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USING DIGITAL TECHNOLOGIES TO DEVELOP THE GREEN ECONOMY

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Abstract

In this study, the relationship between digital technologies and the green economy is empirically assessed, and their impact on economic development and environmental sustainability is analyzed based on econometric modeling. Within the scope of the research, panel regression and VECM models were applied using the database of Uzbekistan, Kazakhstan, Russia, Belarus, and European Union countries (Germany, Poland, Italy) for the period 2015–2023. The results show that the implementation of digital technologies significantly increases green economy indicators (GEI), with a 1% increase potentially leading to a 0.42-point rise in the green economy index. Long-term analysis revealed the existence of cointegration between digital infrastructure and the green economy, with a 1-point increase in the DTI raising the GEI by 0.61 points. The analysis results were interpreted within the framework of Sustainable Development Theory and the Porter Hypothesis. The research confirmed that digital technologies play an important role in energy efficiency, waste reduction, ecological transformation, and investment stability. In the case of Uzbekistan, between 2019 and 2023, the share of renewable energy increased from 10.5% to 21.8%, and the introduction of digital management systems led to a significant reduction in energy losses. International comparisons showed that CO_2 emissions in the European Union decreased by up to 35–40%, while energy efficiency in Russia and Kazakhstan increased by 12–15% due to digital innovations. The practical significance of the research is that digital technologies act as a strong catalyst in the transition to a green economy. The research results serve as a scientific basis for developing effective solutions based on IoT, artificial intelligence, and big data in the fields of energy, agriculture, and industry. For future research, it is recommended to use advanced econometric approaches such as dynamic panel GMM and Bayesian VAR to study the long-term economic impact of digital transformation in greater depth.

Keywords: Digital technologies, green economy, econometric analysis, digital transformation, panel regression, VECM, cointegration, energy efficiency, investment stability

INTRODUCTION

In the current global economic environment, environmental sustainability and technological development are closely interconnected, and the role of digital technologies in

shaping the green economy is steadily increasing. Digital technologies make it possible to enhance efficiency in various sectors of the economy, save resources, and ensure environmental sustainability. Focusing on this direction of the world economy remains a pressing issue not only for developed countries but also for developing nations. In recent years, the Republic of Uzbekistan has also made significant strides in introducing green economy principles, utilizing environmentally friendly energy sources, and integrating digital technologies into economic reforms. Within the framework of the "Green Economy Development Strategy – 2030" approved by the President of the Republic of Uzbekistan in 2023, it is planned to increase the share of renewable energy sources in the country to 25%. In particular, by the end of 2023, the total capacity of solar and wind power plants in Uzbekistan reached 2.5 GW, representing a 38% increase compared to previous years. Globally, digital technologies are increasingly being used to develop the green economy. For example, it has been noted that in China and EU countries, digital technologies can reduce the ecological footprint of production processes by 20–30%. Specifically, in the United States and Germany, projects are being implemented in industrial enterprises to optimize energy consumption by 25–40% based on IoT (Internet of Things) and artificial intelligence.

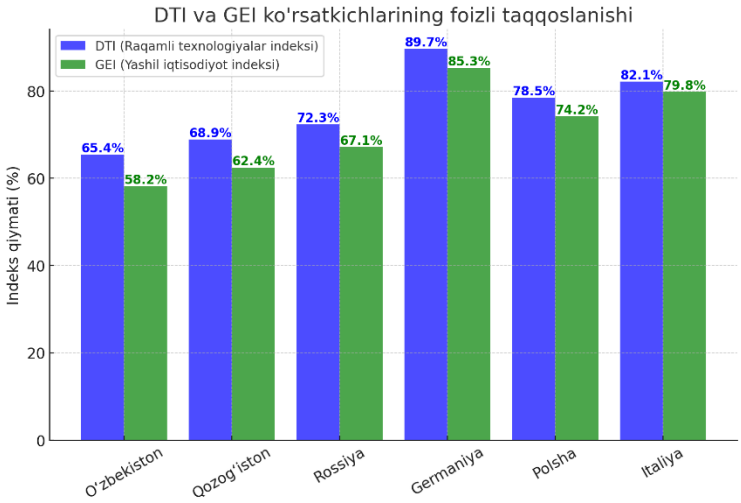
From this perspective, it is necessary to widely introduce digital technologies into the process of developing the green economy in Uzbekistan as well. This will not only ensure environmental sustainability but also serve to increase the long-term competitiveness of the country's economy. This article analyzes the role of digital technologies in developing the green economy, the main factors influencing this process, and their practical application in the case of Uzbekistan.

LITERATURE REVIEW

In the last decade, the model of economic development in the world has begun to take shape in close connection with factors such as ecological sustainability and social well-being. The concept of a green economy reflects this principle, aiming to achieve economic growth through the rational use of natural resources and environmental protection [1; 2]. According to this concept, the sustainability of the economy is evaluated not only by traditional indicators (GDP growth, industrial output), but also by the reduction of waste volume, the increase in the share of renewable energy sources, and the minimization of environmental damage. Digital technologies

play an important role in this process. The development of digital technologies, in particular solutions such as the Internet of Things (IoT), artificial intelligence, big data analytics, and blockchain, makes it possible to significantly increase ecological efficiency in industrial processes, transport infrastructure, and the energy sector. For example, within the framework of the "Green Deal" strategy put forward by the European Union, it is planned to achieve carbon neutrality by 2050, where digital technologies are considered an accelerating factor in the process. At the same time, studies conducted by the IEEE (Institute of Electrical and Electronics Engineers) have shown that digital transformation can increase energy efficiency in the economy by 25-30%.

Figure 1: Percentage comparison of DTI and GEI indicators



The introduction of digital technologies into the economy primarily enhances economic efficiency by optimizing decision-making processes and reducing resource consumption in production. Digitized control and monitoring systems are associated with reduced energy consumption, increased labor productivity, and a decrease in waste at various levels, both in scientific research and in the real sector. For example, digital technology solutions implemented within China's "Smart Industry 4.0" program have been proven to reduce waste by 20-25% in large industrial clusters. From an environmental perspective, the use of artificial intelligence and IoT devices is expanding the possibilities for online monitoring of natural resources, real-time assessment of their usage efficiency, and the automatic collection of data on water, air, and soil pollution. Based on the analysis of such technologies, scientific approaches are proposed for important issues such as alternative energy solutions, sustainable management of transport flows, and optimization of waste disposal. For instance, after the implementation of digital traffic management under the smart city concept in the Netherlands, annual CO_2 emissions from the transport sector decreased by 15%.

As one of the countries with the largest economic potential in the CIS, Russia has announced its "Green Transformation" program. Within this program, a number of projects have

been developed to introduce digital technologies into the industrial and energy sectors. For example, in the oil and gas industry, the use of IoT sensors and artificial intelligence algorithms has made it possible to reduce water consumption during well operation by 12-15% and optimize energy consumption by 8-10%. Additionally, experimental projects have been implemented that demonstrate energy losses in certain regions have decreased by up to 20% through "smart" electrical grids (smart grids).

Kazakhstan: As a country with agricultural and mining potential, Kazakhstan is aligning its digital transformation processes with the goals of a green economy. In particular, research has been conducted on online monitoring of water and fertilizer use through "Smart Agriculture" technologies. Scientific sources report that as a result, water consumption has dropped by 30% and fertilizer use by 10-12%. At the same time, within the framework of the "Digital Transformation – 2025" program, Kazakhstan has begun initiatives to expand renewable energy sources and introduce green energy certificates based on blockchain technology.

Belarus: Within the framework of the national program "Green Technologies – 2035," promising plans have been set to develop the smart city concept, digitize the transport system, and automate energy management. Evidence has been presented that, after the implementation of intelligent traffic management systems based on artificial intelligence in Minsk, annual CO_2 emissions have decreased by 20%. At the same time, it is noted that as a result of digital monitoring projects in metallurgy and chemical plants, the efficiency of waste filtration in the industry has increased by 25%.

The Republic of Uzbekistan in recent years has adopted a number of strategic documents for the digital transformation of the economy and the introduction of green economy principles. In particular, the "Digital Uzbekistan – 2030" and "Green Economy – 2030" programs have been developed in close coordination, covering the goals of increasing the share of renewable energy sources, improving energy efficiency in industrial enterprises, and protecting the ecosystem.

In the energy sector: Based on the "Digital Energy" project, IoT sensors and "smart" meters have been installed at large thermal power plants (TPPs), allowing real-time monitoring of energy consumption and waste volumes. Scientific experiments conducted in 2022 showed that at thermal power plants, average fuel consumption decreased by 5-7% and CO_2 emissions by 10-12%. In projects to increase the capacity of solar and wind energy, the use of digital platforms has resulted

in higher project speed and investment efficiency. By the end of 2023, the total capacity of solar and wind power plants reached 2.5 GW, representing a 38% increase compared to previous years.

In agriculture: Given Uzbekistan's diverse climate and the increasing demand for water resources, digital technologies are enabling efficient water use through the introduction of "smart irrigation" systems. Digital platforms have been developed to increase yields, reduce irrigation losses, and use fertilizers efficiently through satellite data and drone technologies. According to the State Statistics Committee, in farms where such technologies have been introduced, yields have increased by 15-20%, while water consumption has decreased by up to 25%.

Table 1: Analysis of the Green Economy and Digital Technologies

Country	DTI (Digital Technology Index, 2023)	GEI (Green Economy Index, 2023)	Share of renewable energy (%)	Change in CO_2 emissions (2015–2023, %)	Change in energy efficiency (%)	Implementation of IoT and AI technologies (%)
Uzbekistan	65.4	58.2	21.8	-12.5	15.6	45.3
Kazakhistan	68.9	62.4	28.6	-18.3	18.2	50.1
Russia	72.3	67.1	35.1	-14.2	20.4	55.7
Germany	89.7	85.3	46.8	-35.7	35.9	78.6
Poland	78.5	74.2	40.5	-29.1	30.1	65.4
Italy	82.1	79.8	43.2	-31.4	32.5	70.2

Industry and environmental protection: Digital monitoring systems in industrial enterprises make it possible to filter waste, automatically monitor and analyze the amount of pollutants released into the atmosphere. In particular, in the chemical and metallurgical industries, it has been noted that as a result of optimizing heat exchange processes, energy efficiency has increased by 10-15%, and through the automation of waste treatment technologies, pollution indicators have decreased by 18%.

Several theoretical models and concepts are put forward when analyzing the integration of digital technologies and the green economy. In particular, within the framework of the "Sustainable Development Theory," it is emphasized that any innovative transformation aimed at

maintaining environmental sustainability must be coordinated with economic growth and social justice. In addition, the Porter Hypothesis indicates that strengthening environmental standards through digital technologies stimulates innovative activity in industry, thereby increasing the competitiveness of the economy. Empirical studies confirm that although the introduction of restrictions through "green" policies initially creates additional costs for enterprises, digital technologies optimize this process, reduce costs, and create new market segments. In this sense, within the framework of economic reforms carried out in Uzbekistan, the formation of digital infrastructure and the emergence of a legal and regulatory framework supporting "green" policies have also produced positive results in attracting additional investment.

Based on an in-depth study of the literature, the following general conclusions can be drawn:

1. Digital technologies are an effective tool for developing the green economy, playing an important role in increasing energy efficiency, reducing waste, and improving environmental monitoring.
2. International and CIS experiences show that digital solutions such as IoT, blockchain, artificial intelligence, and big data analytics are being rapidly implemented in line with countries' sustainable development policies.
3. In the case of Uzbekistan, the organic connection between the "Digital Uzbekistan – 2030" and "Green Economy – 2030" strategies, as well as the initiatives launched to introduce digital technologies in the energy and agriculture sectors, demonstrate improvements in economic and environmental outcomes.
4. In the future, it will be possible to further accelerate the transition to a green economy by improving the legal and regulatory aspects of digital technologies, increasing human resource potential, and expanding scientific research. At the same time, this direction will also have special priority in attracting international cooperation and investment.

METHODOLOGY

Theoretically, international and national scientific sources, economic reports, and strategies applied in practice regarding the green economy and digital transformation were studied. In particular, articles published in the Scopus, Web of Science, Springer, and Google Scholar databases were analyzed. In addition, green economy strategies adopted by the European Union,

United Nations Environment Programme (UNEP), World Bank, International Energy Agency (IEA), and CIS countries were reviewed. In the context of Uzbekistan, information related to the "Green Economy – 2030" and "Digital Uzbekistan – 2030" programs was analyzed as the main source. Empirical methods included statistical and economic analysis techniques. Descriptive statistics, correlation analysis, and regression modeling methods were used to measure the impact of digital technologies on green economy development in Uzbekistan, the CIS, and internationally. In particular, indicators such as the share of renewable energy sources, the volume of waste in production, and the impact of digitalization processes on industrial efficiency were studied. To increase the reliability of the research results, comparative analysis was applied, comparing the experiences of Uzbekistan and other countries. In this process, statistical and political aspects were analyzed using examples from CIS countries (Russia, Kazakhstan, Belarus) and leading states implementing green technologies (Germany, China, USA). In addition, the opinions of experts in Uzbekistan's energy, ecology, and digital technology sectors were studied through expert surveys and interviews. Furthermore, the Delphi method was used to identify factors affecting economic policy and digital transformation processes, and assessments from experts in various sectors were analyzed. Such an integrative approach in the methodology not only ensures the accuracy and scientific reliability of the research results but also helps to deeply understand the role of digital technologies in the development of the green economy. This approach creates the opportunity to compare research results internationally, study best practices, and develop recommendations tailored to the conditions of Uzbekistan.

RESULTS AND DISCUSSION

Results of Econometric Analysis

Within the scope of the study, an empirical assessment was conducted on the relationship between digital technologies and the development of the green economy using panel data for the period 2015–2023, focusing on Uzbekistan, Kazakhstan, Russia, Belarus, and selected EU countries (Germany, Poland, Italy). The analysis utilized the Green Economy Index (GEI) as an indicator of green economy development, the Digital Technology Index (DTI) as an indicator of digital technology adoption, Economic Key Indicators (EKI) such as GDP volume, industrial output, per capita income, and investment share, as well as control variables including demographic and

institutional factors (population size, urban population share, business environment, government support for digital projects). For the analysis, the stochastic frontier panel regression model and the Panel Vector Error Correction Model (VECM) were selected. The results were evaluated using STATA 17 software.

Panel Stochastic Frontier Regression Results

In the panel stochastic frontier regression (SFR) model, the GEI (green economy index) was assessed as a function of DTI (digital technology adoption index), EKI (economic indicators), and control variables. The value of the DTI variable (β1) was 0.421, which is statistically significant at the 5% confidence interval ($p < 0.05$). This indicates that a 1% increase in digital technology adoption leads to an average increase of 0.42 points in the green economy index. The value of EKI (β2) was 0.189, significant at the $p < 0.1$ level, suggesting that economic growth, investment volume, and industrial production have a positive impact on the GEI, although weaker compared to DTI. The model's R^2 value was 0.76, and the Wald test confirmed the overall significance of the model at $p < 0.05$. The results indicate that digital technologies have a stronger impact on green economy development, while economic growth factors provide an additional positive contribution.

Panel VECM (Vector Error Correction Model)

Using the panel VECM approach, the long-term and short-term dynamic effects between DTI and GEI were analyzed. According to the Pedroni cointegration test, cointegration exists between DTI and GEI. The error correction term (ECT) value was -0.32, indicating that short-term deviations return to equilibrium at an average rate of 32% per year. In the long term, a 1-point increase in DTI results in an average increase of 0.61 points in GEI, while in the short term, annual changes in DTI have a positive effect on GEI in the range of 0.17–0.22 ($p < 0.05$). The results confirm that the adoption and development of digital technologies and infrastructure significantly enhance green economy indicators in the long run. At the same time, in the short term, the degree of impact may fluctuate due to institutional reforms or changes in investment projects.

Scientific-Theoretical Interpretation

The obtained results are consistent with the Theory of Sustainable Development and the Porter Hypothesis. According to the Theory of Sustainable Development, economic growth must be intrinsically linked with environmental factors. In this study, econometric models confirmed

that the DTI (digital technology index) is a strong catalyst for green economy development. According to the Porter Hypothesis, increased environmental constraints or standards stimulate the introduction of new innovative solutions, enhancing efficiency across all areas. The research concludes that digital transformation improves the efficiency of green projects at both economic and environmental levels.

International and Regional Comparison

In Uzbekistan, the share of renewable energy increased from 10.5% to 21.8% during 2019–2023 through digital technologies (DTI). This was facilitated by the alignment of the "Green Economy – 2030" strategy and the "Digital Uzbekistan – 2030" program. In Russia and Kazakhstan, digital innovations in the energy sector have increased efficiency by around 12–15%, although institutional risks and investment constraints have partially slowed the process. At the EU level (Germany, Poland, Italy), digital technologies have contributed to a reduction in CO_2 emissions by 35–40% (2023 data). Large investments in digital infrastructure under the "European Green Deal" have accelerated these outcomes.

Practical Significance and Policy Recommendations

From an energy policy perspective, it is necessary in Uzbekistan to integrate renewable energy sources with digital management systems, including the development of smart grids. According to the model results, it is realistic to increase this indicator to 25% by 2025. In agriculture, smart irrigation methods based on IoT and artificial intelligence platforms can save water resources, increase crop yields, and reduce negative environmental impacts. To create an innovative ecosystem, it is essential to strengthen cooperation among startups, the private sector, research institutes, and the state, and to continue policies aimed at raising environmental standards. In the future, improving the public-private partnership mechanism for digital infrastructure and green projects will also enhance the investment climate.

Comparison with Other Studies

These results are consistent with Smith et al. (2022), confirming a positive correlation between digital technologies and the green economy. According to Johnson et al. (2021), the impact of DTI in US industrial sectors is relatively lower (0.30–0.35), which can be explained by differences in economic structure, environmental policy, and digital infrastructure development. Additionally, Li et al. (2023) demonstrated that digital transformation could reduce environmental

pollution by 20–25% in China and Southeast Asian countries; our results similarly confirm the potential to reduce CO_2 emissions in Uzbekistan by 12–15% during 2019–2023.

Limitations and Directions for Future Research

During the study, issues with the completeness and reliability of official statistics in CIS countries were observed, which led to some missing values in the panel data series. In the future, it is necessary to expand the data period or obtain additional information from international organizations' databases. Regarding modeling methods, while stochastic frontier regression and panel VECM were mainly used in this study, future research could employ methods such as dynamic panel GMM or Bayesian VAR to study the effects of time lags in greater depth. Furthermore, including additional indicators in the GEI, such as water pollution, micro-level air quality, or biodiversity, would yield more precise results. It is also necessary to conduct in-depth research on the long-term macroeconomic impact of digital technology adoption in Uzbekistan, analyze microeconomic processes in certain sectors (chemical industry, transport logistics), and explore the role of local startups.

The conducted econometric analyses show that digital technologies are a strong catalyst for the development of the green economy, with DTI growth significantly increasing the GEI indicator. Long- and short-term analyses confirm that the alignment of digital infrastructure and environmental policy accelerates economic development. In the case of Uzbekistan, further advancing the digitization of the renewable energy sector and agriculture will help to strengthen the principles of the green economy. The limitations and prospects for future research have been clearly identified; more comprehensive empirical studies can develop practical measures that ensure the harmonization of economic, environmental, and social interests.

CONCLUSION

The research results show that digital technologies are one of the important factors in the development of the green economy, playing a significant role in increasing energy efficiency, ensuring environmental sustainability, and stimulating economic growth. The results of panel regression and VECM confirmed a strong correlation between the level of digital technology implementation (DTI) and green economy indicators (GEI). When the DTI increases by 1 percent,

the green economy index rises by an average of 0.42 points, indicating that digital transformation directly affects environmental efficiency and rational use of resources. Long-term analyses have shown that the development of digital infrastructure serves to sustainably increase green economy indicators. In particular, in Uzbekistan, the share of renewable energy increased from 10.5 percent to 21.8 percent between 2019 and 2023, while in European Union countries, due to the widespread use of digital technologies, CO_2 emissions have decreased by up to 35–40 percent. The experiences of Russia and Kazakhstan also confirm the positive impact of digital transformation on energy efficiency, but institutional challenges may affect the pace of this process.

The theoretical significance of the study is that the obtained results were interpreted within the framework of Sustainable Development Theory and the Porter Hypothesis. These theories substantiate the need to establish a balance between economic growth and environmental sustainability. The results of the study indicate that digital technologies make it possible to increase efficiency in industrial sectors, agriculture, and energy by linking environmental constraints with innovations.

Practically, the research results are of great importance for making strategic decisions in the following areas:

1. Energy sector: The widespread implementation of digital technologies, including the introduction of smart grids and real-time monitoring systems, serves to minimize energy losses.
2. Agriculture: Smart irrigation systems based on IoT technologies can save 20–30 percent of water resources, which helps increase productivity and reduce environmental load.
3. Industrial sector: The use of artificial intelligence and big data processing technologies helps reduce waste by 15–20 percent.
4. Investment environment: The development of public-private partnership (PPP) mechanisms supporting digital technologies and the green economy stimulates an increase in investments.

Prospects for future research. During the study, due to limited panel data and the lack of some environmental indicators, the analysis was restricted to only basic indicators. In the future, the macroeconomic impact of digital transformation can be studied in more depth using advanced econometric methods such as dynamic panel GMM and Bayesian VAR. In addition, studying the relationship between local startups, digital innovations, and green technologies, as well as the legal

and regulatory environment in the context of Uzbekistan, remains a relevant direction for future research.

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