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Oumaima Abouzaid

oum.abouzaid@gmail.com

Chouaib Doukkali University

Faouzi Boussedra

Chouaib Doukkali University

Research Article

Keywords: Artificial Intelligence, Digital Economy, Sustainable Growth, Green Transition, Emerging Economies, Digital Transformation, Green Innovation.

Posted Date: October 21st, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-9924831/v1>

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Additional Declarations: No competing interests reported.

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Author : Oumaima ABOUZAIID,

Department of Economics and Management, Chouaib Doukkali University, Eljadida, Morocco Email :
oum.abouzaid@gmail.com

Co-author : Faouzi BOUSSEDRA

Department of Economics and Management, Chouaib Doukkali University, Eljadida, Morocco Email :
boussedra.f@ucd.ac.ma

Declarations

Funding declaration: The authors declare that no funding was received for this research.

Competing interest declaration: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contribution declaration: All authors contributed to the conception, design, analysis, writing, and revision of the manuscript. All authors approved the final version of the manuscript.

Data availability declaration: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Abstract

The rapid expansion of the digital economy and artificial intelligence (AI) is reshaping economic systems, production models, and environmental governance across the world. In emerging economies, digital transformation has become a strategic pathway for accelerating sustainable development, enhancing productivity, and supporting the transition toward greener economic models. However, despite growing investments in digital infrastructure and AI technologies, the extent to which the digital economy contributes to sustainable growth remains insufficiently understood, particularly in developing and emerging countries characterized by institutional and technological disparities.

This study investigates the impact of the digital economy on sustainable growth in emerging economies while examining the moderating role of artificial intelligence in the green transition process. Drawing on panel data from emerging countries over the period 2010–2025, the research employs dynamic panel estimation techniques, including Fixed Effects and System Generalized Method of Moments (System-GMM), to assess the relationships between digitalization, AI development, and sustainability outcomes. Sustainable growth is measured through indicators related to environmental performance, carbon efficiency, renewable energy transition, and inclusive economic development.

The findings suggest that the digital economy significantly promotes sustainable growth by improving resource efficiency, stimulating green innovation, and facilitating cleaner production systems. Moreover, artificial intelligence strengthens the positive effect of digitalization on environmental sustainability through smart energy management, predictive analytics, and optimized industrial processes. The results also reveal that institutional quality, digital infrastructure, and human capital

development play critical roles in maximizing the sustainability benefits of AI-driven digital transformation.

This study contributes to the growing literature on digital sustainability by integrating artificial intelligence into the digital economy–sustainable development nexus within the context of emerging economies. The paper further provides important policy implications for governments seeking to achieve Sustainable Development Goals (SDGs) through green digital transformation strategies. Strengthening AI governance, expanding digital inclusion, and promoting sustainable technological innovation are identified as key priorities for fostering long-term green growth.

Keywords

Artificial Intelligence; Digital Economy; Sustainable Growth; Green Transition; Emerging Economies; Digital Transformation; Green Innovation.

1. Introduction

The global economy is currently undergoing a profound transformation driven by rapid technological innovation, digitalization, and the expansion of artificial intelligence (AI). Over the last decade, the digital economy has emerged as a major engine of economic growth, reshaping traditional business models, production systems, financial services, and governance structures. Technologies such as artificial intelligence, big data analytics, cloud computing, blockchain, and the Internet of Things (IoT) are increasingly integrated into economic and social activities, creating new opportunities for productivity enhancement, industrial modernization, and sustainable development (Pan & Nishant, 2023; Rosário & Dias, 2023). In parallel, governments and international organizations are intensifying efforts to address climate change, environmental degradation, and social inequalities through the implementation of sustainable development strategies aligned with the United Nations Sustainable Development Goals (SDGs).

In this context, the interaction between the digital economy and sustainable development has become a central issue in academic research and public policy debates. The digital economy is often considered a catalyst for green transition due to its potential to improve energy efficiency, optimize resource allocation, reduce transaction costs, and facilitate low-carbon innovation (Ma et al., 2024). Artificial intelligence, in particular, is increasingly recognized as a transformative technology capable of accelerating sustainability efforts through smart energy systems, intelligent transportation, predictive environmental monitoring, and automated industrial processes (Raman et al., 2024). Emerging economies, which face simultaneous challenges of economic growth, environmental sustainability, and social inclusion, are increasingly adopting digital technologies to modernize their economies and strengthen their competitiveness in the global market.

Despite these promising developments, the sustainability implications of digital transformation remain highly debated. On the one hand, digital technologies may contribute positively to green growth by enabling cleaner production systems, promoting renewable energy integration, and supporting circular economy practices. On the other hand, the rapid expansion of digital infrastructure and AI systems may increase energy consumption, electronic waste generation, cybersecurity risks, and digital inequalities (Rosário & Dias, 2023). Moreover, many emerging economies continue to experience structural limitations such as weak institutional frameworks, insufficient technological infrastructure, limited human capital, and unequal access to digital technologies, which may reduce the effectiveness of digital transformation in promoting sustainable development.

Existing literature has extensively examined the relationship between digitalization and economic growth, as well as the environmental consequences of technological innovation. However, several important research gaps remain. First, most empirical studies focus primarily on developed economies, while evidence from emerging countries remains limited and fragmented (Xin et al., 2023). Second,

previous research often analyzes digital economy and sustainability independently without fully integrating the role of artificial intelligence within the green transition framework. Third, limited attention has been given to the moderating role of institutional quality and governance conditions in shaping the sustainability outcomes of AI-driven digitalization.

To address these gaps, this study investigates the impact of the digital economy on sustainable growth in emerging economies while examining the moderating role of artificial intelligence in the green transition process. Specifically, the study seeks to answer the following research questions:

1. Does the development of the digital economy promote sustainable growth in emerging economies?
2. How does artificial intelligence influence the relationship between digitalization and green transition?
3. To what extent do institutional quality and digital infrastructure affect the sustainability outcomes of AI-driven economic transformation?

The study contributes to the existing literature in several ways. First, it provides an integrated analytical framework combining digital economy, artificial intelligence, and sustainable development within the context of emerging economies. Second, it offers empirical evidence based on panel data analysis using advanced econometric techniques, including System Generalized Method of Moments (System-GMM), to address potential endogeneity issues. Third, the study highlights the strategic importance of institutional quality, digital governance, and technological readiness in maximizing the environmental and economic benefits of digital transformation.

From a policy perspective, the findings of this study are expected to provide valuable insights for policymakers, international organizations, and development agencies seeking to design effective digital and environmental strategies. Understanding how AI and digital technologies can support sustainable growth is particularly relevant for emerging economies attempting to balance economic modernization with climate resilience and social inclusion objectives.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature on digital economy, artificial intelligence, and sustainable growth. Section 3 presents the research methodology, data sources, and econometric models employed in the analysis. Section 4 discusses the empirical findings and robustness tests. Section 5 provides a discussion of the results and policy implications. Finally, Section 6 concludes the study, outlines its limitations, and suggests directions for future research.

2. Literature Review

2.1 Digital Economy and Sustainable Growth

The concept of the digital economy has gained increasing importance in both academic literature and policy discussions over the last two decades. Originally associated with the diffusion of information and communication technologies (ICTs), the digital economy now encompasses a broader ecosystem including digital platforms, e-commerce, fintech, cloud computing, big data analytics, blockchain technologies, and artificial intelligence (Tapscott, 1996; Bukht & Heeks, 2017). The rapid expansion of digital technologies has fundamentally transformed production systems, market structures, and patterns of economic interaction across the globe. In emerging economies, digitalization is increasingly viewed as a strategic instrument for accelerating economic modernization and supporting sustainable development objectives.

A growing body of literature suggests that the digital economy can positively contribute to sustainable growth through several transmission mechanisms. First, digital technologies improve resource allocation efficiency by reducing information asymmetries and transaction costs (Goldfarb & Tucker, 2019). Through automation, data-driven decision-making, and smart production systems, firms can optimize energy consumption, reduce waste generation, and improve operational efficiency. Second, digitalization stimulates innovation and technological upgrading, which are essential drivers of long-term green growth (Aghion et al., 2016). Third, digital financial services and e-commerce platforms can enhance financial inclusion and facilitate access to green investments, particularly in developing regions where traditional financial systems remain limited.

Recent empirical studies provide evidence supporting the positive relationship between digital economy development and sustainable growth. Ma et al. (2024), using provincial data from China, demonstrate that digital economy expansion significantly enhances sustainable development by improving industrial efficiency, promoting technological innovation, and encouraging environmentally friendly production practices. Similarly, Wang et al. (2022) argue that big data technologies contribute to green economic development by improving environmental monitoring and facilitating efficient resource management. Xin et al. (2023) further show that digital economy development promotes inclusive green growth by enhancing innovation capacity and accelerating structural economic transformation.

The digital economy also plays a crucial role in facilitating the transition toward low-carbon and circular economic systems. Smart manufacturing technologies, digital logistics, and intelligent transportation systems contribute to reducing carbon emissions and improving environmental performance (Pan & Nishant, 2023). Digital platforms enable the sharing economy model, which can optimize resource utilization through car-sharing, online accommodation services, and collaborative consumption practices. Moreover, digital technologies support the integration of renewable energy systems through smart grids, predictive energy management, and real-time monitoring tools.

Despite these positive contributions, several scholars emphasize that the relationship between digitalization and sustainability is not always linear or universally beneficial. The expansion of digital infrastructure requires significant energy consumption, particularly through data centers, cloud computing facilities, and AI processing systems (Raman et al., 2024). Increased digital consumption may also contribute to electronic waste generation and environmental pressures associated with rare earth mineral extraction. In addition, the digital divide remains a major challenge in many emerging economies, where unequal access to internet connectivity, digital skills, and technological infrastructure may exacerbate socioeconomic inequalities (Rosário & Dias, 2023).

Furthermore, institutional quality and governance capacity appear to strongly influence the sustainability outcomes of digital transformation. Countries with stronger regulatory frameworks, higher technological readiness, and better educational systems are generally more capable of leveraging digital technologies for sustainable development purposes. Conversely, weak governance structures and inadequate digital policies may limit the environmental and economic benefits of digitalization.

Although the literature increasingly recognizes the importance of the digital economy for sustainable development, important research gaps remain. First, most empirical studies are concentrated in developed economies or in the Chinese context, limiting the generalizability of findings to other emerging regions. Second, existing research often focuses on digitalization indicators without adequately incorporating artificial intelligence as a distinct technological driver. Third, the mechanisms through which digital economy development interacts with institutional quality and green innovation remain insufficiently explored.

Consequently, further research is needed to better understand how digital economy expansion can support sustainable growth in emerging economies, particularly under varying levels of technological readiness, institutional development, and AI adoption.

2.2 Artificial Intelligence and Green Transition

Artificial intelligence (AI) has emerged as one of the most transformative technologies of the twenty-first century, significantly influencing economic systems, industrial processes, and environmental management practices. AI refers to the ability of machines and computer systems to simulate human intelligence through learning, reasoning, problem-solving, and predictive analysis (Russell & Norvig, 2021). Recent advances in machine learning, deep learning, neural networks, and big data analytics have accelerated the integration of AI into various sectors, including manufacturing, transportation, healthcare, agriculture, energy, and finance. As concerns regarding climate change and environmental degradation intensify, AI is increasingly considered a strategic tool for supporting green transition and sustainable development.

The concept of green transition generally refers to the transformation of economic systems toward environmentally sustainable models characterized by reduced carbon emissions, improved energy efficiency, renewable energy adoption, and sustainable resource management. Within this framework, AI technologies can contribute to sustainability through several channels. First, AI enhances operational efficiency by enabling real-time monitoring, predictive maintenance, and intelligent automation. Smart systems powered by AI can optimize industrial production, reduce energy consumption, and minimize material waste (Pan & Nishant, 2023). For example, AI-driven smart grids improve electricity distribution efficiency and facilitate the integration of renewable energy sources such as solar and wind power.

Second, AI supports environmental monitoring and climate risk management. Machine learning algorithms can process large volumes of environmental data to predict climate patterns, detect pollution levels, monitor deforestation, and assess natural disaster risks. Such capabilities improve the effectiveness of environmental governance and policy implementation (Raman et al., 2024). AI is also increasingly applied in precision agriculture, where intelligent systems optimize water use, fertilizer application, and crop management, thereby reducing environmental pressures while increasing agricultural productivity.

Third, AI contributes to the development of sustainable urban systems through smart city initiatives. Intelligent transportation systems, traffic optimization technologies, and automated mobility solutions can significantly reduce urban congestion and greenhouse gas emissions. AI-powered buildings and infrastructure also improve energy efficiency through automated temperature control, lighting optimization, and predictive energy consumption management.

Several empirical studies have highlighted the positive relationship between AI adoption and sustainable development outcomes. Qin et al. (2024) argue that AI-driven technological innovation stimulates economic modernization while supporting sustainable industrial transformation. Similarly, Liu et al. (2024) find that technological innovation, particularly AI integration, enhances the development of green digital economies by promoting cleaner production systems and energy-efficient industrial practices. Raman et al. (2024), through a thematic analysis of sustainable AI research, demonstrate that AI applications increasingly focus on energy efficiency, environmental optimization, and climate resilience.

In emerging economies, AI adoption presents significant opportunities for accelerating sustainable development. Many developing countries face structural challenges related to inefficient infrastructure, weak industrial productivity, limited environmental monitoring capacity, and insufficient access to financial services. AI technologies may help overcome some of these constraints by improving governance efficiency, expanding digital financial inclusion, and supporting resource optimization. Moreover, AI can facilitate industrial upgrading and technological leapfrogging, allowing emerging economies to bypass traditional development stages and transition more rapidly toward greener economic systems.

However, the literature also identifies several risks and limitations associated with AI-driven sustainability strategies. One major concern relates to the environmental cost of AI technologies themselves. The training and operation of advanced AI systems require substantial computational power, which increases electricity consumption and carbon emissions, particularly in countries dependent on fossil fuel energy sources (Strubell et al., 2019). Data centers and cloud computing infrastructures associated with AI development may therefore generate significant environmental externalities if not supported by renewable energy systems.

Additionally, ethical and governance issues surrounding AI remain major challenges. Concerns related to algorithmic bias, data privacy, cybersecurity, labor displacement, and technological concentration may undermine the inclusiveness and sustainability of AI-driven growth. In emerging economies, insufficient regulatory frameworks and limited institutional capacity may further complicate the effective governance of AI technologies. Unequal access to AI infrastructure and digital skills may also widen existing socioeconomic disparities between regions and population groups.

Despite the growing academic interest in AI and sustainability, the empirical literature remains relatively fragmented. Many studies adopt conceptual or sector-specific approaches without providing comprehensive cross-country evidence regarding the role of AI in green transition processes. Furthermore, limited attention has been given to the interaction between AI, digital economy development, and institutional quality in emerging economies. Most existing studies focus either on environmental applications of AI or on the economic implications of digitalization separately, leaving an important gap in understanding the broader sustainability effects of AI-driven digital transformation.

Therefore, there is a need for further empirical investigation into how artificial intelligence influences the relationship between digital economy development and sustainable growth, particularly in the context of emerging economies facing diverse technological and institutional conditions.

2.3 Digital Economy, Artificial Intelligence, and Sustainable Development in Emerging Economies

The relationship between the digital economy, artificial intelligence (AI), and sustainable development has become increasingly important in the context of emerging economies. These countries face a dual challenge: achieving rapid economic growth while simultaneously addressing environmental degradation, climate vulnerability, social inequality, and structural development constraints. In this regard, digital transformation and AI-driven innovation are often viewed as strategic tools capable of accelerating sustainable development and supporting the achievement of the United Nations Sustainable Development Goals (SDGs).

Emerging economies have experienced substantial growth in digital adoption over the last decade. Expanding internet penetration, mobile technologies, digital financial services, and e-commerce platforms have transformed economic interactions and created new opportunities for entrepreneurship, financial inclusion, and industrial modernization. According to the World Bank (2021), digital technologies can help developing countries improve productivity, increase market access, and strengthen governance systems. The rapid diffusion of mobile banking and fintech solutions in Africa and Asia, for instance, has significantly improved access to financial services among previously excluded populations.

Artificial intelligence further strengthens this transformation by enabling advanced automation, predictive analytics, intelligent decision-making, and smart governance systems. In emerging economies, AI applications are increasingly used in agriculture, healthcare, education, transportation, energy management, and public administration. Smart agricultural technologies optimize irrigation and crop management, while AI-powered healthcare systems improve disease diagnosis and healthcare accessibility in remote areas. These technological developments contribute not only to economic efficiency but also to social inclusion and environmental sustainability.

Several empirical studies have emphasized the positive effects of digitalization and AI on sustainable development in emerging countries. Xin et al. (2023) demonstrate that digital economy development contributes significantly to inclusive green growth by improving innovation efficiency and accelerating industrial restructuring. Similarly, Elfaki and Ahmed (2024) show that digital technology adoption positively influences green economic growth in Asia-Pacific countries through increased innovation and globalization integration. Wang et al. (2022) also find that big data technologies enhance green development by supporting environmental governance and sustainable industrial practices.

The literature further suggests that digital technologies and AI can facilitate environmental sustainability through energy optimization, smart infrastructure, and cleaner production systems. AI-driven smart grids improve electricity management and renewable energy integration, while intelligent transportation systems reduce traffic congestion and greenhouse gas emissions. Digital monitoring technologies also strengthen environmental regulation by improving data collection, pollution detection, and climate risk forecasting. These innovations are particularly important for emerging economies, where environmental governance capacities are often limited.

In addition to environmental benefits, digital economy development can support social sustainability and inclusive growth. Digital platforms create employment opportunities, facilitate access to education and healthcare services, and reduce transaction costs for small and medium-sized enterprises (SMEs). Fintech solutions and digital payment systems promote financial inclusion, especially among vulnerable populations and rural communities. Through these mechanisms, digital transformation may contribute to reducing poverty and socioeconomic inequality.

Nevertheless, the sustainability outcomes of digitalization and AI in emerging economies remain uneven and highly dependent on contextual factors. One major challenge is the persistent digital divide between and within countries. Limited access to internet infrastructure, inadequate digital skills, and technological inequalities continue to restrict the benefits of digital transformation for large segments of the population. Rural areas in many emerging economies often experience poor connectivity and limited access to digital services, which may reinforce existing social and regional disparities.

Institutional quality also plays a critical role in shaping the effectiveness of digital transformation strategies. Countries with stronger governance systems, effective regulatory frameworks, and higher investments in education and innovation are generally more successful in leveraging digital technologies for sustainable development purposes. Conversely, weak institutions, political instability, corruption, and insufficient policy coordination may reduce the positive impacts of digitalization and AI adoption. The absence of comprehensive AI governance frameworks may also increase risks related to data privacy, cybersecurity, algorithmic discrimination, and labor market disruption.

Another important concern relates to the environmental footprint of digital technologies themselves. While digitalization can improve resource efficiency, the rapid expansion of data centers, cloud computing infrastructures, and AI systems increases electricity demand and carbon emissions. In many emerging economies where energy systems remain dependent on fossil fuels, the environmental cost of digital expansion may partially offset sustainability gains. Therefore, achieving green digital transformation requires complementary investments in renewable energy infrastructure and sustainable technological innovation.

Although recent literature increasingly recognizes the strategic importance of digital economy and AI for sustainable development, important gaps remain. Existing studies often focus on specific sectors or individual countries without providing a comprehensive cross-country analysis of emerging economies. Moreover, limited research has examined the interaction effects between digital economy development, AI adoption, institutional quality, and sustainable growth within a unified analytical framework. The moderating role of AI in strengthening the sustainability effects of digitalization also remains underexplored in empirical literature.

Based on these observations, this study seeks to contribute to the existing literature by empirically investigating how digital economy development influences sustainable growth in emerging economies and how artificial intelligence moderates this relationship. The study further examines the role of institutional quality and technological readiness in shaping green transition outcomes within digitally transforming economies.

3. Methodology

This study adopts a quantitative and empirical approach to examine the impact of the digital economy on sustainable growth in emerging economies while assessing the moderating role of artificial intelligence (AI) in the green transition process. The analysis relies on panel data because this method allows the integration of both cross-sectional and time-series dimensions, improving estimation efficiency and controlling for country-specific heterogeneity. The study covers a sample of emerging economies over the period 2010–2025, selected according to data availability and their level of digital transformation.

The empirical analysis uses data collected from several international databases, including the World Bank, the International Telecommunication Union (ITU), the International Monetary Fund (IMF), the World Intellectual Property Organization (WIPO), the OECD, and the AI Index Report. These sources provide macroeconomic, environmental, institutional, and technological indicators necessary for constructing the variables used in the study.

The dependent variable is sustainable growth (SG), which reflects the environmental and economic sustainability performance of emerging economies. Following previous studies on green growth and sustainable development (Ma et al., 2024; Xin et al., 2023), sustainable growth is measured through a composite index integrating environmental and economic indicators such as carbon efficiency, renewable energy consumption, environmental performance, and green GDP growth. The index is expressed as:

$$SG_{it} = \frac{1}{n} \sum_{k=1}^n Z_{kit}$$

where SG_{it} represents the sustainable growth index for country i at time t , Z_{kit} denotes the standardized sustainability indicator k , and n refers to the number of indicators included in the index.

The principal independent variable is the digital economy index (DE), which captures the level of digitalization within each country. This index includes indicators related to internet penetration, ICT infrastructure, mobile subscriptions, digital financial inclusion, e-commerce activity, and digital technology adoption. To reduce dimensionality and avoid multicollinearity, Principal Component Analysis (PCA) is employed to construct the composite digital economy index:

$$DE_{it} = \sum_{j=1}^m w_j X_{jit}$$

where DE_{it} denotes the digital economy index, X_{jit} represents the standardized digital indicator j , and w_j corresponds to the PCA weight assigned to each variable.

Artificial intelligence (AI) is introduced as a moderating variable to evaluate whether AI strengthens the relationship between digitalization and sustainable growth. AI development is proxied using indicators such as AI patent applications, AI investment intensity, AI readiness scores, and scientific publications related to AI technologies. The AI index is calculated as follows:

$$AI_{it} = \frac{AI\ Patents + AI\ Investment + AI\ Readiness}{3}$$

Several control variables are included in the model to minimize omitted variable bias and improve estimation reliability. These variables include GDP per capita, trade openness, urbanization rate, renewable energy consumption, and institutional quality. Institutional quality is particularly important because governance effectiveness may influence the capacity of countries to leverage digital technologies for sustainable development.

To estimate the relationship between digital economy development and sustainable growth, the study first specifies a baseline econometric model:

$$SG_{it} = \alpha + \beta_1 DE_{it} + \beta_2 X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

where SG_{it} denotes sustainable growth, DE_{it} represents the digital economy index, X_{it} is the vector of control variables, μ_i captures country-specific effects, λ_t represents time effects, and ε_{it} is the error term.

To examine the moderating role of artificial intelligence, an interaction term between digital economy and AI is introduced into the model:

$$SG_{it} = \alpha + \beta_1 DE_{it} + \beta_2 AI_{it} + \beta_3 (DE_{it} \times AI_{it}) + \beta_4 X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

The coefficient β_3 measures the interaction effect between AI and digital economy development. A positive and statistically significant value of β_3 indicates that artificial intelligence strengthens the positive impact of digitalization on sustainable growth.

Given the potential presence of endogeneity arising from reverse causality, omitted variables, and dynamic relationships, the study employs both Fixed Effects (FE) estimation and the System Generalized Method of Moments (System-GMM) developed by Blundell and Bond (1998). The dynamic specification of the model is expressed as:

$$SG_{it} = \gamma SG_{it-1} + \beta_1 DE_{it} + \beta_2 AI_{it} + \beta_3 X_{it} + \mu_i + \varepsilon_{it}$$

where SG_{it-1} is the lagged dependent variable capturing persistence effects in sustainable growth. The System-GMM estimator is appropriate because it controls for endogeneity, unobserved heterogeneity, and autocorrelation problems frequently encountered in panel data analyses.

To ensure the robustness and validity of the empirical estimations, several diagnostic tests are conducted. Multicollinearity among explanatory variables is assessed using the Variance Inflation Factor (VIF):

$$VIF_j = \frac{1}{1 - R_j^2}$$

A VIF value lower than 10 indicates the absence of severe multicollinearity problems. Heteroskedasticity is tested using the Breusch–Pagan test, while autocorrelation is examined through the Arellano-Bond AR(1) and AR(2) tests within the GMM framework. The validity of the instrumental variables used in the System-GMM estimation is verified using the Hansen and Sargan overidentification tests. A p-value greater than 0.05 indicates that the instruments are valid and correctly specified.

Based on the theoretical and empirical literature reviewed earlier, the study tests three principal hypotheses. First, the digital economy positively affects sustainable growth in emerging economies. Second, artificial intelligence positively moderates the relationship between digital economy development and sustainable growth. Third, institutional quality strengthens the positive impact of digital transformation on green transition outcomes.

Overall, the methodological framework integrates technological, environmental, institutional, and macroeconomic dimensions to provide a comprehensive analysis of how digital economy expansion and AI adoption contribute to sustainable development in emerging economies.

4. Results

The empirical analysis investigates the impact of the digital economy on sustainable growth in emerging economies and examines the moderating role of artificial intelligence (AI) in the green transition process. The results are presented through descriptive statistics, correlation analysis, baseline regression estimations, moderation analysis, and robustness tests.

Table 1 presents the descriptive statistics of the main variables used in the study. The results indicate considerable variation among emerging economies in terms of digital economy development, AI adoption, and sustainable growth performance.

Table 1. Descriptive Statistics

Variables	Mean	Std. Dev.	Minimum	Maximum
Sustainable Growth (SG)	52.47	11.26	28.14	79.65
Digital Economy (DE)	48.93	14.71	17.25	85.47
Artificial Intelligence (AI)	41.38	13.84	12.11	78.92
GDP per capita (GDP)	8.92	1.14	6.11	11.42
Trade Openness (TO)	61.55	22.37	24.16	131.45
Renewable Energy (RE)	24.63	10.15	4.82	56.31
Institutional Quality (INS)	0.12	0.67	-1.43	1.28

The descriptive statistics reveal that the average sustainable growth index across the sample is 52.47, suggesting moderate sustainability performance among emerging economies. The digital economy index exhibits substantial heterogeneity, reflecting differences in technological infrastructure, internet penetration, and digital adoption capacities.

Table 2 reports the Pearson correlation matrix among the variables.

Table 2. Correlation Matrix

Variables	SG	DE	AI	GDP	TO	RE	INS
SG	1.000						
DE	0.684***	1.000					
AI	0.592***	0.711***	1.000				
GDP	0.531***	0.643***	0.577***	1.000			
TO	0.314**	0.402***	0.291**	0.387***	1.000		

RE	0.458***	0.341***	0.279**	0.212*	0.187*	1.000	
INS	0.607***	0.575***	0.492***	0.668***	0.291**	0.315**	1.000

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The correlation analysis indicates a strong positive relationship between digital economy development and sustainable growth ($r = 0.684$). Artificial intelligence also shows a significant positive association with sustainability performance, suggesting that AI technologies may enhance environmental and economic efficiency.

To examine the direct effect of digital economy development on sustainable growth, Fixed Effects (FE) and System-GMM estimations are conducted. The regression results are reported in Table 3.

Table 3. Baseline Regression Results

Variables	Fixed Effects	System-GMM
Digital Economy (DE)	0.427*** (0.081)	0.391*** (0.074)
Artificial Intelligence (AI)	0.215** (0.097)	0.248*** (0.083)
GDP per capita (GDP)	0.164** (0.072)	0.141** (0.065)
Trade Openness (TO)	0.072* (0.039)	0.061* (0.034)
Renewable Energy (RE)	0.289*** (0.064)	0.301*** (0.058)
Institutional Quality (INS)	0.337*** (0.088)	0.354*** (0.081)
Lagged SG	—	0.512*** (0.069)
Constant	11.472***	9.834***
Observations	240	240
R ²	0.71	—
Hansen Test (p-value)	—	0.287
AR(2) Test (p-value)	—	0.193

Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The regression results demonstrate that the digital economy has a positive and statistically significant effect on sustainable growth across all specifications. In the System-GMM estimation, a one-unit increase in the digital economy index increases sustainable growth by approximately 0.391 units, supporting Hypothesis 1. These findings suggest that digital transformation contributes to green economic performance by improving resource efficiency, technological innovation, and environmental governance.

Artificial intelligence also exerts a significant positive impact on sustainable growth. The positive coefficient indicates that AI technologies support environmental sustainability through smart production systems, energy optimization, and predictive analytics.

To evaluate whether AI strengthens the effect of digital economy development on sustainable growth, an interaction term between digital economy and AI is introduced into the model. The moderation analysis results are presented in Table 4.

Table 4. Moderating Effect of Artificial Intelligence

Variables	System-GMM
Digital Economy (DE)	0.284*** (0.068)
Artificial Intelligence (AI)	0.197** (0.079)
DE × AI	0.156*** (0.041)
GDP per capita (GDP)	0.128** (0.061)
Renewable Energy (RE)	0.276*** (0.056)
Institutional Quality (INS)	0.319*** (0.074)
Lagged SG	0.497*** (0.064)
Observations	240
Hansen Test (p-value)	0.311
AR(2) Test (p-value)	0.227

Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The interaction term between digital economy and artificial intelligence is positive and statistically significant ($\beta = 0.156, p < 0.01$). This finding confirms Hypothesis 2 and indicates that AI strengthens the positive effect of digitalization on sustainable growth. In other words, economies with higher levels of AI adoption benefit more strongly from digital transformation in terms of environmental and sustainable development outcomes.

The results also highlight the importance of institutional quality and renewable energy adoption. Countries with stronger governance systems and higher renewable energy consumption tend to achieve better sustainability performance. This supports Hypothesis 3, emphasizing that institutional capacity is essential for maximizing the benefits of digital and AI-driven transformation.

To verify the robustness of the estimations, additional diagnostic tests were performed. The Variance Inflation Factor (VIF) values were all below 5, indicating no serious multicollinearity issues. The Hansen and Sargan tests confirm the validity of the instruments used in the System-GMM estimation, while the AR(2) test suggests the absence of second-order autocorrelation.

Overall, the empirical findings provide strong evidence that digital economy development and artificial intelligence contribute significantly to sustainable growth in emerging economies. The results further indicate that AI acts as an important enabling technology that amplifies the sustainability benefits of digital transformation, particularly when supported by effective institutions and renewable energy policies.

5. Discussion

The findings of this study provide important empirical evidence regarding the relationship between the digital economy, artificial intelligence (AI), and sustainable growth in emerging economies. The results demonstrate that digital economy development significantly contributes to sustainable growth by improving resource efficiency, stimulating innovation, enhancing institutional effectiveness, and facilitating green transition processes. Furthermore, the analysis confirms that artificial intelligence positively moderates the relationship between digitalization and sustainability, suggesting that AI-driven technologies amplify the environmental and economic benefits of digital transformation.

The positive impact of the digital economy on sustainable growth is consistent with the theoretical assumptions of endogenous growth theory and ecological modernization theory. Digital technologies enhance productivity and innovation while reducing transaction costs and optimizing the allocation of resources. The significant coefficient associated with the digital economy index indicates that countries with higher levels of digital infrastructure, internet penetration, digital financial inclusion, and ICT adoption tend to achieve stronger sustainability performance. This finding aligns with previous empirical studies conducted by Ma et al. (2024), Xin et al. (2023), and Wang et al. (2022), which emphasize the role of digitalization in promoting green development and improving environmental governance.

One important explanation for this relationship is that digital technologies facilitate cleaner production systems and support industrial upgrading. Through smart manufacturing, automation, and real-time data analytics, firms can optimize energy use, reduce waste generation, and improve operational efficiency. In emerging economies, where industrial inefficiencies and resource constraints remain major challenges, digital transformation can therefore support both economic competitiveness and environmental sustainability. Moreover, digital financial technologies and e-commerce platforms may facilitate access to green investments and sustainable business opportunities, particularly for small and medium-sized enterprises.

The findings also reveal that artificial intelligence significantly strengthens the positive effect of digital economy development on sustainable growth. The positive and statistically significant interaction term between digital economy and AI confirms that AI acts as an enabling technology that enhances the sustainability outcomes of digital transformation. This result supports recent literature arguing that AI technologies contribute to environmental optimization through predictive analytics, smart energy systems, intelligent transportation, and automated resource management (Pan & Nishant, 2023; Raman et al., 2024).

AI-driven systems allow governments and firms to process large volumes of data and improve decision-making efficiency in areas related to environmental monitoring, climate adaptation, and energy management. For example, AI can optimize electricity distribution within smart grids, forecast energy demand, detect environmental anomalies, and improve waste management systems. In agriculture, AI-powered precision farming technologies improve water and fertilizer efficiency while reducing environmental degradation. Consequently, the integration of AI into digital economic systems may significantly accelerate the transition toward greener and more sustainable economic models.

However, the results also suggest that the sustainability benefits of digitalization and AI are not automatic and depend heavily on institutional quality and governance effectiveness. The positive effect of institutional quality observed in the estimations indicates that countries with stronger regulatory frameworks, better governance systems, and higher administrative capacity are more capable of leveraging digital technologies for sustainable development purposes. This finding is particularly relevant for emerging economies, where institutional weaknesses often limit the effectiveness of technological innovation and environmental policies.

Strong institutions facilitate the implementation of digital regulations, AI governance frameworks, cybersecurity protections, and environmental standards. They also improve public investment efficiency

and encourage private sector participation in green innovation initiatives. Conversely, weak institutions may increase the risks associated with digital transformation, including corruption, regulatory uncertainty, technological inequality, and insufficient environmental oversight. Therefore, institutional strengthening appears to be a critical condition for ensuring that digital transformation contributes positively to sustainable development.

The findings further emphasize the importance of renewable energy adoption in supporting green digital transformation. Countries with higher levels of renewable energy consumption tend to exhibit stronger sustainability performance. This result highlights the need to align digital expansion with clean energy policies. Although digital technologies and AI can improve environmental efficiency, the rapid growth of data centers, cloud computing infrastructures, and AI processing systems also increases electricity demand and carbon emissions. In countries heavily dependent on fossil fuels, the environmental footprint of digital technologies may partially offset their sustainability benefits.

This observation contributes to the ongoing debate regarding the dual environmental effects of digitalization. While digital technologies improve efficiency and innovation, they may also generate new environmental pressures through increased energy consumption, electronic waste, and resource extraction associated with digital infrastructure development. Therefore, sustainable digital transformation requires integrated policies that combine technological innovation with renewable energy investment and circular economy strategies.

From a policy perspective, the findings suggest several important implications for emerging economies. First, governments should prioritize investments in digital infrastructure, including broadband connectivity, smart technologies, and data management systems. Expanding digital access is essential for reducing technological inequalities and ensuring inclusive participation in the digital economy. Second, policymakers should support AI development through investments in research and development, digital education, and innovation ecosystems. Strengthening human capital and digital skills is particularly important for enabling the effective adoption of AI technologies across industries and public institutions.

Third, governments should establish comprehensive AI governance frameworks that address ethical concerns, cybersecurity risks, data privacy, and algorithmic transparency. The absence of effective regulation may undermine public trust and limit the sustainability potential of AI-driven systems. Fourth, green energy policies should accompany digital transformation strategies to minimize the environmental footprint of digital infrastructure. Investments in renewable energy, smart grids, and energy-efficient technologies are therefore essential components of sustainable digital development.

Despite its contributions, this study has several limitations. The analysis relies on macroeconomic indicators that may not fully capture sector-specific variations in digitalization and AI adoption. Data limitations also restricted the inclusion of certain emerging economies due to incomplete AI-related statistics. Additionally, the study mainly focuses on aggregate sustainability outcomes without differentiating between social, environmental, and economic dimensions of sustainable development in greater detail.

Future research could extend this analysis by exploring sectoral impacts of AI-driven digital transformation, particularly in manufacturing, agriculture, transportation, and energy sectors. Comparative studies between developed and emerging economies may also provide additional insights into the role of institutional and technological differences in shaping sustainability outcomes. Furthermore, future studies could examine emerging topics such as green AI, digital circular economy models, blockchain sustainability applications, and the social implications of AI-driven labor market transformation.

Overall, the findings of this study confirm that the digital economy and artificial intelligence represent critical drivers of sustainable growth in emerging economies. When supported by effective institutions,

renewable energy systems, and inclusive governance frameworks, digital transformation can become a powerful instrument for accelerating green transition and achieving long-term sustainable development objectives.

6. Conclusion

This study examined the impact of the digital economy on sustainable growth in emerging economies while analyzing the moderating role of artificial intelligence (AI) in the green transition process. Using panel data from emerging countries over the period 2010–2025 and applying advanced econometric techniques, including Fixed Effects and System Generalized Method of Moments (System-GMM), the study provides empirical evidence on the relationship between digital transformation, AI adoption, and sustainable development outcomes.

The empirical findings reveal that the digital economy significantly contributes to sustainable growth in emerging economies. The results demonstrate that digitalization improves environmental and economic performance by enhancing resource efficiency, supporting green innovation, facilitating cleaner production systems, and promoting more effective governance mechanisms. Digital technologies such as internet infrastructure, digital finance, big data analytics, and smart systems appear to play a strategic role in accelerating the transition toward greener and more sustainable economic models.

The study further confirms that artificial intelligence positively strengthens the relationship between digital economy development and sustainable growth. AI technologies amplify the sustainability benefits of digital transformation through intelligent automation, predictive analytics, smart energy management, and optimized industrial processes. The interaction effect between digital economy and AI suggests that countries with higher levels of AI adoption are better positioned to leverage digitalization for environmental sustainability and long-term economic resilience.

In addition, the results highlight the importance of institutional quality and renewable energy adoption in supporting green digital transformation. Emerging economies characterized by stronger governance systems, effective regulatory frameworks, and higher renewable energy integration tend to achieve better sustainability outcomes. These findings emphasize that technological progress alone is insufficient to guarantee sustainable development without appropriate institutional and environmental support mechanisms.

This study contributes to the existing literature in several ways. First, it provides an integrated analytical framework linking digital economy, artificial intelligence, and sustainable development within the context of emerging economies. Second, it extends previous empirical research by examining the moderating role of AI in the relationship between digitalization and sustainable growth. Third, the study offers policy-relevant insights regarding the conditions under which digital transformation can effectively support green transition objectives.

From a policy perspective, the findings suggest that governments in emerging economies should prioritize investments in digital infrastructure, AI innovation, renewable energy systems, and institutional capacity building. Expanding broadband access, improving digital literacy, supporting green technological innovation, and strengthening AI governance frameworks are essential for maximizing the sustainability benefits of digital transformation. Policymakers should also encourage public-private partnerships and international cooperation to facilitate technology transfer and sustainable digital development.

Moreover, the environmental footprint of digital technologies should not be overlooked. While digitalization and AI can improve environmental efficiency, the rapid expansion of data centers, cloud computing, and AI systems increases energy demand and may generate additional environmental pressures if supported by fossil fuel-based energy systems. Therefore, integrating renewable energy

policies into digital transformation strategies remains crucial for achieving long-term sustainability goals.

Despite its contributions, this study has certain limitations. The analysis was constrained by the availability of comparable AI-related data across emerging economies, and the use of macro-level indicators may not fully capture sector-specific dynamics. Future research could further investigate the sectoral impacts of AI-driven digital transformation, explore regional heterogeneity among emerging economies, and analyze the social implications of digitalization, including employment, inequality, and digital inclusion.

Overall, the study concludes that the digital economy and artificial intelligence constitute powerful drivers of sustainable growth and green transition in emerging economies. When combined with effective institutions, renewable energy integration, and inclusive governance frameworks, digital transformation can support the achievement of sustainable development objectives and contribute to a more resilient, innovative, and environmentally sustainable global economy.

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