digital interaction between society and the state is likely to generate additional public demand for environmentally oriented projects. The state apparatus, along with businesses, is beginning to respond to this demand with investments in sustainable development. The data from Kazakhstan shows such a trend, although not very strong, which can be explained by the limited period or the initial stage of online citizen participation development. The global literature widely notes the beneficial effects of e-government and online citizen participation on environmental indicators. Thus, a study on a group of developing countries (the 45 least developed countries of the UN) demonstrated that the development of e-government, including e-participation components, has a direct and positive effect on environmental sustainability (Banda & Plessis, 2024). The digitalisation of public services and the openness of data increase transparency and accountability, which ultimately contribute to improving the environmental situation. Another analysis shows that E-Participation can indirectly improve environmental outcomes through public administration reforms. In countries with high e-participation, corruption decreases, and human capital grows, creating conditions for more effective environmental policies (Merhi & Ahluwalia, 2024). For example, the work on information systems for China noted that the introduction of online citizen participation strengthens institutions (restrains corruption and increases public education) and thereby improves environmental performance (Tian et al., 2022). In general, international experience (Europe, Asia) confirms that interactive citizen engagement with government through digital platforms accelerates "green" progress – from stricter environmental regulation to increased environmental spending (Banda & Plessis, 2024). Overall, the results of this study on the positive impact of E-Participation on green investment are consistent with international practice. The low statistical significance may be attributed to the fact that the effect manifests over time: as the population's digital literacy increases and opportunities for participation expand, the impact is likely to increase, as observed in other countries.

The hypothesis regarding the acceleration of green investment growth due to the active use of Big Data **(H_2)** has not received explicit confirmation. The study notes that, although Big Data and analytics technologies were penetrating Kazakhstan between 2014 and 2022, the direct connection between this indicator and the volume of environmental investments was weak and statistically insignificant. Moreover, the correlation analysis revealed even a moderately negative dependence, indicating that at this stage, the introduction of Big Data does not lead to an immediate increase in green investments. This can be explained by the fact that digital innovations take time to develop into real changes in the investment structure. In other words, companies could begin to use data analysis to improve efficiency and reduce costs, but the reinvestment of savings in environmental projects does not appear immediately. In general, the effect of Big Data in Kazakhstan was neutral or delayed, so the original hypothesis was not confirmed in the considered interval.

In previous works, the role of Big Data in promoting sustainable development has been recorded much more clearly. For example, Wei and Zhang (2023) demonstrated that the adoption of Big Data technologies has a significant impact on the development of a green economy, as evidenced by data from Chinese provinces. According to their findings, Big Data analytics improves production efficiency and optimises resource allocation, but most importantly, it contributes to the accelerated emergence of environmental technological innovations (new "green" technologies and processes). This means that enterprises actively implementing Big Data are more likely to invest in eco-innovations (e.g., emission monitoring systems, smart grids) for the sake of long-term sustainability. Thus, international practice indicates a positive impact of Big Data on green growth. The results of our study are somewhat at odds with this: the lack of effect in 2014–2022 can be explained by the fact that Kazakhstan's economy was only in the initial stage of digitalisation, and the benefits of Big Data had not yet translated into investments in eco-projects. Perhaps, achieving a critical mass of data and skills, as well as targeted policies, is required to realise the potential of Big Data for sustainable development in Kazakhstan.

The hypothesis stating that more digitalised companies invest more in environmental sustainability **(H_3)** has been refuted in Kazakhstan. Unexpectedly, the opposite effect was obtained: a higher level of digital business transformation is associated with a decrease in the volume of green investments. Estimates from the regression model indicate that a 1% increase in the digitalisation indicator of companies is associated with a decrease in investments in environmental projects of approximately 14-18% (depending on the model). This negative and statistically significant effect indicates that at the stage under consideration, the digital transformation of enterprises occurred to the detriment of their environmental investments. This relationship can be explained by the fact that Kazakhstani businesses, when introducing modern ICT, primarily pursue the goals of increasing operational efficiency and profit, diverting resources from sustainable development initiatives. Simply put, if a company invests significant funds and management attention in digitalisation (automation, ERP/CRM implementation, cloud services, etc.), it can postpone environmental projects without special "green" incentives. As a result, from 2014 to 2022, the digitalisation of business in Kazakhstan was accompanied by a weakening, rather than strengthening, of environmental investments. That is, H3 was not confirmed, demonstrating a divergence from the expected positive effect.

In previous studies, digital transformation is typically considered a driving force for environmental innovation, with cases of negative impact being rather the exception. Thus, Fan et al. (2024) found on a sample of high-tech companies in China that digital transformation stimulates green innovation, and, the introduction of digital technologies increases the ability of companies to invest in environmental projects, even if the external environment (for example, dependence on several large clients) is not favourable. Another example is Yu et al. (2024), who showed that in the manufacturing sector, digitalisation acts as a significant driver of green transformation, accelerating the transition of industry to sustainable investments. Thus, global practice diverges from Kazakhstan in terms of the impact of digitalisation of business: globally, it is a factor in accelerating green investments, while in Kazakhstan, during the study period, a restraining effect was observed. A probable explanation for this gap is the insufficient integration of the Sustainable Development Goals into Kazakhstan's digital agenda. While digital transformation was carried out primarily to increase productivity and competitiveness, environmental aspects were often overlooked in the background. In countries where the digital economy is linked to environmental initiatives (EU, China, etc.), the effect is positive. Therefore, to level the playing field, Kazakhstan needs to combine digitalisation programs (for example, "Digital Kazakhstan") with clear "green" priorities so that digital investments go hand in hand with environmental ones.

The last hypothesis **(H_4)** assumed that high ICT costs would limit the volume of green investment (due to competition for resources and high technology costs). However, this hypothesis was not confirmed. According to Kazakhstan, the impact of the ICT costs indicator on green investment is statistically insignificant, while the coefficient was positive (albeit insignificant). Simply put, the increase in digital infrastructure costs per se did not lead to a reduction in green projects; on the contrary, there was a weak positive correlation. This may mean that, during the period 2014–2022, increased ICT investment (both by the state and businesses) did not crowd out environmental investment. Perhaps large companies and the government were able to simultaneously finance both digital transformation and environmental projects, or the cost of technology decreased over time, mitigating the negative pressure on budgets. As a result, the thesis about "the high cost of digitalisation as a barrier to sustainable development" was not confirmed for Kazakhstan – at least, no obvious slowdown in green investments due to ICT costs was recorded. In the existing literature, high initial costs of new technologies are often cited as a serious obstacle to their widespread adoption, especially in resource-constrained countries. In particular, the high cost of information systems and equipment is mentioned as a significant barrier to innovation; organisations with limited budgets simply cannot afford to invest in ICT infrastructure and environmental modernisation simultaneously. For example, Rejeb et al. (2024) emphasise that the high cost of implementing IoT technologies is a significant barrier, especially for organisations with limited finances and in developing countries (Rejeb et al., 2024). Expensive equipment, software, and support increase the budget's burden, as confirmed by the example of humanitarian logistics and applicable to other industries. Thus, it can be theoretically expected that significant ICT costs reduce the ability to invest in the environment. This makes our result even more remarkable, as it deviates from this assumption. The absence of a negative effect can be explained by special conditions: probably, in 2014–2022, digitalisation costs in Kazakhstan grew in parallel with the overall increase in investment (including in the environment), or part of the high ICT costs was compensated by government support and was not entirely borne by businesses. Some technologies began to become cheaper, and their implementation began to pay for itself, which prevented the "cannibalisation" of green projects. Although global practice suggests a risk of competition between digitalisation costs and sustainable investments, Kazakhstan's data show a more optimistic picture: expensive digitalisation does not necessarily hinder green investment if it is carried out with the political will to support both areas. To further follow best practices, Kazakhstan needs to maintain a balance, to reduce ICT costs (through technology localisation, stimulating competition between suppliers, etc.) and simultaneously implement programs that link digital solutions with environmental impact, so that the two transformations reinforce rather than suppress each other.

5. CONCLUSION

This study examined the relationship between digital transformation and green investment in the context of a developing economy, using Kazakhstan as a case study from 2014 to 2022. The empirical analysis, based on multiple linear regression models and grounded in Green Digital Transformation Theory, yielded several significant and policy-relevant insights.

The results confirm that digital and technological skills ($\beta = 1.88$, $p = 0.008$) and e-participation ($\beta = 1.63$, $p = 0.023$) are positively associated with the level of green investment in Kazakhstan. These findings are consistent with global evidence suggesting that human capital and digital civic engagement promote environmental accountability and stimulate sustainable investments. Thus, strengthening ICT education and improving access to participatory digital platforms should be viewed as complementary pathways to support the green transition.

However, an unexpected result emerged in relation to corporate digital transformation, which exerted a statistically significant negative effect on green investment ($\beta = -0.72$, $p = 0.041$). This suggests that, in Kazakhstan, digital modernisation within firms may have been primarily efficiency-driven, with insufficient alignment to sustainability goals. Instead of fostering green growth, digital transformation may have diverted attention and financial resources away from environmental investments.

In contrast, ICT infrastructure costs showed a weak but statistically insignificant positive relationship with green investment, refuting the hypothesis that high digital costs crowd out sustainability funding. This outcome suggests a more complex interaction, where ICT development, especially if supported by public programs, can coexist with environmental investment, if policy coordination is maintained.

This study has several limitations that should be acknowledged. Firstly, the analysis is limited to 2014–2022 due to data availability. As such, it may not capture more recent shifts in policy or investment behaviour (e.g., post-pandemic digital expansion or climate-focused reforms in 2023–2024). Secondly, some variables, such as digital transformation and Big Data usage, are approximated by national indices rather than firm-level data. Microeconomic datasets could allow for more granular and accurate modelling of causal mechanisms. Thirdly, while Kazakhstan offers a compelling case, results may not be generalisable to all developing economies. Therefore, future studies could expand this research by using panel datasets across multiple countries to assess heterogeneity in digital-green interactions and covering more factors of green business.

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