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The Role of Digitalization in Driving Green Growth: A Global Panel Data Perspective

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Abstract

This paper analyzes the green growth (GG) effects of digitalization using panel data from 164 countries spanning the period from 1990 to 2023. The study uses four measures of digitalization: internet users, broadband, mobile cellular, and fixed telephone subscriptions. The empirical results are estimated employing pooled ordinary least squares, fixed effects, random effects, system generalized method of moments, and panel quantile regression estimation approaches. STATA software is used to analyze the data. The results suggest that the proliferation of digitalization measures tends to boost GG. The results based on principal component analysis also confirm the positive impact of digitalization on GG. Furthermore, the GG-improving influence of digitalization remains robust across all quantiles. The role of renewable energy also turns out to be conducive to improving GG prospects. However, the roles of financial development and trades are not robust in influencing GG. The GG effects of financial development vary from a positive influence at lower quantiles to a negative influence at higher quantiles. Conversely, the GG effect of trade varies from a negative influence at lower quantiles to a positive influence at higher quantiles.

Keywords: Digitalization, carbon emissions, financial development, renewable energy consumption, trade openness.

1. Introduction

The global impact of the COVID-19 pandemic still persists, and the concept of green development is ascribed as an effective approach to hinder the spread of unknown infectious diseases. fThis approach has transformed people's beliefs about conventional economic growth models, thereby accelerating efforts toward achieving green prosperity. Since the 1970s, resource scarcity and ecological disruptions such as natural resource decline, global warming, environmental degradation, and land desertification—degradation of land from flora and fauna to arid land—have become pressing issues that many economies are striving to resolve. For instance, to address the deteriorating environment and climate change, many urban areas in developed economies have shifted their focus to a green economy and sustainable development. This shift aims to bring constructive improvements in the environment, resource use, and economic prosperity by utilizing resources efficiently and economically (Lee et al., 2023).

Against this background, the importance of green growth (GG) has attracted worldwide attention from policymakers, academic researchers, energy experts, economists, and international organizations. Prioritizing GG helps decouple economic growth from carbon emissions (Ozturk et al., 2021). According to the OECD (2020), GG is achieved without degrading the environment and is sustained by overcoming inefficiencies in natural resource use. Thus, the efficient and sustainable use of natural resources is essential for expanding economic activities. Recently, researchers have increasingly focused on exploring the potential sources of GG. In this context, the role of advanced technologies is critical for attaining and sustaining a green economy. In effect, contemporary theoretical frameworks in the discourse of green economic performance emphasize the role of technological progress, environmental innovations, research and development (R&D) expenditures, and knowledge spillovers as catalysts for economic expansion and prosperity (Ullah et al., 2021).

Theoretically, the direct effect of digital advancement on the GG can broadly be manifested in two aspects (Lee et al., 2023). First, digital development considers data a key production element, markedly reducing the dependency on extensive physical resources and energy in conventional industrial production. Through this mechanism of emission reduction and energy conservation, social economies can accelerate the adjustment of factor assembly, enhance element utilization, and refine the high-quality GG. This transition fosters the restructuring of factor compositions, elevating resource utilization efficiency, and fostering high-quality, eco-friendly economic growth by reducing emissions and conserving energy. Second, due to advancements in digital knowledge, the barriers to the flow of information, data, talent, and technology have greatly reduced across many regions. This reduction supports an environment conducive to enterprise innovation in clean and green technologies, driven by both spillover and demonstrative effects. Accordingly, enterprises contribute to clean and sustainable economic growth. Conversely, the literature also predicts that as digitalization penetrates society, it leads to increased manufacturing of digitalization products, enhanced usage of digitalization applications, and a surge in electronic waste, all of such changes hinder green economic initiatives (OECD, 2010; Houghton, 2015; Majeed, 2018).

Empirically, literature advocates digitalization's association with growth depending upon the specific measures of digitalization and the degree of economic development of sampled economies (Myovella et al. 2020; Usman et al. 2020; Majeed and Ayub, 2018). Myovella et al. (2020) for Sub-Saharan African economies and Usman et al., 2020) for South Asian economies propose that economic advantages from digitalization differ across economies. Nonetheless, Majeed (2020) validated that digitalization is a significant component of economic growth, utilizing a sample of 122 developing economies. These studies explored the effect of digitalization on economic growth across countries. Yet, the role of digitalization in facilitating or hindering the GG remains underexplored and poses a significant research question.

In this context, this research paper makes significant contributions to the ongoing discourse on managing the GG through digitalization. To the best of the authors' knowledge, no previous study has explored the diverse impacts of digitalization on GG within a global economic framework. By incorporating four distinct proxies of digitalization—internet users, broadband, mobile cellular, and fixed telephone subscriptions—this study offers a more nuanced understanding of the relationship between digitalization and GG. Additionally, we have developed a composite index using Principal Component Analysis to provide a clearer depiction of this association.

The integration of digitalization—alongside its varied measures—significantly enhances the relevance of this study to contemporary sustainability challenges, particularly in the context of promoting GG. By exploring the interplay between digitalization and GG, this research addresses a crucial gap in the existing literature and offers insights into how digital technologies can be leveraged to meet environmental targets. Methodologically, the study employs panel quantile regression, a technique that facilitates a nuanced examination of the distributional effects of digitalization on GG. This method provides a deeper understanding of how digitalization's impacts may vary across different levels of GG.

The study offers useful practical implications for policymakers, business managers, and other stakeholders. Policymakers can use the insights of this study to design regulations and incentives that promote the adoption of digitalization necessary for environmental sustainability, particularly in critical sectors. Additionally, policymakers can leverage these insights to develop strategies that simultaneously advance digitalization and GG, considering potential trade-offs and differences among various population segments.

2. Literature Review

Managing a green economy has increasingly become the need of the present world owing to climatic changes and mounting pressure on ecological footprints. Section 2.1 provides theoretical perspectives on GG in the context of digitalization. Section 2.2 presents empirical studies. Section 2.3 concludes the literature section and provides the research gaps and significance of this study.

2.1 Theoretical Perspectives on Green Growth

The theoretical underpinnings of GG include diverse insights from economic, ecological, and social perspectives. The extant theories consider a balance between economic development and environmental sustainability. Economic network theory contemplates scientific models to discover the economic outcomes and postulates global economic shifts are increasingly influenced by the proliferation of evolving information technologies (Majeed and Ayub, 2018). Besides, innovations and connectedness are retransforming not only the dynamics of the economic system but also reshaping many socio-economic, cultural, and advance technological transformations, that collectively formulate a new society (Castells, 2000).

The growing usage of digitalization is supporting in lowering of communication costs and enhancing information flow. Digitalization is seen as a modern icon of revolution in technology and a key driving force of economic performance, particularly in industrial economies (Farhadi et al., 2012). Over recent decades, the widespread usage of the internet and mobile phones has deepened digitalization penetration across nations, hence connecting the world economies into a globally networked system. Besides this trend, institutional superstructures and the technical infrastructures related to digitalization are rapidly integrated into a dense multimodal network spanning from an individual micro-level company to a global business through world supply chains (Majeed and Ayub, 2018).

Decoupling theory suggests that economic growth can be decoupled from emissions. Its implication for GG is that production processes need to be designed in such a way that more efficiency and innovations are used to minimize environmental impacts. Digitalization helps in optimizing energy usage through smart grids, the Internet of Things, and artificial intelligence in buildings and industries with decreased environmental impact. Circular economy supports such an economic system which is restorative and regenerative by design that reuses, remakes, and recycles material in the production process, thereby lowering waste and the use of new material. Digitalization helps in creating digital platforms that can better manage the lifecycle of products more efficiently, supporting recycling technologies and enabling the traceability of materials.

According to endogenous growth theory Aghion et al. (1998), growth is determined internally by human capital, innovation, and knowledge. Policies aiming at supporting endogenous growth can foster GG by supporting R&D in eco-friendly technologies and sustainable practices. The role of digitalization in human capital, innovation, and knowledge is critical as it supports digital skills and digital knowledge required for endogenous growth theory integrated with less environmental impacts. Institutional theory emphasizes enhancing institutional quality to enforce environmental laws and regulations, thereby supporting GG. Mobile applications, e-government, and e-governance can support public participation in environmental decision-making and improve the enforcement of regulations.

However, opposing theories also exist which suggest that digitalization can hinder progress toward a green economy. In this respect, resource degradation and e-waste are major concerns in the digitalization and GG nexus. Digital products require extensive extraction of resources which create environmental footprints. Moreover, the life span of digital products such as mobile phones and laptops is short, and their recycling rate is low. As the demand for data and networking increases, the carbon footprint associated with digital products also increases. According to rebound effects theory, the usage of digital products increases due to their efficiency, thereby burdening the environment. The theory of the digital divide suggests that the potential benefits may be limited to high-income regions and urban areas where digital infrastructure persists while low-income regions and rural areas may not get the benefits. The theory of complexity and systemic risk predicts that digital infrastructure and networks also possess complex and systemic risks such as cybersecurity threats. Any failure in the digital system compromises its' efficiency and support for a green economy.

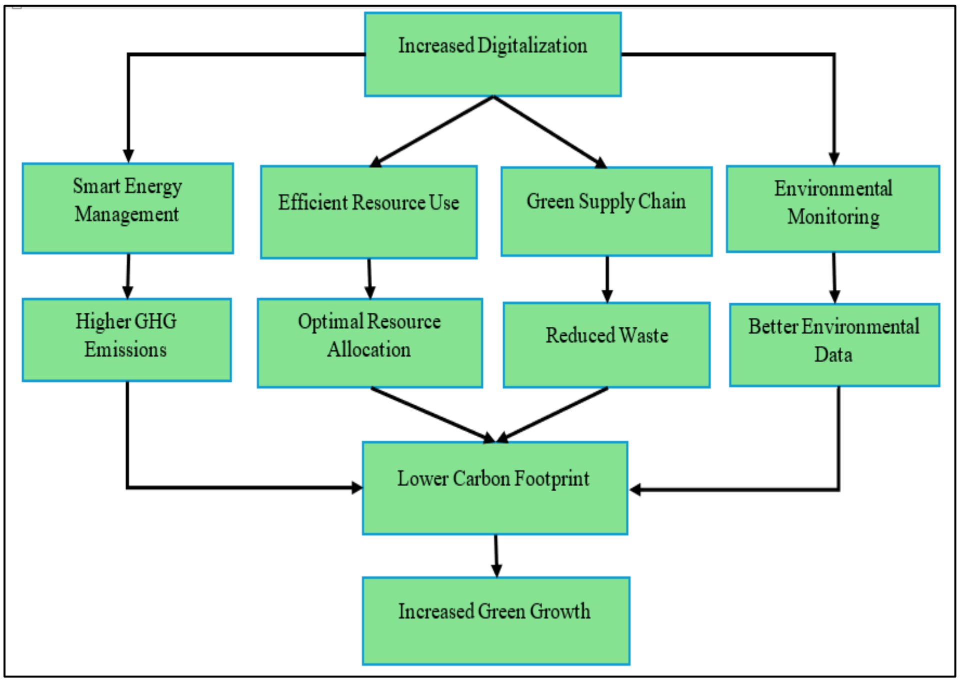

Figure 1: Greening Through Digitalization

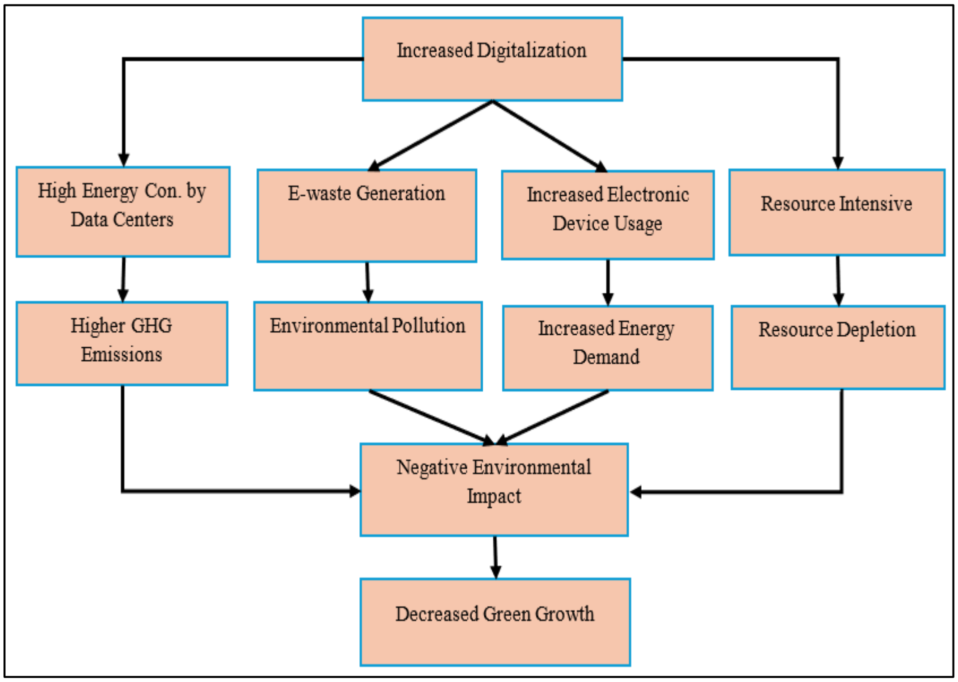

Figure 2: Environmental Degradation by Digitalization

2.2 Empirical Studies

The empirical studies on digitalization and GG are categorized as follows. First, the studies have analyzed the impact of digitalization on economic growth. Second, the studies have investigated the effect of digitalization on carbon emissions. Third, the studies have analyzed the influence of digitalization on GG. Note: In the academic literature, the concepts of digitalization and information and communication technology (ICT) are often used as proxy measures for each other because both reflect the extent to which digital technologies are integrated into economic activities.

2.2.1 Digitalization and Economic Growth

Theoretical literature predicts the favorable role of digital technology in the economic performance of an economy. One key mechanism through which digital technology contributes to economic growth is that it overcomes barriers to information access required for investment and growth (Levine, 1997). Likewise, Quah (2002) contends that ICT serves as a pivotal mechanism in supporting broad-based education, labor skills, and consumer sophistication. This escalation in technological adoption improves labor productivity which in turn improves economic growth. Mahyideen et al. (2012) explained ICT and growth nexus using two channels. First, the conventional channel suggests that ICT improves growth by increasing input productivity and reducing the cost of production. The second channel suggests that ICT helps in saving time and costs of people and enhancing their efficiency.

Contrary to this, some studies have shown the negative contribution of digitalization in economic growth. For instance, Stiroh (2002) reported a negative output elasticity of ICT using US manufacturing industries data over the time period 1984-1999. Likewise, O'Mahony and Vecchi (2005) showed a negative role of ICT in the output growth of industries in the UK. The authors contend that lack of skill and paucity of ICT investment are responsible for negative contributions to growth.

2.2.2 Digitalization and CO2 Emissions

Theoretically, the literature predicts the varied effects of digitalization on the green economy. Some propose that digitalization hampers the development of a green economy and some advocate digitalization's positive role in green economic development. The key argument is that as digitalization penetrates society, it leads to increased manufacturing of digitalization products, enhanced usage of digitalization applications, and a surge in electronic waste, all of such changes hinder green economic initiatives (OECD, 2010; Houghton, 2015; Majeed, 2018). Additionally, the phenomenon known as ‘rebound effects’ further complicates green growth management because digitalization accelerates production efficiency. As a result, the production cost declines, and the demand for production increases, hence potentially offsetting the environmental benefits (Majeed, 2018; Plepys, 2002).

Furthermore, ICT creates a dematerialization impact that is a shift from delivering physical products to delivering services (Majeed 2018). In the modern world, paper-based and physical communication modes are being substituted by digital alternatives, supported by technologies such as telephony and the Internet. Similarly, the dependency on physical transportation declines contributing to lower CO2 emissions. Moreover, ICT facilitates the implementation of intelligent and automated solutions, incorporating, energy generation, digitalization, and the development of smart cities.

The empirical studies have reported mixed effects of ICT on environmental quality. One group of studies has demonstrated the favorable role of ICT in environmental sustainability by reducing carbon emissions. Lashkarizadeh and Salatin (2012) for 43 countries, Zhang and Liu (2015) for China over the period 2000-2010, and Ozcan and Apergis (2018) for 20 developing economies from 1990 to 2015, Sahoo et al. (2021) for India from 1990 to 2018 have demonstrated the favorable role of ICT in environmental sustainability.

In contrast to the aforementioned studies, a second group of studies elucidates the environmentally harmful effects of ICTs. For example, Liu et al. (2006) illustrated the negative environmental impacts of electronic waste in China, Salahuddin et al. (2016)

documented the adverse environmental consequences of ICT usage for OECD economies from 1991 to 2012, Avom et al. (2020) in Sub-Saharan African nations, Alataş (2021) demonstrated that ICTs are associated with increased CO2 emissions across a sample of 93 economies during the period from 1995 to 2016.

The third group of studies reveals a nuanced understanding of the conditional effects of ICTs on environmental sustainability. Raheem et al. (2020) reported the CO2 escalating effect of ICT in G7 countries but its combined effect with FDI mitigates emissions. Chien et al. (2021) and N'dri et al. (2021) offer further insights. Using data from 1995 to 2018 for BRICS economies, Chien et al. (2021) found that the emission-reducing effects of ICTs are significant only at lower emission levels. Using a sample of 58 developing economies from 1990 to 2014, N'dri et al. (2021) showed that an increase in ICT exerts a positive influence on the environment in lower income developing economies while a discernible impact was found in high-income developing economies.

2.2.3 Digitalization and Green Growth

Tawiah et al. (2021) examined GG determinants employing a sample of 123 developed and developing countries. They showed that economic development exerts a positive influence on GG while trade exerts a negative influence on GG. Furthermore, they showed that energy consumption has a negative effect on GG while renewable energy supports the drive to GG. However, their results turn out to be dissimilar across developed and developing economies.

Tawiah et al. (2021) analyzed green growth determinants at the global level, however, they did not consider the importance of digitalization in influencing global GG. Conversely, another study by Hao et al. (2023) focused on the role of digitalization on GG in the case of China from 2013 to 2019. Their findings support a positive association between digitalization and GG. The findings of Hao et al. (2023) are limited to China and cannot be generalized globally. The existing research stream on digitalization and the GG nexus lacks a comprehensive analysis of how digitalization influences green prosperity on a global scale.

2.3 Conclusion, Research Gaps, and Contribution

Research scholars have elucidated the multifaced nature of the potential associations between digitalization and GG, highlighting the diverse interaction and implications for sustainability. The sustainability-supporting role of digitalization is noted by many studies, but contradicting effects are also found. Likewise, the literature highlighted the favorable effect of digitalization on economic growth, some exceptions are also found. However, an important research gap persists in thoroughly explaining the multifaceted relationships between digitalization and GG, particularly, in a world economy context. Though some research studies show positive effects, other studies draw attention to adverse outcomes. The absence of a cohesive framework and a clear understanding of the underlying channels and conditions driving these associations necessitates further research.

This study makes numerous important contributions to the existing literature on digitalization and GG nexus. The analysis provides a holistic understanding of digitalization and GG nexus by including four different measures of digitalization that are internet users, broadband, mobile, and fixed telephone subscriptions. Moreover, to capture an overall picture of digitalization and GG nexus, Principal Component Analysis is also conducted for different measures of digitalization. This multi-dimensional modeling provides a more robust analysis by capturing the varied effects of different aspects of digitalization on GG. The individual impacts as well as the influence of a composite index on GG are valuable contributions to the literature.

Unlike prior studies which focus on either CO2 emissions or economic growth, this study initiates a new theme in the sustainability literature by combining these two separate indicators into GG. By analyzing digitalization and green GG nexus, the present research covers a critical gap in the literature and offers deeper insight into how digital technologies can be aligned with sustainable development goals. This study also adds to the literature methodologically by using panel quantile regression approach. This approach provides a nuanced analysis of the distributional profile of GG, providing a deeper comprehension of how digitalization affects GG across economies with lower, median, and higher levels of existing GG. The present research's comprehensive analysis and methodological advances provide actionable insights for policy formulation geared towards sustainable development. Policymakers can leverage the study's findings to craft such solutions that support both digitalization deployment and GG, while also considering potential trade-offs and country heterogeneity.

3. Data and Methodology

This study investigates the connectedness between digitalization and GG. For empirical analysis, the study employs global panel data from 1990 to 2023 for 164 economies. The data is retrieved from the World Bank (2024). The outcome variable is GG which is calculated using real GDP per capita after adjusting for CO2 emissions. That is, the part of economic growth that comes without emissions. The focused variable of interest digitalization is measured using four indicators and conducting their component analysis.

The theoretical foundation of the empirical model is based on the endogenous growth model which considers the effects of technology inside the system in the form of human capital, knowledge, and innovations. The empirical model can be presented as follows:

$$GG_{i,t} = \beta_0 + \beta_1 REC_{i,t} + \beta_2 DCP_{i,t} + \beta_3 Urban_{i,t} + \beta_4 Trade_{i,t} + \beta_5 Net_{i,t} + \varepsilon_{i,t} \quad (1)$$

$$GG_{i,t} = \emptyset_0 + \emptyset_1 REC_{i,t} + \emptyset_2 DCP_{i,t} + \emptyset_3 Urban_{i,t} + \emptyset_4 Trade_{i,t} + \emptyset_5 FB_{i,t} + \varepsilon_{i,t} \quad (2)$$

$$GG_{i,t} = \alpha_0 + \alpha_1 REC_{i,t} + \alpha_2 DCP_{i,t} + \alpha_3 Urban_{i,t} + \alpha_4 Trade_{i,t} + \alpha_5 MCS_{i,t} + \varepsilon_{i,t} \quad (3)$$

$$GG_{i,t} = \gamma_0 + \gamma_1 REC_{i,t} + \gamma_2 DCP_{i,t} + \gamma_3 Urban_{i,t} + \gamma_4 Trade_{i,t} + \gamma_5 FTS_{i,t} + \varepsilon_{i,t} \quad (4)$$

$$GG_{i,t} = \theta_0 + \theta_1 REC_{i,t} + \theta_2 DCP_{i,t} + \theta_3 Urban_{i,t} + \theta_4 Trade_{i,t} + \theta_5 Digital_{it} + \varepsilon_{i,t} \quad (5)$$

Where GG represents green growth, Digital indicates digitalization measured using four indicators: internet users (Net), fixed broadband (FB) subscriptions, mobile cellular subscriptions (MCS), and fixed telephone subscription s(FTS). The abbreviation, REC shows renewable energy consumption, Urban is urban population and Trade shows trade openness. Moreover, the subscript "i" refers to panel units (N= 164 economies listed in Table A), and "t" indicates the time horizon (here T=34 years) ranging from 1990 to 2023. The notation $\varepsilon_{i,t}$ captures the error term in regression models while $\beta_{1,..5}$ shows slope coefficients of the variables used in the model.

The key focused variable of the study digitalization is measured using four indicators: internet users, broadband subscriptions, mobile cellular subscriptions, and fixed telephones. PCA is also conducted on these four measures to assess the robustness of the impact and composite effect. Gross domestic product (GDP) is measured in per capita (constant 2015 US $). It calculates the "sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources" (World Bank, 2024). The control variable REC is measured as "Renewable energy consumption is the share of renewable energy in total final energy consumption" (World Bank, 2024).

The control variable DCP is measured as "Domestic credit to private sector refers to financial resources provided to the private sector by financial corporations, such as through loans, purchases of nonequity securities, and trade credits and other accounts receivable, that establish a claim for repayment. For some countries, these claims include credit to public enterprises. The financial corporations include monetary authorities and deposit money banks, as well as other financial corporations where data are available (including corporations that do not accept transferable deposits but do incur such liabilities as time and savings deposits). Examples of other financial corporations are finance and leasing companies, money lenders, insurance corporations, pension funds, and foreign exchange companies" World Bank (2024). The control variable Trade is the sum of export and imports of goods and services in the form of percentage share of GDP (World Bank, 2024). FDI in the form of percentage of GDP is utilized in current work which is defined as "the net inflows of investment to acquire a lasting management interest (10 percent or more of voting stock) in an enterprise operating in an economy other than that of the investor. It is the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments" (World Bank- 2024). It is obtained by dividing investment inflows by GDP. Urban refers to urban population that refers to people living in urban areas as defined by national statistical offices (World Bank-2024). The data is measured as a percentage of the total population of the respective country.

4. Results and Discussion

The descriptive statistics are provided in Table 1. The observations on GG vary from -3.7 to 0.61. The share of REC in the total energy mix is 35 percent. However, its mean value varies considerably from zero to 98.34 percent. The highest mean value of digitalization measures is 63.84 percent for MCS, and the lowest value of FB is 10.10 percent. The data shows considerable variation in detecting expected relationships between focused and control variables.

Table 1. Descriptive Statistics

Variables	Obs.	Mean	Std. Dev.	Min	Max
GG	3,589	-.0122909	.1217852	-3.695445	.6154899
REC	3,589	35.36463	30.91311	0	98.34
Net	3,589	28.87974	30.78612	0	100
FB	2,448	10.10156	12.27818	0	47.49841
MCS	3,554	63.84981	52.68859	0	221.3088
FT	3,547	16.80641	18.39765	0	74.51804
DCP	3,589	48.5348	43.83741	0.0016138	304.5751
Urban	3,589	55.77413	23.66256	5.491	100
Trade	3,589	82.41292	50.83142	9.955145	437.3267

The results of pairwise correlation matrix and Variance Inflating Factor (VIF) outcomes are presented in Table 2. The mean value of VIF score indicates that there are no issues related to multicollinearity problem in the selected model. All measures of digitalization indicate a positive correlation with GG.

Table 2: Correlation and VIF Results

Panel A: Correlation Matrix									
Correlation	**GG**	**REC**	**Net**	**FB**	**MCS**	**FT**	**DCP**	**Urban**	**Trade**
GG	1.000								
REC	-0.05	1.0000							
Net	0.214	-0.292	1.000						
FB	0.224	-0.152	0.859	1.000					
MCS	0.130	-0.226	0.707	0.557	1.000				
FT	0.207	-0.333	0.605	0.648	0.333	1.000			
DCP	0.156	-0.251	0.640	0.578	0.463	0.637	1.000		
Urban	0.196	-0.412	0.584	0.502	0.463	0.568	0.458	1.000	
Trade	0.111	-0.246	0.292	0.272	0.277	0.209	0.216	0.189	1.000

Panel A: VIF Outcomes (Dep. Var. GG)			
Variable	**VIF Score**	**1 / VIF**	**Mean VIF**
REC	1.25	0.799376	1.37
Digitalization	1.47	0.682562	
DCP	1.42	0.703124	
Urban	1.57	0.635377	
Trade	1.13	0.883098	

Table 3 reports the baseline results of the digitalization on GG for models construed in equations 1-5 using pooled OLS. Columns (1-5) present the results of the alternative measures of digitalization. The last column presents the results of a single measure of digitalization constructed using the PCA. The results reported in column (2) indicate that the effect of internet users on GG is positive and statistically significant. This finding aligns with the growing body of literature on sustainable development from the perspective of fostering digitalization. Existing studies have shown that digital technologies can alleviate carbon emissions (Majeed, 2018), boost energy efficiency (Chen et al., 2024), and support smarter resource management (Lee et al., 2020). This finding is also in line with Xie et al. (2023), who demonstrated the favorable role of digitalization in GG across a sample of 280 cities in China from 2011 to 2019. Zheng et al. (2023) also reported similar results for China. This finding supports the narrative of environmentally sustainable economic development, providing empirical evidence for the view that growing digitalization fosters sustainability along with economic growth.

This finding can be explained from the perspective of network economic network theory. This theory contemplates scientific models to discover the economic outcomes and postulates global economic shifts are increasingly influenced by the proliferation of evolving information technologies (Majeed and Ayub, 2018). Besides, digital networks facilitate information sharing, innovations, and best practices across countries. This finding also supports endogenous growth theory which suggests that economic growth is determined internally by human capital, innovation, and knowledge. The role of digitalization in human capital, innovation, and knowledge is critical as it supports digital skills and digital knowledge required for endogenous growth theory integrated with less environmental impacts.

Moreover, this result is consistent with eco-innovation theory which predicts that environmentally friendly innovations support new business models and economic opportunities. In this perspective, digitalization reflects a form of eco-innovation that not only mitigates environmental disruption but also supports economic growth through new digital products and services. Another relevant theory Porter's hypothesis suggests that environmentally stringent policies foster innovations, increasing competitiveness and profitability. In the contemporary digital global economy, this might inspire businesses to adopt green technology to not only comply with regulations but also to gain a competitive advantage, therefore, supporting GG (Majeed et al. 2023).

The empirical evidence on digitalization's contribution to GG is in line with sustainable development goals (SDGs), especially SDG 9 (Industry, Innovation, and Infrastructure), and SDG 13 (Climate Action). Thus, this finding implies that investment in digitalization can foster progress toward SDGs by facilitating efficient resource use and alleviating environmental loss. This finding contradicts the implications of rebound effects, digital divide, complexity, and systemic risk theories. According to rebound effects theory, the usage of digital products increases owing to their efficiency, therefore burdening the environment. The theory of the digital divide predicts that the potential gains from digital technologies remain limited to high-income regions and urban areas where digital infrastructure persists while low-income regions and rural areas may not get the benefits.

The theory of complexity and systemic risk postulates that digital infrastructure and networks also possess complex and systemic risks such as cybersecurity threats. Any failure in the digital system can compromise digital efficiency and support for a green economy. Besides, this finding contrasts the studies that emphasize the environmentally damaging effects of digitalization owing to its contribution to e-waste and carbon footprints. For example, Liu et al. (2006) illustrated the negative environmental effects of electronic waste in China. Alataş (2021) demonstrated that digital technologies are associated with increased CO_2 emissions across a sample of 93 economies during the period from 1995 to 2016.

Table 3: Pooled OLS Results

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**GG**	**GG**	**GG**	**GG**	**GG**
REC	0.0704	0.219*	0.0742	0.149	0.308***
	(0.138)	(0.120)	(0.138)	(0.139)	(0.119)
DCP	0.288	0.291	0.605***	0.288	0.218
	(0.206)	(0.237)	(0.203)	(0.208)	(0.251)
Urban	1.763***	2.355***	2.262***	1.657***	2.414***
	(0.508)	(0.480)	(0.496)	(0.513)	(0.507)
Trade	0.741*	0.908**	0.825**	1.003**	1.015***
	(0.407)	(0.360)	(0.406)	(0.397)	(0.365)
Net	0.0393***				
	(0.00888)				
FB		0.0980***			
		(0.0188)			
MCS			0.00995**		
			(0.00472)		
FT				0.0710***	
				(0.0154)	
Digital					0.0472***
					(0.0123)
Constant	-13.47***	-16.36***	-16.38***	-14.49***	-17.92***
	(2.715)	(2.592)	(2.619)	(2.603)	(2.621)
Observations	3,505	2,448	3,554	3,547	2,404

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Other than digitalization, the effect of REC also turned out to be positive and significant. The increasing share of REC in the total energy mix can alleviate the pressure on carbon footprints, thereby improving GG. This finding is consistent with Hwang (2023) and Razzaq et al. (2023) who demonstrated the positive influence of REC on GG in Latin American countries and China, respectively. Similarly, this find supports the results of Chen and Majeed (2024) who desaturated the friable effect of digital technologies on green investment in high-polluting economies. However, this finding is inconsistent with another stream of the literature which considers the beneficial effects depending upon the level of REC or the presence of other environmentally favorable conditions (see, for details, Murshed, 2024). The effect of other control variables such as DCP, urbanization, and trade are also statistically significant with positive signs.

The POLS or common effect model assumes that all cross-sectional units are homogenous, and they have a common intercept. This approach overlooks the role of country-specific effects or temporal effects which can influence the association between digitalization and economic growth. To address this concern, we have employed fixed effects model (FEM) and random effects model (REM). The FEM allows the variation of intercept of each cross-sectional, therefore capturing unobserved country-specific effects. The REM treats country-specific effects as random and uncorrelated with the independent variables. REM becomes more efficient than FEM when the assumption of no correlation holds true, as it considers both within-entity and between-entity variations.

The results reported in Table 4 also confirm that digitalization is positively associated with GG. The measures of internet users and mobile users exert significant effects on GG while fixed broadband and fixed telephones have insignificant effects. The control variable REC has a positive and significant influence on GG across all models, implying the conducive role of REC in GG. Similarly, the effect of urbanization on GG is positive and statistically significant. The effects of financial development and trade are negatively significant. The possible reason for the negative effect could be that the financial sector supports conventional energy sources. Similarly, trade is not supporting GG because trade can increase production and consumption based on conventional energy sources. Table 5 reports the results based on the random effects model. In this case, all measures of digitalization have been playing a positive and significant role in GG.

Table 4: Fixed Effects Results

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**GG**	**GG**	**GG**	**GG**	**GG**
REC	1.707**	1.938***	1.997***	1.902***	2.074***
	(0.690)	(0.677)	(0.669)	(0.708)	(0.590)
DCP	-1.247***	-2.144***	-1.252***	-1.007**	-2.322***
	(0.460)	(0.656)	(0.464)	(0.439)	(0.690)
Urban	6.249**	9.046**	5.669**	7.945***	9.264*
	(2.468)	(4.356)	(2.614)	(2.318)	(4.938)
Trade	-1.864*	-2.257*	-2.207**	-1.826*	-1.541
	(1.114)	(1.260)	(1.099)	(1.092)	(1.272)
Net	0.0210*				
	(0.0120)				
FB		0.0242			
		(0.0317)			
MCS			0.0110*		
			(0.00643)		
FT				-0.0214	
				(0.0437)	
Digital					0.183
					(0.371)
Constant	-18.78*	-24.29	-16.00	-25.99***	-27.72
	(10.47)	(18.45)	(10.99)	(9.602)	(20.75)
Observations	3,505	2,448	3,554	3,547	2,404
R-squared	0.007	0.013	0.007	0.007	0.013
Number of id	164	164	164	164	164

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 5: Random Effects Results

	(1)	(2)	(3)	(4)	(5)
VARIABLES	GG	GG	GG	GG	GG
REC	0.0832	0.271	0.135	0.205	0.369**
	(0.144)	(0.167)	(0.166)	(0.164)	(0.159)
DCP	0.259	0.0897	0.429*	0.209	0.370
	(0.215)	(0.302)	(0.240)	(0.240)	(0.289)
Urban	1.841***	2.947***	2.622***	2.019***	3.587***
	(0.533)	(0.688)	(0.609)	(0.617)	(0.654)
Trade	0.733*	0.869*	0.756	0.931**	1.348***
	(0.425)	(0.519)	(0.486)	(0.467)	(0.498)
Net	0.0382***				
	(0.00902)				
FB		0.0793***			
		(0.0220)			
MCS			0.00869*		
			(0.00493)		
FT				0.0657***	
				(0.0178)	
Digital					0.0591
					(0.254)
Constant	-13.64***	-17.80***	-16.95***	-15.35***	-22.93***
	(2.837)	(3.623)	(3.162)	(3.076)	(3.408)
Observations	3,505	2,448	3,554	3,547	2,404
Number of id	164	164	164	164	164

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$

The issue of endogeneity is likely to persist in our model as the focused variable can correlate with an error term and there can be a reverse causality issue. On the one hand, digitalization can increase GG, on the other hand, an increase in GG can create more demand for digitalization. Moreover, as the selected sample of economies is cross-sectional, country-specific heterogeneity can lead to biased outcomes. To resolve this issue, we use the SGMM as an alternative estimation technique. SGMM produces more efficient and consistent results in the presence of heterogeneity and endogeneity issues. The validity of instruments is tested by applying the test of overidentification. Table 6 reports the results based on SGMM. In this study lag variables and time dummies are used as instrument variables. The results confirm that the effect of digitalization measures on GG is positively significant across all regressions.

Table 6: System-GMM Results

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**GG**	**GG**	**GG**	**GG**	**GG**
GG_{t-1}	-0.473***	-0.326***	-0.591***	-0.565***	-0.297***
	(0.0057)	(0.023)	(0.00394)	(0.00483)	(0.0251)
REC	0.017***	0.038***	0.0238***	0.0248***	0.0482***
	(0.0006)	(0.0013)	(0.000762)	(0.000597)	(0.00158)
DCP	-0.033***	-0.030***	-0.0244***	-0.0201***	-0.0222***
	(0.0006)	(0.0033)	(0.000966)	(0.000935)	(0.00307)
Urban	0.190***	0.281***	0.219***	0.210***	0.307***
	(0.0027)	(0.0081)	(0.00155)	(0.00161)	(0.00803)
Trade	0.008***	0.009***	0.0122***	0.0167***	0.0147***
	(0.0006)	(0.0022)	(0.00138)	(0.000592)	(0.00238)
Net	0.0007***				
	(0.00001)				
FB		0.002***			
		(0.0002)			
MCS			0.00017***		
			(0.00014)		
FT				0.00028**	
				(0.00004)	
Digital					0.0057***
					(0.0021)
Constant	-0.752***	-1.176***	-0.922***	-0.918***	-1.350***
	(0.00677)	(0.0369)	(0.0118)	(0.00617)	(0.0399)
Observations	3,358	2,412	3,404	3,395	2,374
Number of id	163	163	163	163	163

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

The issue of cross-sectional dependency in the error term across countries can influence the standard errors of the estimates. To address this, we employed the estimator developed by Driscoll & Kraay (1998). This estimator considers heteroscedasticity and autocorrelation within panels. In particular, it is suitable in the presence of cross-sectional dependence across countries. The results reported in Table 7 confirm the favorable role of all measures of digitalization in GG.

For further robustness analysis, sensitivity analysis is conducted using other potential determinants of GG. Table 8 reports the results of adding FDI into the GG model. The results reported in columns (1-5) confirm that the effect of digitalization on GG is robustly positive and significant. Moreover, the effect of FDI turns out to be insignificant suggesting that the role of FDI is not conducive in GG. Table 9 presents the results with industrialization as another potential predictor of GG. The result on GG remains intact while the effect of industrialization on GG varies across measures of digitalization. Finally, Table 9 presents the results with non-renewable energy consumption (NREC) as a potential predictor of GG. The results remain the same. Thus, it can be inferred that the findings of the study are not sensitive to additional control variables.

Table 7: Driscoll and Kraay Results

	(1)	**(2)**	**(3)**	**(4)**	**(5)**
VARIABLES	**GG**	**GG**	**GG**	**GG**	**GG**
REC	0.0704	0.219***	0.0742	0.149	0.308***
	(0.169)	(0.0735)	(0.155)	(0.144)	(0.104)
DCP	0.288*	0.291	0.605***	0.288	0.218
	(0.163)	(0.182)	(0.173)	(0.181)	(0.155)
Urban	1.763***	2.355***	2.262***	1.657***	2.414***
	(0.480)	(0.422)	(0.682)	(0.564)	(0.542)
Trade	0.741**	0.908***	0.825**	1.003***	1.015***
	(0.273)	(0.242)	(0.327)	(0.226)	(0.250)
Net	0.0393***				
	(0.00567)				
FB		0.0980***			
		(0.0191)			
MCS			0.00995*		
			(0.00570)		
FT				0.0710***	
				(0.0124)	
Digital					0.0472***
					(0.0144)
Constant	-13.47***	-16.36***	-16.38***	-14.49***	-17.92***
	(2.687)	(2.598)	(3.891)	(2.742)	(3.172)
Observations	3,505	2,448	3,554	3,547	2,404
R-squared	0.033	0.063	0.029	0.034	0.057
Number of groups	164	164	164	164	164

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 8: Sensitivity Analysis (FDI)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**GG**	**GG**	**GG**	**GG**	**GG**
REC	0.111	0.287***	0.122	0.192	0.373***
	(0.178)	(0.0795)	(0.167)	(0.155)	(0.107)
DCP	0.280*	0.296*	0.577***	0.284	0.170
	(0.157)	(0.167)	(0.166)	(0.175)	(0.158)
Urban	2.025***	2.673***	2.496***	1.907***	2.750***
	(0.484)	(0.367)	(0.671)	(0.553)	(0.504)
Trade	0.743**	0.948***	0.820**	1.047***	0.987***
	(0.289)	(0.234)	(0.349)	(0.252)	(0.244)
FDI	0.00097	-0.0036	0.0023	-0.0041	-0.0019
	(0.0042)	(0.0038)	(0.0044)	(0.0049)	(0.0036)
Net	0.0380***				
	(0.0057)				
FB		0.0954***			
		(0.0189)			
MCS			0.0108*		
			(0.0054)		
FT				0.0697***	
				(0.0123)	
Digital					0.0488***
					(0.0153)
Constant	-14.59***	-18.00***	-17.41***	-15.75***	-19.23***
	(2.742)	(2.304)	(3.957)	(2.802)	(2.833)
Observations	3,454	2,424	3,498	3,491	2,384
R-squared	0.034	0.068	0.031	0.035	0.062
Number of groups	164	164	163	164	163

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 9: Sensitivity Analysis (Industrialization)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**GG**	**GG**	**GG**	**GG**	**GG**
REC	0.00565	0.125	-0.0392	0.0952	0.193*
	(0.161)	(0.0773)	(0.137)	(0.134)	(0.0980)
DCP	0.261	0.197	0.525***	0.271	0.102
	(0.168)	(0.196)	(0.177)	(0.174)	(0.163)
Urban	1.844***	2.622***	2.444***	1.732**	2.732***
	(0.551)	(0.395)	(0.758)	(0.681)	(0.546)
Trade	0.761***	0.897***	0.842**	0.937***	1.001***
	(0.274)	(0.235)	(0.322)	(0.231)	(0.242)
Industry	-0.0179	-0.0285**	-0.0391	-0.0119	-0.0352**
	(0.0189)	(0.0134)	(0.0231)	(0.0208)	(0.0160)
Net	0.0380***				
	(0.00520)				
FB		0.0922***			
		(0.0178)			
MCS			0.00957		
			(0.00582)		
FT				0.0697***	
				(0.0133)	
Digital					0.0438***
					(0.0136)
Constant	-13.09***	-15.96***	-15.50***	-13.92***	-17.32***
	(2.858)	(2.589)	(3.777)	(2.907)	(3.015)
Observations	3,403	2,427	3,452	3,448	2,383
R-squared	0.033	0.066	0.030	0.034	0.060
Number of groups	164	164	164	164	164

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 10: Sensitivity Analysis (NREC)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**GG**	**GG**	**GG**	**GG**	**GG**
REC	0.360*	0.360**	0.317*	0.472**	0.377**
	(0.193)	(0.146)	(0.175)	(0.187)	(0.160)
DCP	0.0833	0.523**	0.444	-0.0317	0.288
	(0.177)	(0.216)	(0.278)	(0.293)	(0.183)
Urban	1.868***	2.392***	2.267***	1.466**	1.993***
	(0.257)	(0.391)	(0.468)	(0.610)	(0.288)
Trade	0.909**	1.155***	0.844*	1.237***	1.113***
	(0.400)	(0.229)	(0.409)	(0.337)	(0.252)
NREC	0.0383	0.00946	0.0297	0.0376	0.00990
	(0.0228)	(0.0121)	(0.0219)	(0.0237)	(0.0139)
Net	0.0409***				
	(0.00813)				
FB		0.0709**			
		(0.0254)			
MCS			0.0159**		
			(0.00648)		
FT				0.0748***	
				(0.0161)	
Digital					0.0429***
					(0.0105)
Constant	-17.06***	-19.02***	-18.88***	-17.23***	-17.34***
	(2.946)	(2.909)	(3.814)	(3.761)	(2.988)
Observations	2,088	1,385	2,115	2,113	1,365
R-squared	0.033	0.060	0.031	0.035	0.054
Number of groups	142	138	142	141	137

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

The effect of digitalization on GG growth can vary depending upon the existing level of GG of sampled economies. To assess the role of the conditional distribution of GG in shaping its relationship with digitalization we have performed quantile regression analysis. Table 11-14 reports the results of quantile regression analysis using alternative measures of digitalization.

Table 11(a, b) reports the results of quantile regression analysis with internet users. The positive effect of internet users on GG remains robust across all quantiles except at the top quantiles (0.9 and 0.95). The effects of control variables DCP and trade vary across quantiles. The effect of DCP on GG remains positively significant from 0.1 to 0.5 quantiles, turns out to be insignificant at quantiles 0.6 and 0.7, and becomes negatively significant at quantiles 0.8, 0.9, and 0.95. This finding suggests that financial development only helps in improving GG prospects in economies where GG levels are lower while it leads to lower GG in economies where GG levels are higher. The effect of trade is the opposite of financial development. That is, it escalates GG in economies at higher levels of GG and diminishes GG in economies where GG is lower. Table 12 (a, b) reports the results with fixed broadband subscriptions. The results of FB remain positively significant across all quantiles. The findings on financial development and trade remain similar to findings with intern users.

Table 13 (a, b) presents the results with MCS as a measure of digitalization. The effect of MCS on GG remains positive across all quantiles. However, it is statically significant only in quantiles from 0.4 to 0.7 suggesting that economies with highest and lowest levels do not benefit from MCS in the perspective of GG. Finally, Table 14 (a, b) presents the results with FTS. The effect of FTS on GG is robustly positive and significant in all quantiles except quantiles (0.9 and 0.95). Thus, the quantile regression analysis also confirms that digitalization measures have the potential to enhance GG irrespective of the levels of GG while the effects of financial development and trade vary depending upon the existing levels of GG of the sampled economies.

Table 11a: Quantile Regression Results (Net)

	(1)	**(2)**	**(3)**	**(4)**	**(5)**
VARIABLES	**GG=0.1**	**GG=0.2**	**GG=0.3**	**GG=0.4**	**GG=0.5**
REC	0.0505	0.193	0.153	0.222**	0.240***
	(0.229)	(0.137)	(0.111)	(0.0944)	(0.0858)
DCP	2.209***	1.222***	0.899***	0.505***	0.377***
	(0.343)	(0.206)	(0.166)	(0.141)	(0.128)
Urban	5.214***	3.403***	2.100***	1.723***	1.217***
	(0.843)	(0.506)	(0.408)	(0.347)	(0.316)
Trade	-1.285*	-0.763*	-0.313	0.172	0.604**
	(0.676)	(0.405)	(0.327)	(0.278)	(0.253)
Net	0.0257*	0.0280***	0.0302***	0.0320***	0.0299***
	(0.0147)	(0.00884)	(0.00714)	(0.00607)	(0.00552)
Constant	-33.64***	-21.76***	-15.04***	-12.76***	-10.64***
	(4.506)	(2.704)	(2.182)	(1.857)	(1.687)
Observations	3,505	3,505	3,505	3,505	3,505

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 11b: Quantile Regression Results (Net)

	(6)	(7)	(8)	(9)	(10)
VARIABLES	**GG=0.6**	**GG=0.7**	**GG=0.8**	**GG=0.9**	**GG=0.95**
REC	0.314***	0.429***	0.512***	0.612***	0.711**
	(0.0786)	(0.0962)	(0.121)	(0.171)	(0.278)
DCP	0.0747	-0.0460	-0.393**	-0.778***	-1.256***
	(0.118)	(0.144)	(0.180)	(0.256)	(0.416)
Urban	1.277***	1.202***	1.363***	-0.492	-2.690***
	(0.289)	(0.354)	(0.444)	(0.629)	(1.022)
Trade	1.009***	1.176***	1.631***	2.817***	3.663***
	(0.232)	(0.284)	(0.356)	(0.505)	(0.820)
Net	0.0344***	0.0291***	0.0244***	0.0114	0.0157
	(0.00506)	(0.00619)	(0.00776)	(0.0110)	(0.0179)
Constant	-10.47***	-9.125***	-8.491***	-0.948	8.603
	(1.546)	(1.893)	(2.373)	(3.366)	(5.467)
Observations	3,505	3,505	3,505	3,505	3,505

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 12a: Quantile Regression Results (FB)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**GG=0.1**	**GG=0.2**	**GG=0.3**	**GG=0.4**	**GG=0.5**
REC	0.153	0.221	0.0983	0.201*	0.311***
	(0.226)	(0.153)	(0.122)	(0.114)	(0.0991)
DCP	2.520***	1.344***	0.950***	0.655***	0.415**
	(0.447)	(0.303)	(0.241)	(0.226)	(0.196)
Urban	5.942***	3.241***	1.941***	1.498***	1.396***
	(0.906)	(0.615)	(0.488)	(0.458)	(0.398)
Trade	-0.638	-0.666	-0.162	0.485	0.734**
	(0.679)	(0.461)	(0.366)	(0.344)	(0.298)
FB	0.0651*	0.0950***	0.104***	0.0849***	0.0962***
	(0.0355)	(0.0241)	(0.0192)	(0.0180)	(0.0156)
Constant	-40.53***	-22.00***	-15.12***	-13.35***	-12.06***
	(4.889)	(3.320)	(2.637)	(2.474)	(2.147)
Observations	2,448	2,448	2,448	2,448	2,448

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 12b: Quantile Regression Results (FB)

	(6)	**(7)**	**(8)**	**(9)**	**(10)**
VARIABLES	**GG=0.6**	**GG=0.7**	**GG=0.8**	**GG=0.9**	**GG=0.95**
REC	0.393***	0.440***	0.565***	0.538***	0.446
	(0.0917)	(0.109)	(0.139)	(0.183)	(0.284)
DCP	0.196	-0.125	-0.480*	-1.071***	-1.889***
	(0.181)	(0.216)	(0.274)	(0.362)	(0.563)
Urban	1.342***	1.288***	1.765***	-0.256	-2.031*
	(0.368)	(0.439)	(0.556)	(0.734)	(1.141)
Trade	1.247***	1.273***	1.936***	2.946***	3.828***
	(0.276)	(0.329)	(0.417)	(0.550)	(0.856)
FB	0.0847***	0.0836***	0.0614***	0.0505*	0.0576
	(0.0144)	(0.0172)	(0.0218)	(0.0288)	(0.0448)
Constant	-11.98***	-9.375***	-10.97***	-1.387	8.327
	(1.986)	(2.370)	(3.001)	(3.962)	(6.160)
Observations	2,448	2,448	2,448	2,448	2,448

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 13a: Quantile Regression Results (MCS)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	GG=0.1	GG=0.2	GG=0.3	GG=0.4	GG=0.5
REC	0.0147	0.193	0.154	0.195**	0.286***
	(0.237)	(0.142)	(0.108)	(0.0973)	(0.0855)
DCP	3.033***	1.649***	1.183***	0.781***	0.552***
	(0.348)	(0.208)	(0.159)	(0.143)	(0.126)
Urban	5.202***	3.866***	2.880***	2.176***	1.898***
	(0.851)	(0.509)	(0.389)	(0.350)	(0.307)
Trade	-1.243*	-0.636	-0.140	0.230	0.688***
	(0.696)	(0.416)	(0.318)	(0.286)	(0.251)
MCS	0.00243	0.00160	0.00369	0.00610*	0.00758***
	(0.00810)	(0.00485)	(0.00370)	(0.00333)	(0.00292)
Constant	-36.26***	-24.96***	-19.31***	-15.12***	-14.02***
	(4.491)	(2.687)	(2.051)	(1.846)	(1.622)
Observations	3,554	3,554	3,554	3,554	3,554

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 13b: Quantile Regression Results (MCS)

	(6)	(7)	(8)	(9)	(10)
VARIABLES	**GG=0.6**	**GG=0.7**	**GG=0.8**	**GG=0.9**	**GG=0.95**
REC	0.336***	0.416***	0.587***	0.643***	0.704**
	(0.0847)	(0.0960)	(0.123)	(0.166)	(0.287)
DCP	0.442***	0.176	-0.147	-0.595**	-1.191***
	(0.125)	(0.141)	(0.180)	(0.244)	(0.422)
Urban	1.501***	1.485***	1.744***	-0.248	-2.111**
	(0.305)	(0.345)	(0.441)	(0.596)	(1.032)
Trade	1.123***	1.254***	1.776***	2.923***	3.930***
	(0.249)	(0.282)	(0.361)	(0.487)	(0.843)
MCS	0.00902***	0.00910***	0.00541	0.00273	-0.00125
	(0.00290)	(0.00329)	(0.00420)	(0.00567)	(0.00982)
Constant	-12.76***	-10.99***	-11.21***	-2.996	5.505
	(1.608)	(1.822)	(2.329)	(3.146)	(5.443)
Observations	3,554	3,554	3,554	3,554	3,554

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 14a: Quantile Regression Results (FT)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**GG=0.1**	**GG=0.2**	**GG=0.3**	**GG=0.4**	**GG=0.5**
REC	-0.00182	0.158	0.0986	0.241**	0.343***
	(0.236)	(0.139)	(0.105)	(0.100)	(0.0846)
DCP	2.061***	1.045***	0.642***	0.280*	0.349***
	(0.354)	(0.209)	(0.158)	(0.150)	(0.127)
Urban	4.593***	2.998***	1.787***	1.552***	1.184***
	(0.872)	(0.514)	(0.389)	(0.371)	(0.312)
Trade	-1.029	-0.602	-0.0225	0.497*	0.761***
	(0.674)	(0.397)	(0.301)	(0.286)	(0.241)
FT	0.0694***	0.0601***	0.0597***	0.0647***	0.0554***
	(0.0262)	(0.0154)	(0.0117)	(0.0111)	(0.00937)
Constant	-32.23***	-20.41***	-14.29***	-12.96***	-11.52***
	(4.422)	(2.603)	(1.974)	(1.878)	(1.582)
Observations	3,547	3,547	3,547	3,547	3,547

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 14b: Quantile Regression Results (FT)

	(6)	(7)	(8)	(9)	(10)
VARIABLES	**GG=0.6**	**GG=0.7**	**GG=0.8**	**GG=0.9**	**GG=0.95**
REC	0.425***	0.528***	0.661***	0.672***	0.756***
	(0.0879)	(0.0953)	(0.127)	(0.177)	(0.279)
DCP	0.131	-0.163	-0.413**	-0.987***	-1.462***
	(0.132)	(0.143)	(0.190)	(0.265)	(0.419)
Urban	1.214***	1.085***	1.509***	-0.309	-2.592**
	(0.325)	(0.352)	(0.467)	(0.654)	(1.031)
Trade	1.519***	1.582***	1.965***	2.950***	4.127***
	(0.251)	(0.272)	(0.361)	(0.505)	(0.797)
FT	0.0504***	0.0543***	0.0352**	0.0302	0.0320
	(0.00974)	(0.0106)	(0.0140)	(0.0196)	(0.0309)
Constant	-12.82***	-10.36***	-10.71***	-1.974	6.840
	(1.645)	(1.784)	(2.368)	(3.314)	(5.226)
Observations	3,547	3,547	3,547	3,547	3,547

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

5. Conclusion

Managing a green economy has become an important global policy agenda in the wake of pressing issues created by climatic changes and ecological disruptions. Transiting towards a green economy requires rethinking conventional growth models to align economic prosperity with environmental preservation. In this context, the role of digitalization is important as it is instrumental in enhancing resource use efficiency, reducing resource waste, and supporting sustainable resource management. Against this milieu, this study explores the relationships between digitalization and GG employing panel data from 164 countries from 1990 to 2023. The study employs four measures of digitalization: internet users, broadband, mobile cellular, and fixed telephone subscriptions. The empirical results are estimated employing POLS, FEM, REM, SGMM, and panel quantile regression estimation approaches.

The results suggest that the proliferation of digitalization measures tends to boost GG. Moreover, the PCA analysis also confirms the favorable role of digitalization in GG. The role of renewable energy also turns out to be conducive to improving GG prospects. The GG improving influence of digitalization remains robust across all quantiles. The GG effects of financial development vary from a positive influence at lower quantiles to a negative influence at higher quantiles. Conversely, the GG effect of trade varies from a negative influence at lower quantiles to a positive influence at higher quantiles. The present study enriches the extant literature by providing a nuanced analysis of the interplay between digitalization and GG, delivering valuable insights for policymaking in today's digitally driven and environmentally aware world.

5.1 Contribution of the Study

The interconnection of digitalization with GG represents an emerging area of academic research. The availability of literature in this research area remains relatively scarce. The literature has explored the role of digitalization in environmental sustainability or economic sustainability. These studies are limited in their scope as they focus on one dimension of sustainable development while ignoring the other. Moreover, the empirical outcomes of these studies are largely conflicting. However, how digitalization influences GG is not yet well explored. There is one notable study on digitalization and GG nexus in the case of China. However, its implications are limited to a country and cannot be generalized on a global scale.

Given these significant literature gaps, the present study offers several unique significant contributions. First, this study provides global evidence on digitalization and GG nexus for the first time. Second, empirical analysis is based on diverse measures of digitalization rather than confining the analysis to a single measure of digitalization. Third, the potential issue of endogeneity is addressed using appropriate methodology. Fourth, PCA analysis is conducted to assess the robustness of findings. Fourth, the conditional distribution of the outcome variable is explored to assess the role of digitalization in GG across diverse levels of existing GG in sampled economies. Finally, this study uses diverse econometric approaches to assess the soundness of data, variables, and empirical findings.

5.2 Theoretical and Practical Implications

The study offers useful practical implications for policymakers, business managers, and other stakeholders. Policymakers can use the insights of this study to design regulations and incentives that promote the adoption of the digitalization necessary for environmental sustainability, particularly in critical sectors. Additionally, policymakers can leverage these insights to develop strategies that simultaneously advance digitalization and GG, considering potential trade-offs and differences among various population segments. Businesses in the technology and digital sectors can use the findings to make strategic investment decisions that support GG through digitalization. Broadly, the study also offers social and economic implications. Increased digitalization can enhance societal well-being by improving resource efficiency, reducing emissions, optimizing resource allocation, and preserving the environment. On the economic front, increased digitization can lead to the emergence of new industries and job creation, accelerating a resilient and sustainable economy.

The empirical outcomes of the study are in line with the decoupling theory, circular economy theory, and endogenous growth theory. The findings, however, do not validate the digital divide theory and the theory of complexity and systematic risk. Theoretical consistencies have important policy implications. The study identified digitalization as favorable for GG. Thus, supporting digital technologies in public and private spheres will bring about increased GG. Managing and supporting a green economy needs investment in digital infrastructure. In this respect, the role of governments is imperative as they can support investment, incentivize green technologies, and align digital and environmental policies to ensure rapid and sustainable economic performance. Capacity development and education provision on digital skills and environmental awareness need to be prioritized in macroeconomic policy frameworks. Besides, public-private partnerships to develop ecosystems and innovation hubs accelerate sustainable practices.

5.3 Limitations and Future Research Directions

The present study has certain limitations. The study explored the linear association between digitalization and GG while future studies can inspect the nonlinear association between these two variables. This study considers four measures of digitalization and the index of digitalization. This study, however, did not consider the role of artificial intelligence in shaping GG prospects. Future studies can focus on artificial intelligence and GG growth nexus.

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REFERENCES

Aghion, P., Howitt, P., Brant-Collett, M., & García-Peñalosa, C. (1998). *Endogenous growth theory*. MIT press.

Alataş, S. (2021). The role of information and communication technologies for environmental sustainability: Evidence from a large panel data analysis. *Journal of Environmental Management*, *293*, 112889.

Avom, D., Nkengfack, H., Fotio, H. K., & Totouom, A. (2020). ICT and environmental quality in Sub-Saharan Africa: Effects and transmission channels. *Technological Forecasting and Social Change, 155*, 120028.

Castells, M. (2000). The Rise of the Network Society: Economy, Society and Culture: The Information Age: Economy, Society and Culture. Wiley Blackwell Publishing.

Chen, B., Wang, K., Li, Y., & Wang, W. (2024). Can digitalization effectively promote green energy efficiency? The linear and nonlinear relationship analysis. *Environmental Science and Pollution Research,* 1-22.

Chen, R., & Majeed, M. T. (2024). How does green investment respond to ICT and financial development? *Borsa Istanbul Review,* 1-10.

Chien, F., Anwar, A., Hsu, C. C., Sharif, A., Razzaq, A., & Sinha, A. (2021). The role of information and communication technology in encountering environmental degradation:

Proposing an SDG framework for the BRICS countries. *Technology in Society*, *65*, 101587.

Driscoll, J. C., & Kraay, A. C. (1998). Consistent covariance matrix estimation with spatially dependent panel data. *Review of Economics and Statistics, 80*(4), 549-560.

Farhadi, M., Ismail, R., & Fooladi, M. (2012). Information and communication technology use and economic growth. *PloS one*, *7*(11), e48903.

Hao, X., Li, Y., Ren, S., Wu, H., & Hao, Y. (2023). The role of digitalization on green economic growth: Does industrial structure optimization and green innovation matter?. *Journal of environmental management*, *325*, 116504.

Houghton, J. W. (2015). ICT, The Environment, and Climate Change. *The International Encyclopedia of Digital Communication and Society*, 76, 39-60.

Hwang, Y. K. (2023). The synergy effect through combination of the digital economy and transition to renewable energy on green economic growth: Empirical study of 18 Latin American and Caribbean countries. *Journal of Cleaner Production, 418*, 138146.

Lashkarizadeh, M., & Salatin, P. (2012). The Effects of Information and Communications Technology (ICT) on Air Pollution, *Elixir Pollution*, 46, 8058-8064.

Lee, C. C., He, Z. W., & Yuan, Z. (2023). A pathway to sustainable development: Digitization and green productivity. *Energy Economics*, *124*, 106772.

Levine, R. (1997). Financial Development and Economic Growth: Views and Agenda. *Journal of Economic Literature, 35*(2), 688–726.

Liu, X., Tanaka, M., & Matsui, Y. (2006). Electrical and Electronic Waste Management in China: Progress and the Barriers to Overcome. *Waste Management & Research, 24*(1), 92-101.

Mahyideen, J., Ismail, N. W., & Law, S. H. (2012). A Pooled Mean Group Estimation on ICT Infrastructure and Economic Growth in ASEAN-5 Countries. *International Journal of Economics and Management*, *6*(2), 360-378.

Majeed, M. T. (2018). Information and communication technology (ICT) and environmental sustainability in developed and developing countries. *Pakistan Journal of Commerce and Social Sciences*, *12*(3), 758-783.

Majeed, M. T. (2020). Do digital governments foster economic growth in the developing world? An empirical analysis. NETNOMICS: *Economic Research and Electronic Networking*, *21(1)*. 1-16.

Majeed, M. T., & Ayub, T. (2018). Information and communication technology (ICT) and economic growth nexus: A comparative global analysis. *Pakistan Journal of Commerce and Social Sciences*, *12*(2), 443-476.

Majeed, M. T., Mazhar, M., & Hussain, Z. (2023). Environmental impact of digital financial inclusion and green growth: Insights from global panel data analysis. *Pakistan Journal of Commerce and Social Sciences*, *17*(3), 558-587.

Murshed, M. (2024). Can renewable energy transition drive green growth? The role of good governance in promoting carbon emission-adjusted economic growth in next eleven countries. *Innovation and Green Development*, *3*(2), 100123.

Myovella, G., Karacuka, M., & Haucap, J. (2020). Digitalization and economic growth: A comparative analysis of Sub-Saharan Africa and OECD economies. *Telecommunications Policy*, *44*(2), 101856.

N'dri, L. M., Islam, M., & Kakinaka, M. (2021). ICT and environmental sustainability: Any differences in developing countries?. *Journal of Cleaner Production*, *297*, 126642.

OECD (2010). Greener and Smarter: ICTs, The Environment and Climate Change. Paris, France: Organization for Economic Co-operation and Development. Available at www.oecd.org/ site/stitff/45983022.

OECD (2020) OECD work on green growth. https://issuu.com/oecd. publishing/docs/gg_brochure_2019_web

O'Mahony, M., & Vecchi, M. (2005). Quantifying the Impact of ICT Capital on Output Growth: A Heterogeneous Dynamic Panel Approach. *Economica*, *72*(288), 615-633.

Ozcan, B., & Apergis, N. (2018). The Impact of Internet Use on Air Pollution: Evidence from Emerging Countries. *Environmental Science and Pollution Research, 25*(5), 4174-4189.

Ozturk, I., Majeed, M. T., & Khan, S. (2021). Decoupling and decomposition analysis of environmental impact from economic growth: a comparative analysis of Pakistan, India, and China. *Environmental and Ecological Statistics*, *28*, 793-820.

Plepys, A. (2002). The Grey Side of ICT. *Environmental Impact Assessment Review*, 22(5), 509-523.

Quah, (2002). Technology dissemination and economic growth: Some lessons for the new economy. In C.E. Bai, &C. W. Yuen (Eds.), Technology and the new economy (pp. 95–156). Cambridge, MA: MIT Press.

Raheem, I. D., Tiwari, A. K., & Balsalobre-Lorente, D. (2020). The role of ICT and financial development in CO2 emissions and economic growth. *Environmental Science and Pollution Research, 27(2),* 1912-1922.

Razzaq, A., Sharif, A., Ozturk, I., & Skare, M. (2023). Asymmetric influence of digital finance, and renewable energy technology innovation on green growth in China. *Renewable Energy, 202,* 310-319.

Sahoo, M., Gupta, M., & Srivastava, P. (2021). Does information and communication technology and financial development lead to environmental sustainability in India? An empirical insight. *Telematics and Informatics*, *60*, 101598.

Salahuddin, M., Alam, K., & Ozturk, I. (2016). The Effects of Internet Usage and Economic Growth on CO2 Emissions in OECD Countries: A Panel Investigation. *Renewable and Sustainable Energy Reviews, 62*, 1226-1235.

Stiroh, K. J. (2002). Are ICT Spillovers Driving the New economy? *Review of Income and Wealth, 48*(1), 33–57.

Tawiah, V., Zakari, A., & Adedoyin, F. F. (2021). Determinants of green growth in developed and developing countries. *Environmental Science and Pollution Research, 28*(29), 39227-39242.

Ullah, S., Ozturk, I., Majeed, M. T., & Ahmad, W. (2021). Do technological innovations have symmetric or asymmetric effects on environmental quality? Evidence from Pakistan. *Journal of Cleaner Production, 316*, 128239.

Usman, A., Ozturk, I., Hassan, A., Zafar, S. M., & Ullah, S. (2021). The effect of ICT on energy consumption and economic growth in South Asian economies: an empirical analysis. *Telematics and Informatics, 58*, 101537.

World Bank (2024). World Development Indicators. Washington, DC: World Bank. [Online] Online available at: https://databank.worldbank.org/source/world-developmentindicators (Accessed: Feb 12, 2024).

Xie, Z., Ma, J., Huang, S., & Zhu, J. (2023). Digital economy and inclusive green growth: The moderating effect of government environmental regulation. *Environmental Science and Pollution Research, 30*(49), 107938-107955.

Zhang, C., & Liu, C. (2015). The Impact of ICT Industry on CO2 Emissions: A Regional Analysis in China. *Renewable and Sustainable Energy Reviews, 44*(1), 12-19.

Zheng, S., Ahmed, D., Xie, Y., Majeed, M. T., & Hafeez, M. (2023). Green growth and carbon neutrality targets in China: do financial integration and ICT matter?. *Journal of Cleaner Production*, *405*, 136923.

Appendix

Table A1: List of Countries

No	Country	No	Country	No	Country	No	Country
1	Afghanistan	42	Cyprus	83	Kenya	124	Russian Federation
2	Albania	43	Czechia	84	Korea, Rep.	125	Rwanda
3	Algeria	44	Denmark	85	Kuwait	126	Samoa
4	Angola	45	Djibouti	86	Kyrgyz Rep.	127	Saudi Arabia

5	Antigua and Barbuda	46	Dominica	87	Lao PDR	128	Senegal
6	Argentina	47	Dominican Republic	88	Latvia	129	Serbia
7	Armenia	48	Ecuador	89	Lebanon	130	Seychelles
8	Australia	49	Egypt, Arab Rep.	90	Lesotho	131	Sierra Leone
9	Austria	50	El Salvador	91	Libya	132	Singapore
10	Azerbaijan	51	Equatorial Guinea	92	Lithuania	133	Slovak Republic
11	Bahamas, The	52	Eritrea	93	Luxembour g	134	Slovenia
12	Bangladesh	53	Estonia	94	Madagascar	135	Solomon Island
13	Barbados	54	Eswatini	95	Malaysia	136	South Africa
14	Belarus	55	Fiji	96	Mali	137	South Sudan
15	Belgium	56	Finland	97	Malta	138	Spain
16	Belize	57	France	98	Mauritania	139	Sri Lanka
17	Benin	58	Gabon	99	Mauritius	140	Sudan
18	Bhutan	59	Gambia, The	100	Mexico	141	Suriname
19	Bolivia	60	Georgia	101	Micronesia	142	Sweden
20	Bosnia and Herzeg.	61	Germany	102	Moldova	143	Switzerland
21	Botswana	62	Ghana	103	Mongolia	144	Syrian Arab Republic
22	Brazil	63	Greece	104	Montenegro	145	Tajikistan
23	Brunei Darussalam	64	Guatemala	105	Morocco	146	Tanzania
24	Bulgaria	65	Guinea	106	Namibia	147	Thailand
25	Burkina Faso	66	Guinea-Bissau	107	Nepal	148	Timor-Leste
26	Burundi	67	Guyana	108	Netherlands	149	Togo
27	Cabo Verde	68	Haiti	109	New Zealand	150	Tonga
28	Cambodia	69	Honduras	110	Nicaragua	151	Tunisia
29	Cameroon	70	Hungary	111	Niger	152	Türkiye
30	Canada	71	Iceland	112	North Macedonia	153	Uganda
31	Central African Rep.	72	India	113	Norway	154	Ukraine
32	Chad	73	Indonesia	114	Oman	155	UAE
33	Chile	74	Iran, Islamic Rep.	115	Pakistan	156	UK
34	China	75	Iraq	116	Panama	157	United States
35	Colombia	76	Ireland	117	Paraguay	158	Uruguay
36	Comoros	77	Israel	118	Peru	159	Uzbekistan
37	Congo, Dem. Rep.	78	Italy	119	Philippines	160	Vanuatu
38	Congo, Rep.	79	Jamaica	120	Poland	161	Viet Nam
39	Costa Rica	80	Japan	121	Portugal	162	Yemen, Rep.
40	Cote d'Ivoire	81	Jordan	122	Qatar	163	Zambia
41	Croatia	82	Kazakhstan	123	Romania	164	Zimbabwe