Journal of Economic Sciences
Volume 3, Issue 2
https://www.jesciences.com

Analyzing Digital Economy's Role in Global Green Growth Opportunities: An Asymmetric MMQR Approach

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Timeline
Received: Oct 16, 2024
Revised: Nov 13, 2024
Accepted: Nov 16, 2024
Published: Nov 23, 2024

DOI
https://doi.org/10.55603/jes.v3i2.a4

Abstract
In terms of environmental consequences, global economies fail to keep the temperature at the targeted level. The green growth economic opportunity is considered the essential solution to achieve SDG 12, which focuses on producing and consuming sustainable patterns. The connection between green growth economic opportunities (GGEO) and the digital economy (DEI) has been neglected in literature. Thus, to fill this void, the present study analyzes the aggregate influence of the DEI on green growth economic opportunities. The data span 2000-2022 for a panel of 106 economies. This study uses the method of moment quantile regression to assess the influence of the aggregate digital economy, trade (TRDP), government expenditures, urbanization (UBN), and ecological taxes (ETX) on green growth economic opportunities. The outcome demonstrates that the DEI considerably impacts GGEO around the globe in the short, medium, and long run. In addition, the outcomes for sub economic groups, i.e., high-, upper middle-, lower middle-, and low-income economies, also reveal a positive impact of the DEI on green growth. The results for GGEO and TRDP show a positive influence on GGEO. In contrast, UBN and ETX have a negative impact on GGEO. The study suggests some policy recommendations to achieve the sustainable development goal.

Keywords: *Digital Economy, Green Growth, MMQR, SDG*

JEL Classification: O33, Q01, C21, Q42

1. Introduction
The traditional output growth model derives from the substantial use of fossil fuel and industrialization and substantially influences ecological pollution. Global economies receive short-term economic benefits over compromises on long-term sustainability. Thus, the results stimulate emissions, natural resource depletion, and deforestation. All these factors add to ecological changes and cause biodiversity loss (Stern, 2008; Hong et al., 2024; Desha et al., 2010).

The adverse effects of the conventional growth model have pressured environmentalists and researchers to adopt an alternative growth model that balances ecological sustainability and economic development (UNEP, 2011). Without a paradigm shift in output growth, urgent solutions are needed to improve the environmental quality and standard of living and promote the production and consumption of sustainable patterns (Edwards, 2005; Glavič, 2021; Lorek & Spangenberg, 2014).

Hence, the COVID-19 pandemic poses severe climate consequences that enhance the importance of DEI and green growth. Besides, ecological degradation emphasizes the environment, and researchers should adopt digital technologies that provide a sustainable solution through resource efficiency and reduced pollution emissions. Further, the DEI plays a vital role in enhancing efficiency in productivity, accelerating innovative results, and stimulating green productivity (Liu et al., 2024; Xia et al., 2024).

To overcome these environmental challenges, green growth strategies are crucial for attaining the target of sustainable development goals (SDGs). In addition, green growth economic opportunities (GGEO) focus on encouraging economic activities that decrease environmental risk, enhance resource efficiency, and create green jobs in emerging green areas. This growth model aligns with SDG 12, which forces the production and consumption of sustainable patterns.

In addition, the digital economy (DEI) is an economic system based on digital technologies such as digital finance, e-commerce, the Internet, online businesses, etc. It creates green jobs and enhances productivity and efficiency, which stimulate sustainable output growth (Wang et al., 2024). The World Economic Forum (2020) reports demonstrate that the DEI is crucial to achieving sustainable and long-term future prosperity. Furthermore, these findings suggest that economies should prioritize investment in DEIs. It improves environmental quality, promotes an efficient economic system, encourages the production of technological innovations, and minimizes waste. In addition, DEI currently accounts for approximately 15.5% of output growth globally, and by 2021, it will reach 70% globally (WEF, 2020).

On the other hand, global economies can achieve sustainable and long-term prosperity by encouraging investment in green energy, sustainable infrastructure, green growth, and green technology that mitigates the conventional effects of output growth (UNEP, 2011). The GGEO principles in global economies are necessary to ensure future generation growth, protect environmental sustainability, and be socially inclusive.

In addition, the DEI has experienced exponential growth during the past few decades, sharply transforming trade and business practices globally. According to the World Bank (2021), approximately 3 million people use the internet and are engaged in online business activities. Surprisingly, by 2021, up to 2.3 billion people had engaged in online trading and online payments, highlighting the significance of the DEI (World Bank, 2021).

Furthermore, recent studies have recognized DEI and environmental sustainability as crucial elements for reducing the low-carbon future. In addition, the Paris Agreement Agenda 2030 listed the role of DEI in promoting sustainable development. DEI clearly enhances energy efficiency, promotes the development of green technological products, and facilitates efforts toward climate adaptation (UNFCCC, 2016; 2023). Similarly, UNCTAD (2021; 2023) highlights that adaptation and transformation toward DEI are essential to achieve sustainable economic activities.

To the best of our knowledge, this is the first study to measure economic opportunity, an essential component of green growth. The study created an index of GGEO based on four indicators: green trade, green employment, green investment, and green innovations. These indicators are essential for fostering sustainable output growth and minimizing ecological impact. Thus, the GGEO index provides a robust analysis to achieve SDG 12. Second, this study constructs a digital economy index based on six dimensions. Past studies have used a single indicator or dimension to measure the digital economy, which may produce unreliable or biased results. To overcome this deficiency, this study constructs a comprehensive index that provides a reliable and robust outcome. Third, based on empirical findings, this study offers valuable insight for policymakers, researchers, and environmentalists on how the digital economy is essential in achieving SDG 12. Fourth, this study uses an advanced econometric technique, the asymmetric method of moment quantile regression, to inspect the nonlinear influence of the DEI on GGOE and understand the dynamics in the short, median and long run.

Despite this, several studies on DEI and green growth are available in the literature. However, a substantial gap exists in inspecting the nonlinear effect of the DEI on GGEO. In addition, past studies have focused on the linear connection between the digital economy and green growth. The present study fills this void by using asymmetric MMQR analysis. It provides a comprehensive analysis of how DEI is essential to achieving SDGs.

The rest of the study is organized as follows: Section two elaborates on the literature review, the third section explains the methodology and data description, the fourth section highlights the results and discussion, and the final section presents the conclusion and policy suggestions.

2. Literature Review

Owing to their environmental consequences, the DEI and sustainable output growth receive attention. Environmentalists and researchers consider DEI the central pillar for achieving the goal of green growth or protecting the environment from further deterioration. Hence, world economies fail to keep the temperature at the targeted level. Thus, economies shift their resources toward digital economies.

Ozturk and Ullah's study (2022) infers that a rise in the DEI significantly enhances environmental quality, along with resource allocation optimization and encouragement of technological products, resulting in improved sustainability. Furthermore, Li et al. (2020) demonstrated that the DEI is critical in optimizing resource efficiency and minimizing waste, enhancing sustainable output growth. The findings also infer that the rise in the level of the DEI over the period stimulated environmental performance. Similarly, Guo et al. (2023) highlight the importance of DEI and green growth. This suggests a trade-off between DEI and green growth in such a way that increases the level of DEI, leading to significant declines in pollution emissions and causing improvements in environmental performance. However, the study of Naz and Kousar (2024) indicates that globalization stimulates the sustainability of developed economies. Badiru (2024) demonstrates that institutional quality significantly promotes sustainable output growth in west Africa.

A study by Peng et al. (2024) revealed that DEI through blockchain technology improves transparency in supply chain management. Furthermore, using renewable energy sources in big data centers enhances energy efficiency, reducing pollution emissions. Thus, the DEI improves environmental performance through energy efficiency in blockchain technology. Hence, Li et al. (2022) indicate that green technological developments could occur through the DEI. This study considers the DEI as an entailing driver of green growth. In addition, using clean energy sources is linked with ecological innovations, and the DEI plays a role in advancing environmentally friendly innovations.

Ghanem et al. (2022) reported that technological advancement is impossible without improvement in the DEI. Furthermore, the DEI has a spillover effect on increasing sustainable output growth. For example, it creates new economic and business opportunities through innovations, expands new companies, creates green jobs, and results in green growth in world economies. Another study by Rossi et al. (2020) argues that the DEI facilitates every individual's life in society. In the case of students, it eases education. Now, students get an education while staying at home. This reduces travel and transit costs. These activities directly stimulate sustainable output growth in the long run. In addition, Ma and Zhu (2022) suggest that the DEI makes all types of transactions accessible through digital finance. It enhances the productivity of every section of the economy due to instant income-transferring advancement.

Furthermore, the studies of Asongu et al. (2018) and Yi et al. (2022) demonstrate that a green growth level could be attained with the transformation and implementation of a DEI. This significantly reduces the environmental consequences when the DEI endorses the transaction facility at home. It increases efficiency and productivity and reduces household and business class travel and transaction costs, significantly improving environmental quality. However, other studies by Avom et al. (2020), Li et al. (2020), and Qin et al. (2022) suggest that DEI improves energy efficiency through energy savings with the help of innovative industries, smart cities, and intelligent energy systems. In addition, the DEI is considered an essential driver of digital finances, stimulating investment activities and consumption levels, causing pollution emissions, and reducing sustainable output growth. It is thought that DEI could positively and negatively influence the environment.

Additionally, many researchers suggest that the DEI has a substantial and positive connection with technological innovations (Horoshko et al., 20221; Pan et al., 2022). Therefore, the DEI incorporates knowledge associated with new products and technologies based on blockchain, AI, cloud computing, and other affiliations. New technologies replace traditional technology, provide new opportunities for the business class to establish a business, and help in innovative industrial products. In addition, innovation in the industrial sector produces energy-efficient products that emit fewer emissions and improve environmental performance (Kahouli et al., 2022; Yang et al., 2022). Moreover, another study by Oyinlola et al. (2021) argues that it improves productivity and opens new economic opportunities.

Another study by Liu et al. (2024) highlights the connection between DEI and sustainable outgrowth from 2011 to 2022 in China. The study uses a panel fixed effect to find the long-run coefficient values. Thus, the outcome indicates that DEI significantly promotes sustainable output growth. Similarly, the study of Ma et al. (2024) finds similar results for the 282 Chinese cities. The findings depict that the DEI enhances sustainable development. In addition, Ranta et al. (2021) DEI stimulates green technologies and influences efficiency, significantly affecting sustainable output growth. Further, the DEI plays a crucial role in reducing asymmetric information, which substantially reduces market uncertainty, results in declines in the environmental effects, and leads to an upsurge in sustainable output growth (Xu and Hou., 2022; Hidalgo et al., 2020).

On the other hand, the DEI may have a negative effect on sustainable output growth. Wang et al. (2023) depict that the development of digital infrastructure and other digital products, such as data centers and cloud computing, enhance the use of energy utilization, which significantly stimulates pollution emissions and results in declines in sustainable output growth. Another study by Robinson (2009) highlights that the productivity of digital devices is increased; it not only raises energy consumption but also enhances electronic waste, promoting ecological pollution. Similarly, Firoozi et al. (2024) point out that DEI promotes resource efficiency and postulates environmental challenges.

3. Methodology and Data

To apply the appropriate technique, the 1st step is to investigate the cross-sectional dependence in the panel series. CSD may be present when we take data from global economies or an extensive panel dataset. If this problem is not solved, it will yield unreliable, unacceptable, and invalid outcomes (Ng et al., 2020). Thus, in the case of CSD, traditional unit root tests may yield biased outcomes. Hence, the study uses the CSD proposed by Pesaran (2015) to address CSD problems in the case of CSD. The study employs 2nd generation "CIPS and CADF" unit root tests to inspect the order of stationarity. The mathematical expression is written as:

$$\Delta Y_{it} = \Delta \oint_{it} + \beta_i X_{it} + \delta_{it} + \sum_{j=1}^{n} \theta_{ij} \Delta X_{i,t-j} + \alpha_{it} \quad (1)$$

$$\text{CIPS} = N^{-1} \sum_{I=1}^{N} CADF_1 \quad (2)$$

Here, α_{it}, $\Delta\oint_{it}$, T, Δ, and X_{it} "indicates white noise, intercept, time period, variances operators and factor estimation." Thus, the CIPS unit analyzes the impact of the enduring factors, and the order of integration of each attribute is examined. It focuses on the first differences. After each attribute's integration order is analyzed, the 2nd generation Westerlund cointegration test is used to inspect the cointegration

(Westerlund, 2007). In addition, this test is better than other traditional cointegration tests. This is because it considers CSD and heterogeneity. However, traditional cointegration tests have fewer power residual bases and allow standard factor residuals (Persyn & Westerlund, 2008). It can be expressed as:

$$\Delta Y_{it} = \mathcal{Z}_i d_t + a_i Y_{i,t-1} + \Omega_i X_{i,t-1} + \sum_{j=1}^{pi} \psi_{i,j} \Delta Y_{i,t-1} + \sum_{j=qi}^{pi} \omega_{i,j} \Delta X_{i,t-1} + t_{it} \quad (3)$$

where $\Omega_i = -a_i \beta_i$ represents the adjustments of speed after a shock toward the equilibrium level. Hence, $a_i$reveals the presence or absence of cointegration in the panel data series. For example, if the value of $a_i < o$, it indicates the existence of cointegration. In contrast, if $a_i = 0$, there is no cointegration in the model. Additionally, the Westerlund cointegration reveals that four types of test statistics, Ga and Gt, demonstrate cointegration in the panel series. In contrast, the other two test statistics, Pa and Pt, inspect cross-sectional cointegration in the panel model.

After we have shown that the long-run cointegration is true, we estimate the long-run coefficients to ascertain how the dependent variable reacts to shocks in the variables that explain it. By Morshed and Hossain (2022), the following is the basic model that we developed:

$$GGEO_t = DEI_t + GGE_t + TRDP_t + UBN_t + ETX_t + e_t \quad (4)$$

Here, GGEO is a dependent variable representing the green growth economic opportunity. The other DEI is the primary variable and denotes the DEI index. Other control variables are general government expenditures (GGE), trade openness (TRDP), urbanization (URB), and ecological taxes (ETX). Details and descriptions of the variables are shown in Table 1. Thus, to accomplish this goal, this study uses an innovative moment-quantile regression (MMQR) method proposed by (Machado etl., 2019). The utilization of this method can track the heterogeneous and distributional differences that occur across various quantiles between the response variable and the chosen determinants. However, when unobserved heterogeneity exists across the panel cross-section, the standard quantile regression technique (Koenker & Bassett, 1982) performs poorly. This is because it analyses the asymmetric properties of variable distributions. Zhu et al. (2016) reported that this technique could perform better. Thus, the current research employs novel econometric techniques to address this issue.

It has various advantages over traditional quantile methods. Furthermore, it determines the whole distribution, analyzes the heterogeneous covariance effect of the dependent variables, and considers the individual fixed effects. Furthermore, the MMQR can address the covariance influence and endogeneity issues compared with conventional quantile methods, which cannot capture these issues (the studies of Canay, 2011; Koenker & Bassett, 1982). Thus, the MMQR provides validated and reliable turns in terms of endogeneity, nonnormality, and nonlinearity. Additionally, the MMQR could consider the endogeneity properties of the dependent variables and capture the model's location-based asymmetries (Awan et al., 2022). However, the following model mathematically demonstrated as quantiles $Q_Y \left(\frac{t}{X}\right)$:

$$Y_{it} = a_i + X`_{i,t} \beta + \left(\mathcal{Z}_i Z`_{it} \psi\right) + U_{it} \quad (5)$$

In the above equation, Y_{it} & $X`_{i,t}$ denote the dependent, independent, and explanatory identically distributed attributes, respectively. Furthermore, the coefficient values of attributes such as α, β, $\mathcal{Z}$, and ψ need to be determined. Additionally, Z is a k-vector of the known components of X, where i=1,……,n represents the fixed effect of i individuals. Thus, the probability value of P is $\{\mathcal{Z}_i + Z`_{it} \psi .0\}$. Additionally, $U_{it}$ denotes the identical and independent distribution across i individuals and, vie, time and perpendicular to $X^{`}_{it}$, is standardized to the method of moment execution. Thus, the following lkw et al. (20202) is denoted as:

$$Q_Y\left(\frac{t}{X_{it}}\right) = \left(a_i + \left(\delta_i\left({}^{q}/_{t}\right)\right)\right) + X^{`}_{i,t}\,\beta + Z^{`}_{it}\,\psi\left({}^{q}/_{t}\right) \quad (6)$$

Here, $Q_Y\left(\frac{t}{X_{it}}\right)$ represents the dependent attributes of the distribution's quantile, and Y_{it} *as GGI* and $X^{`}_{i,t}$ represent the explanatory variable vectors, i.e., DEI, GGE, TRDP, UBN, and ETX. Additionally, i denotes the individual quantiles, t represents the fixed effect, and the scalar coefficient is $a_i t = X_i + \delta_i q(t)$. Thus, the MMQR model can be written in basic form:

$$QGGI_{it}\left({}^{t_k}/_{\alpha_i}, x_{it}\right) = a_i + \psi_{1t} DEI_{it} + \psi_{2t} GGE_{it} + \psi_{1t} TRDP_{it} + \psi_{1t} UBN_{it} + \psi_{1t} ETX_{it} \quad (7)$$

Thus, MMQR is the primary method used in the present study. After the MMQR method, this study uses two-step system GMM methods for robustness analysis. The two-step GGM method could address endogeneity issues and provide robust results. Hence, the two-step system GMM is the most potent method compared with traditional methods, such as dynamic OLS, fully modified OLS, OLS, and panel ARDL methods. However, MMQR has a few limitations. For example, sometimes, when the researcher finds multiple quantiles, it may be challenging to interpret the specific results if different quantiles give different results. 2nd, it is suitable for large data sets, in the case of small datasets, if it gives biased outcomes. Lastly, MMQR applies to large data sets. It may take time and power.

Figure: 1 Econometric Methodology Flow Chart

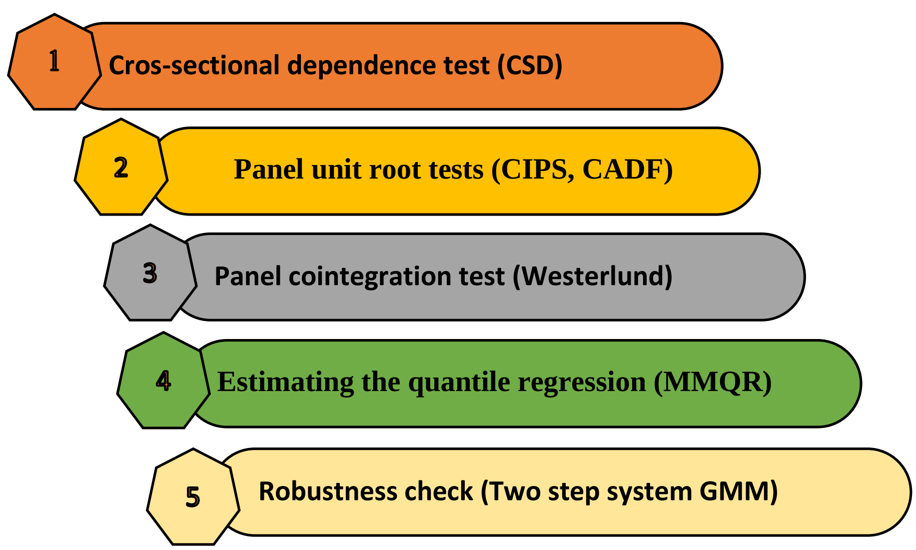


Table 1: Details and Description of Variables

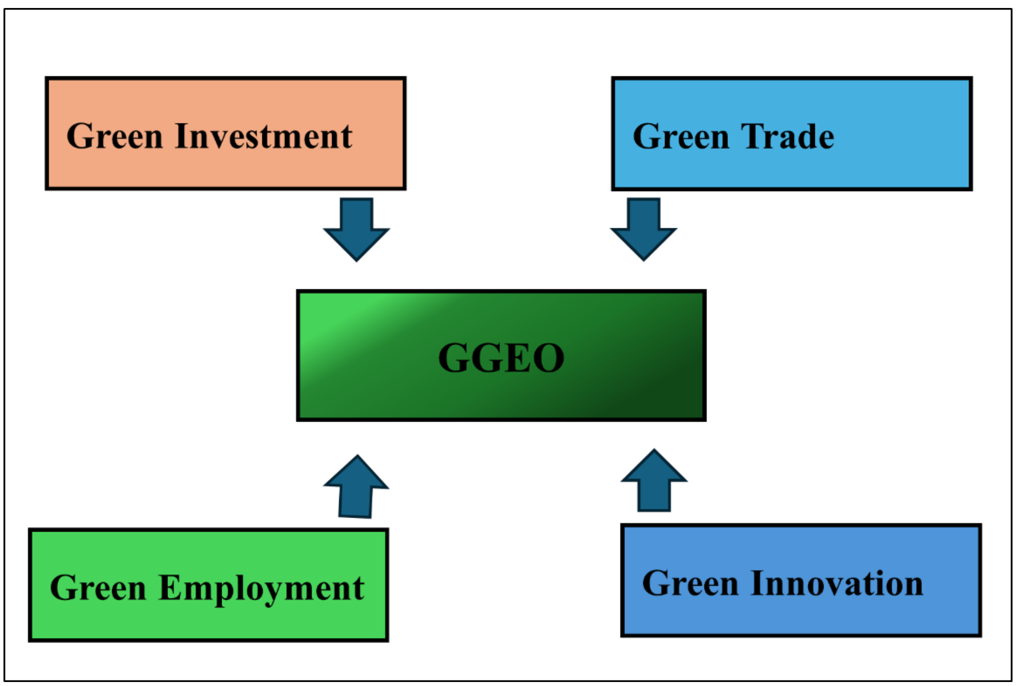
Variable	Symbol	Description of indicators	Source
Green growth economic opportunity	GEEO	The author constructed this index, which comprises four indicators: green trade, green investment, green innovations, and green employment.	Author`s owner

Digital economy index	DEI	This index consists of 6 different dimensions and each dimension consists of various indicators, which the author develops.	Author`s owner
Trade openness	TRDOP	Trade openness is calculated as the sum of exports and imports of goods and services as a percentage of GDP	WDI
Urbanisation	UBN	urbanization represents the percentage of the total population living in urban areas	WDI
Ecological taxes	ETX	The ecological tax is tax revenue as a percentage of GDP.	OECD Statistics
General government expenditures	GGE	The general government expenditures is measured by total current government spending.	WDI

3.1 Data

The present study aims to inspect the aggregate influence of DEI on green economy opportunities (GGEO) from 2000-2022. It uses a panel of 106 economies and incorporates the additional variables GGEO, TRDP, UBN, and ETX. Thus, the GGEO is a dependent study variable. The study creates an index of green growth economic opportunities based on a growth index report (2020). The index has four components: green trade, green investment, green innovations, and green employment. Figure 2 shows the graphical construction of the GGOI. Furthermore, the index is constructed via principal component analysis (PCA). Several studies have used PCA to construct environmental and social study indices (Dabbous, 2018; Ahmed et al., 2022; Latif et al., 2018). Hence, PCA gives various advantages to each variable, reduces the dimensions, and ensures that the index captures the most substantial variances. In addition, details and an index description are provided in Table 2.

Figure 2: Graphical construction of the GGEO index



The DEI is reflected primarily in information and communication technology research. However, there is a lack of clear understanding of what it entails. Consequently, the indicator systems constructed are often flawed and one-sided. Additionally, the lack of standardized methodologies for calculating the development level of the DEI makes accurate calculations challenging. To address this, we selected 29 indicators to comprehensively measure the national DEI's development stage. These indicators cover DEI infrastructure, financial systems and services, and social support systems, including healthcare provisions. These indicators are based on previous studies (Qi et al., 2021; Xu et al., 2019) and publications by international bodies such as the International Telecommunication Union and the World Economic Forum. Table 3 provides details about each indicator and dimension of the DEI. Fig. 3 shows the graphical details of the DE index.

Figure 3: Construction of the Digital Economy Index

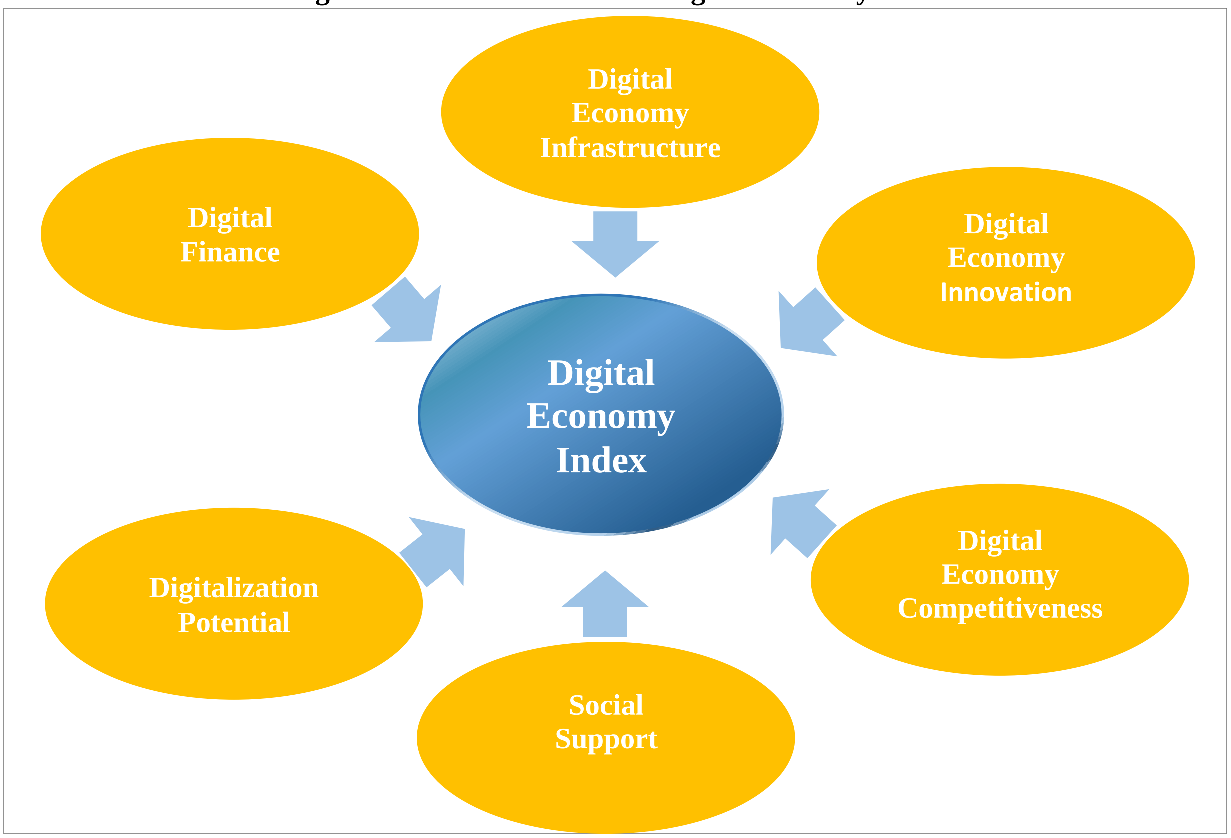


Table 2: Green Growth Economic Opportunities

Indicators	Symbol	Description of indicators	Source
Green investment	gi	"Adjusted net savings, which takes into account the economic impact of emission damage as a percentage of Gross National Income (%GNI)"	WDI
Green trade	gr	"Percentage of environmental goods' share in total exports	UN
Green employment	ge	The proportion of environmentally friendly jobs in the whole manufacturing workforce."	OECD

Green innovation	gin	"The proportion of patent applications in the field of environmental technology relative to the overall number of people employed"	WIPO

Table 3: Variables for the Construction of the Index for Digital Economy

	Symbols	Secondary indicators	Data Source
Primary index Digital economy infrastructure	DI	"Percentage of the population uses the internet"	ITU
		"Fixed telephone subscribers per 100 people"	ITU
		"Subscribers per 100 people of fixed broadband"	ITU
		"Bandwidth users per internet user internationally in (bit/s)"	ITU
		"% of households with internet"	ITU
		"% of households with computer"	ITU
		"Mobile cellular subscriptions (per 100 people)"	ITU
		"Active mobile-broadband subscriptions (per 100 inhabitants)"	ITU
Digital economy innovation environment	DEIE	"Venture capital availability"	WEF
		"Scientific and technical journal articles"	WDI
		"Human capital index"	EGOVKB
		"Intellectual property protection"	WEF
		"Availability of latest technologies"	WEF
		"School enrollment, tertiary (% gross)"	WDI
National digital competitiveness	NDC	"ICT goods exports (% of total goods exports)"	WDI
		"Government information disclosure and network participation"	EGOVKB
		"Government online service index"	EGOVKB
		"ICT service exports (% of service exports)"	WDI
Digital Finance	DF	"Mobile money account (% age 15+)"	WDI
		"Owns a credit card (% age 15+)"	WDI
		"Owns a debit card (% age 15+)"	WDI
		"Used a mobile phone or the internet to pay bills (% age 15+)"	WDI
Digitalization potential	DP	"Regional research and development personnel"	OECD
		"R and D intensity"	WDI
		"Proportion of scientific spending in the financial budget"	OECD
		"Number of college students"	WDI
Social Support	SS	"Per capita value added of service industry"	WDI

Note: *ITU is the International Telecommunication Union; WEF is the World Economic Forum; WDI is the World Development Indicator; OECD is the Organization for Economic Cooperation and Development; EGOVKB is the United Nations E-Government knowledgebase*

4. Results and Discussions

The descriptive statistics are displayed in Table 4. The average value of the GGEO is -0.241, and the minimum and maximum values range from -3.287 to 7.952, indicating large variations. Furthermore, the mean value of the DEI is 0.209, and the maximum and minimum values significantly differ. However, the mean value of TRDP is greater than that of the other variables, and there is a large difference between the maximum and minimum values. This indicates that trade has a significant effect on economic activities. The study uses data from global economies. Hence, economies have integrated due to trade and globalization, and cross-sectional dependence (CSD) is possible. The study uses Pesarsn's (2004) CSD tests, and the turnout is presented in Table 5. The CSD test indicates the existence of CSD in all considered variables. Panel b elaborates on the slope heterogeneity tests. The outcome shows the presence of heterogeneity in the t statistics and adjusted t statistics at the 1% significance level. This confirms the substantial slope heterogeneity in the model across all attributes.

Table 4: Descriptive Statistics

	GGEO	DEI	GGE	TRDP	UBN	ETX
Mean	-0.241	0.209	15.510	85.383	1.999	1.730
Maximum	7.952	10.926	43.482	437.327	19.612	6.4
Minimum	-3.287	-6.13615	1	2	-14.025	-1.53
Jarque-Bera	1476.573	161.804	300.199	9460.04	18071.9	28.276
Probability	0.000	0.000	0.000	0.000	0.000	0.000

Table 5: Cross-sectional Dependence and Slope Heterogeneity Tests

Panel A		
Variables	T-Stats.	
GGEO	41.990***	
DEI	336.212***	
GGE	41.90***	
TRDP	50.65***	
UBN	19.144***	
ETX	19.31***	
Panel B		
Slope Heterogeneity test		
	$\tilde{\Delta}$	$\tilde{\Delta}_{Adjusted}$
Model	32.553 ***	39.037***

Note: *** indicates the 1% significance level—source: Authors' estimation.

Once the CSD is checked, the next step is to inspect the unit root of each incorporated variable. The results are presented in Table 6. For these purposes, the study uses 2nd generation unit root tests, i.e., CADF and CIPS; the outcome indicates that GGI, GGE, TRDP, and EX are stationary after taking the first differences. On the other hand, the DEI and UBN are stationary at a given level. Hence, both tests' outcomes are similar, indicating the tests' reliability. Thus, after performing the unit root tests, the Westerlund cointegration tests are used to inspect the cointegration among the panel series. The findings from Westerlund demonstrate the presence of cointegrations among the panel series, and the outcome is displayed in Table 7.

Table 6: Second-generation Unit Root Tests

	GGEO	DEI	GGE	TRDP	UBN	ETX
CADF						
I (0)	-0.996	-2.098***	-1.472	-1.034	-1.996**	-0.900
I (1)	-31.326***		-3.651***	-3.428***		-2.699***
CIPS						
I (0)	-1.720	-2.434***	-2.242**	-2.932	-1.17	-1.850
I (1)	-4.652***			-1.905**	-3.888*	-2.699**

Note: *** & ** indicate significance at the 1% and 5% levels, respectively
Source: Authors' estimation.

Table 7: Westerlund (2007) cointegration test

Statistic	Gt	Ga	Pt	Pa
Model	-2.758***	-6.993***	-27.616***	-18.053***

Note: *** indicates the 1% significance level—source: Authors' estimation.

Also, following a series of preliminary tests, the MMQR estimation approach is applied to evaluate the short-, medium-, and long-term quantiles. Results from the application of MMQR show that DEI positively and significantly relates to green growth within the short, medium, and long-term quantiles. A 1 percent increase in DEI slightly increases GGEO by 0.093, 0.092, and 0.093 in the short, medium, and long term, respectively. Moreover, the result of GGE suggests a positive relationship with GGI over the short and medium span. Global outcomes are displayed in Table 8. On the other hand, a 1 percent improvement in GGEO suggests the levels of GGE in the simulations would be about 0.014 and 0.009 over the short and medium horizons, respectively. However, the results also emphasize that UBN and ETX negatively relate to GGEO over the short, medium, and long run. A 1 percent increase in UBN and ETX leads to the levels of GGEO falling by – 0.074 and – 0.043 over the short run, – 0.086 and – 0.084 for the median run quantiles, and –0.110 and -0.084 for the long run quantiles respectively.
As such, the findings indicate that TRRDP has a significant and beneficial impact on GGI in the short, middle, and long run.

Table 8: MMQR Estimates for Global Economies

	Short run quantiles		Median run quantiles	Long run quantiles	
	0.10	0.25	0.50	0.75	0.90
DEI	0.093***	0.093***	0.092***	0.092***	0.092***
GGE	0.019***	0.014***	0.009*	0.002	0.001*
TRDP	0.004	0.004***	0.004***	0.007***	0.009***
UBN	-0.062**	-0.074***	-0.086***	-0.100***	-0.110***
ETX	-0.004	-0.043***	-0.084***	-0.133***	-0.169***

Note: ***, **, and * signify the 1%, 5%, and 10% significance levels, respectively.
Source: Authors' estimation.

4.1 Robustness analysis

The study employs a two-step system GGM method for robustness analysis, as seen in Table 9, where DEI enhances GGI in the long term. This figure estimates that the effect of a 1% increase in the DEI translates to about a 0.817% increase in the GGEO. Therefore, the finding for GGE about GGI is that GGE is negatively correlated. It has been estimated that a 1% rise in GGE brings an absolute drop of GGI of roughly 0.013% in the long-term views. TRDP tends to positively influence GGI at short, medium, and extended quarter sizes. However, it indicates. For example, a change in TRDP of 1% results in a rise in GGI Use of approximately 0.004%, 0.007%, and 0.009% in median, short, and long-run estimates, respectively. The findings from the two systems, GMM, support that GGI in levels goes down by 0.003% for every 1% increase in UBN and 0.029% for every 1% ETX in the long run when both were raised separately. Thus, the two-step system GMM interpretations yield support for the workings and the recommendations of MMQR. Hence, these findings suffice to establish accuracy as well as the consistency of the findings obtained.

Table 9: System GMM Two-step estimates for global economies

	Coefficient Value	**Prob.**
L. GGEO	0.817***	0.000
DEI	0.042***	0.000
GGE	-0.013***	0.000
TRDOP	0.002***	0.000
URBN	-0.003***	0.000
ETX	-0.029***	0.000
Constant		0.000
Observations	2330	
Wald test		45216.58

Note: ***, **, and * signify the 1%, 5%, and 10% significance levels, respectively.
Source: Authors' estimation.

4.2 Heterogeneous analysis across countries' income groups

The MMQR estimates across various income group economies reveal diverse relationships among the variables. The turnout is displayed in Tables 10, 11, 12, and 13. In high-income economies, the DEI index (DEI) positively affects the lower quantiles but becomes insignificant at higher quantiles. Conversely, GGE significantly negatively affects higher quantiles. TRDP consistently has a positive effect across all quantiles, whereas urbanization (UBN) negatively impacts all quantiles. ETX consistently has a strong positive effect across quantiles.

In upper middle-income economies, DEI has a progressively stronger positive effect across quantiles, whereas GGEO significantly negatively impacts lower quantiles. TRDP positively influences all quantiles, whereas UBN and ETX positively impact lower quantiles but diminish or turn negative at higher quantiles. The DEI maintains a robust positive influence across all quantiles for lower-middle-income economies, whereas the GGEO and UBN have mixed or negative impacts. TRDP positively affects higher quantiles, and ETX consistently negatively influences all quantiles.

In low-income economies, DEI starts insignificantly but becomes positive at higher quantiles, whereas GGE is mostly insignificant except at higher quantiles where it is positive. TRDP has a positive effect in the middle to higher quantiles, UBN consistently positively influences quantiles, and ETX has a significant negative effect throughout. These results highlight varying dynamics based on income levels, with substantial implications for policy across different economic contexts.

Table 10: MMQR estimates of high-income group economies

	Short run quantiles		Median run quantiles	Long run quantiles	
	0.10	0.25	0.50	0.75	0.90
DEI	0.068***	0.047***	0.026**	0.001	0.018**
GGE	0.001	-0.012	-0.025***	-0.424***	-0.055***
TRDP	-0.002*	0.001***	0.004***	0.007***	0.010***
UBN	-0.073***	-0.092***	-0.109***	-0.131***	-0.149***
ETX	0.153***	0.161***	0.168***	0.177***	0.184***

Note: ***, **, and * signify the 1%, 5%, and 10% significance levels, respectively.
Source: Authors' estimation

Table 11: MMQR Estimates of Upper-Middle-Income Group Economies

	Short run quantiles		Median run quantiles	Long run quantiles	
	0.10	0.25	0.50	0.75	0.90
DEI	0.051	0.143***	0.218***	0.301***	0.442***
GGE	-0.062***	-0.039***	-0.021	-0.008	0.034
TRDP	0.007***	0.007***	0.006***	0.005***	0.004
UBN	0.200***	0.254***	0.299***	0.348***	0.0432***
ETX	0.165***	0.094***	0.037	-0.026	-2.347

Note: ***, **, and * signify the 1%, 5%, and 10% significance levels, respectively.
Source: Authors' estimation

Table 12: MMQR Estimates of Low- to Middle-income Group Economies

	Short run quantiles		Median run quantiles	Long run quantiles	
	0.10	0.25	0.50	0.75	0.90
DEI	0.274***	0.239***	0.185***	0.149***	0.124***
GGE	0.018	0.014	0.009	0.005	0.003
TRDP	-0.009	0.001	0.005***	0.008***	0.010***
UBN	0.034	-0.014	-0.090***	-0.139***	-0.175***
ETX	-0.422***	-0.432***	-0.447***	-0.457***	-0.465***

Note: ***, **, and * signify the 1%, 5%, and 10% significance levels, respectively.
Source: Authors' estimation

Table 13: MMQR estimates of low-income group economies

	Short run quantiles		Median run quantiles	Long run quantiles	
	0.10	0.25	0.50	0.75	0.90

DEI	-0.017	-0.415	0.065*	0.093***	0.122***
GGE	-0.024	-0.130	-0.002	0.011	0.024***
TRDP	0.009	0.007	0.006***	0.004**	0.002*
UBN	0.095	0.177***	0.259***	0.359***	0.459***
ETX	-0.512***	-0.638***	-0.764***	-0916***	-1.068***

Note: ***, **, and * signify the 1%, 5%, and 10% significance levels, respectively.

Source: Authors' estimation

4.3 Discussion

The outcome from MMQR indicates that DEIs are positively connected with GGEO around the globe in the short, medium, and long run. Furthermore, the findings show that DEIs positively connect with GGEO across various income groups, especially in the long run. Thus, the behavior of the DEI is persistent around the globe. For heterogeneity, i.e., in income group-level analysis, the DEI is the most significant pillar for achieving sustainable development goals and protecting the environment from further deterioration. The DEI enhances the GGEO through various channels, first stimulating innovative processes, developing new clean technologies, and encouraging industrial units to upgrade their technology from high emissions to more sustainable production techniques. In this way, global economies can achieve SDGs (Xin et al., 2023). Second, digital economies across various sectors stimulate operational efficiency, reduce resource consumption, increase productivity, and increase sustainable output growth (Feroz et al., 2021; Luo et al., 2022). The DEI allows people to connect globally, collaborate, and share ideas, ultimately enhancing technological innovations and improving GGEO. Thus, low-income economies benefit from the DEI through this channel and enhance sustainable output growth (Li et al., 2020).

Moreover, the turnout for the variable GGE positively influences GGEO in the median, short-, and long-run global economies. Surprisingly, the outcome for high-income economies adversely affects GGEO in the median and long run only. In contrast, for low-income economies, GGE positively affects GGEO in the long run. In addition, GGE is considered a crucial determinant of GGEO (López et al., 2011; Fayissa & Nsiah, 2013). Thus, government spending on educational upgrades results in the transformation of the industrial sector. Investing in human capital and industrial activities may reduce emissions and enhance GGEO. Additionally, the government spends time on research and development and encourages society to adopt green and eco-friendly technologies, enhancing the GGEO level. On the other hand, the government increases spending on public goods to stimulate output growth. Hence, increasing trends in growth have resulted in worsening environmental quality (We and Zhou, 2021).

The following independent variable is TRDP. The findings infer that TRDP demonstrates a positive link with GGEO in the short, medium, and long-run worldwide and across various income levels. Hence, the TRDP behaviour is consistent globally and across various income levels. This finding indicates that TRDP is also a crucial determinant of GGEO. The reason is that TRDP provides facilities to develop economies, imports energy effects and environmentally friendly technologies, optimizes resource efficiency, and encourages sustainable output growth (Ahmad et al., 2022; Huang, 2023; Copeland, 2012). Surprisingly, the findings show that UBN harms global GGEO and high and lower middle income in the median and long run. In comparison, the outcomes for upper and lower middle incomes depict a negative link with GGEO. Hence, owing to its complex linkage, UBN has different influences on GGEO worldwide and across various income levels. In addition, unplanned and sharp growth in UBN increases resource consumption, leading to the degradation of environmental performance and reducing the GGEO level.

Furthermore, a negative or positive linkage of UBN depends on environmental policies, industrial structure, and economic progress (Kwilinski et al., 2023; Wang et al., 2022).

The findings for ETX imply a negative link with GGEO worldwide in the short, medium, and long run in the lower-middle- and lower-income economies. However, the outcomes for high income reveal a positive connection with GGEO in the short median and long run. Although the purpose of the ETX is to protect environmental sustainability, it has different effects across different income group levels. When the government imposes ETX, the cost of products increases, and the financial burden on consumers and the business class increases. This may affect economic development, and due to the extra burden, industrial units cannot invest in clean technologies. These factors and the rising cost of goods and services adversely affect GGEO (Okombi et al.,2024; World Bank, 2022). However, high-income economies reinvest ETX in environmentally friendly technologies. Furthermore, these economies efficiently manage financial resources, and institutions work allegiantly to impose ETX, stimulating the GGEO in high-income groups (Mahmood et al., 2022; Saleem et al., 2019).

5. Summary and Conclusion

This study assesses the overall importance of DEI on green growth economic opportunities. It also adds GGEO, TRDP, UBN, and ETX as other variables. The data extends from 2000 to 2022 for a panel of 106 economies. In addition, in this research, the authors apply MMQR methods to explore how the DEI could nonlinearly affect green growth economic opportunities. Moreover, to increase confidence in the robustness of the analysis, we use the two-step system GMM, which can solve the problem of endogeneity and give valid estimation results. The MMQR result demonstrates that the DEI also influences GGEO in the short, middle, and long term in countries worldwide. Other results also show that GGEO is influenced positively by DEI in countries at varying group levels of economy, namely high-income, upper-middle-income, lower-middle-income, and low-income countries. Results of the two-step system GMM, as well as findings of the MMQR estimates, are such that.

Moreover, the empirical findings from the global sample and heterogeneous analysis support the evidence that the DEI is considered the central economic pillar after the industrial and agricultural economies in determining the sustainable development of the economy. It may play a key role in achieving SDG number 12, which supports the production and consumption of sustainable goods and services. Additionally, the present study indicates that DEI plays a vital role in promoting the GGEO across various income levels. However, the effect of DEI on various income levels is different due to investment and development in digital infrastructures, especially in developing countries, focusing more on green investment. On the other hand, developing economies face various challenges with budgets, limited access to digital technologies, and skills shortages.

Thus, based on empirical findings, several policy recommendations are suggested to stimulate the influence of the DEI on the GGEO for global economies. High-income economies should promote clean and green innovations to maximize digital efficiency and support sustainable digital practices. On the other hand, low-income economies prioritize investment in digital infrastructure, essential for sustainable output growth. Government bodies and economic stakeholders should invest in the promotion of digital infrastructure and digital literacy and ensure access to digital technologies. Furthermore, given the leverage for digital advancement, the government should encourage innovation and green technological development. This could be achieved through public-private partnerships, tax incentives, and subsidies. In addition, international cooperation should share best practices and technologies that may drive sustainable development globally. Hence, the DEI initiative with SDGs, specifically SDG number 12, will help and align with output growth and environmental sustainability.

Acknowledgments
The authors acknowledge the useful comments from the Editor and anonymous reviewers. Certainly, all remaining errors are our own.
Data Availability Statement
The data that support the findings of this study are available from the corresponding author upon reasonable request.
Disclosure statement
No potential conflict of interest was reported by the author(s).
Funding if any
Nil

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