



The Impact of Renewable Energy, Green Finance, and Carbon Emission on Economic Growth: Perspective from Newly Industrialized Economies

Agyemang Kwasi Sampene¹ · Takyi Kwabena Nsiah² · John Wiredu³

Received: 29 December 2023 / Revised: 14 July 2024 / Accepted: 16 July 2024 / Published online: 29 July 2024
 © The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2024

Abstract

This research assesses the dynamic affiliation among carbon emission, green finance, eco-innovation, international trade, digitalization, and cleaner energy and economic progress among the ten industrialized nations, namely Indonesia, Thailand, South Africa, Turkey, Philippines, Malaysia, India, Mexico, China, and Brazil, over the period 1990–2020. Utilizing a panel dataset, this research employs econometric approaches comprising of common correlated effects mean group (CCEG) and augmented mean group (AMG) to analyze the effects comprehensively. The results of this investigation reveal several noteworthy findings. Carbon emissions consistently adversely influence economic growth, underscoring the detrimental impact of environmental pollution on economic development. In contrast, eco-innovation, green finance, international trade, digitalization, and renewable energy have been discovered to impact economic growth significantly. This underscores the significance of investing in innovation that promotes environmental sustainability to drive economic development. This research offers pertinent knowledge regarding the interplay of environmental and economic indicators within the context of industrialized nations. By reducing carbon footprints and fostering sustainable economic practices, the research underscores the necessity for integrating green finance and renewable energy to achieve long-term ecological balance and economic resilience.

Keywords Carbon emissions · Eco-innovation · International trade · Digitalization · Green finance · Renewable energy · Economic growth

Abbreviations

CCEG	Common correlated effects mean group
AMG	Augmented mean group
EG	Economic growth
NIEs	Newly industrialized economies
CE	Carbon emission

ECO	Eco-innovation
INT	International trade
DIG	Digitalization
GF	Green finance
REC	Renewable energy
MENA	Middle East and North Africa
CUP-FM	Continuously updated fully modified
CUP-BC	Continuously updated bias-corrected
DID	Difference-in-difference method
FGLS	Feasible generalized least squares
PCSE	Panel-corrected standard errors
WDI	World development indicators
OECD	Organization for economic co-operation and development
CIPS	Cross-sectional Im Pesaran and Shin
CADF	Cross-sectional augmented Dickey–Fuller
CS-ARDL	Cross-sectional augmented autoregressive distributed lag
C-DP	Cobb–Douglas production
MINT	Mexico, Indonesia, Nigeria, and Turkey

✉ Agyemang Kwasi Sampene
 akwasiagyemang91@gmail.com

Takyi Kwabena Nsiah
 takyi@utb.cz

John Wiredu
 johnwiredu50@gmail.com

¹ School of Management, Jiangsu University,
 Zhenjiang 212013, Jiangsu, China

² Department of Applied Economics, Tomas Bata University,
 Mostni 5139, 76001 Zlín, Czech Republic

³ School of Management, Northwestern
 Polytechnical University, Xi'an 710072, Shaanxi,
 People's Republic of China

1 Introduction

As global economies traverse the difficulties in recent times, the search for sustainable economic development has never been more relevant. Newly industrialized economies (NIEs) are especially focused, serving as crucial incubators for integrating sustainable measures for environmental quality and economic growth. The ten industrialized economies (Indonesia, Thailand, South Africa, Turkey, Philippines, Malaysia, India, Mexico, China, and Brazil) are undeniably on a trajectory of economic evolution. Nevertheless, they face some momentous challenges on their path to growth. The need to maintain sustainable economic growth (EG) rates while addressing challenges like carbon emissions (CE) is one of the most pressing (Habiba and Xinbang 2023; Wiredu et al. 2023). Global EG and CE may become more correlated, aggravating ‘expansive coupling’. Escalating levels of CE might raise concerns about energy sustainability and environmental pollution, potentially contributing to catastrophic environmental events. Such events might significantly aggravate the effects of climate change (Feng et al. 2024; Sampene et al. 2024a, b). According to Sampene et al. (2024a, b), increased EG drives a spike in production intending to meet a wider spectrum of human needs, which increases the generation of waste and pollution, straining the ecosystem and its natural resources. The increase in economic activity leads to an increase in energy demand; data from 2010 show that emerging economies surpassed developed countries in energy consumption by 16%, and it is projected that by 2040, their energy consumption will outstrip that of developed countries by 88% (Alam et al. 2016).

Furthermore, World Bank figures show that the global economy grew from 37.88 trillion to 84.85 trillion US dollars between 1990 and 2019. Accordingly, in an era marked by increasing environmental concerns and the urgent need to mitigate climate change, these elements play dynamic and interrelated roles in shaping the economic landscapes of advanced economies. These elements are carbon emissions, eco-innovation, international trade, digitalization, green finance, and renewable energy. While contributing significantly to global economic output, these nations grapple with CE’s detrimental consequences on ecological health (Nadiri et al. 2024; Zhang et al. 2017). The quest of EG often conflicts with sustainability goals, exacerbated by international trade dynamics that consider the current gains, not depreciation, to the environmental concerns. Green innovation and eco-innovation become critical components in addressing this dilemma, necessitating technologies and practices that are environmentally friendly (Tang, Li, and He, 2023).

The challenge lies in balancing economic growth with sustainable practices, fostering international co-operation

to mitigate carbon emissions, and promoting innovative solutions aligning with economic and ecological objectives. Each of these ten NIEs faces unique circumstances, and finding a harmonious equilibrium among these factors is imperative for a more sustainable and resilient global economy. This research sits at the crossroads of these fundamental domains, attempting to map the trajectory of long-term, sustained economic advancement within the context of the ten NIEs. Despite these comprehensive investigations, there remains a lacuna in understanding how these elements synergize to influence the growth trajectories of NIEs. Research on complete models that combine eco-innovation, international trade, digitization, and green finance (GF) within the particular developmental settings of NIEs is scarce. Furthermore, there is a lack of empirical studies examining the long-term implications of these factors on economic indicators, environmental sustainability, and technological advancement in these rapidly expanding nations. Moreover, the ten newly industrialized economies are under consideration in this research because they represent a diverse range of economic structures and development stages, making this study even more compelling (Su et al. 2021). According to the literature synthesis, CE has been one of the most pressing global problems in recent decades. Thus, Khan, Hussain, and Sampene (2023a; b) believe that as fast economic expansion is achieved, carbon emissions endanger biological communities and the long-term resilience of biodiversity.

In addition, eco-innovation (ECO) represents a promising path toward sustainable development. It involves adopting novel technologies and practices that reduce environmental harm while fostering economic growth (Andabaka et al. 2019). Ahmad and Wu (2022) also explored ECO in twenty OECD nations. The data from 1990 to 2017 indicated that eco-innovation promotes economic progress. Consequently, examining the extent to which eco-innovation positively influences the economies of these ten nations is a pertinent aspect of this research. By examining the interplay between eco-innovation, digitalization, green finance, and renewable energy within these nations, the evaluation better understands their unique challenges and opportunities and the transferability of successful models across borders. This study may help shape future legislation and investment decisions and underscores the importance of a sustainable, low-carbon economy as an engine for future economic growth.

Green finance (GF), which encompasses sustainable investment and financing mechanisms, is vital for expediting the transformation to a carbon-free society (Nawaz et al. 2021). In addition, GF is characterized as a novel financial paradigm to preserve and improve the environment, as described by Odugbesan et al. (2021), which offers financial backing to environmentally friendly industries. Green finance has materialized as a prominent feature in

the financial industry, presenting considerable potential and significant room for economic growth (Wang et al. 2021). To learn more about the economic development paths of these industrialized nations, it is important to examine the availability and efficacy of green financing technologies in these nations. In addition, renewable energy can significantly reduce carbon emissions as a sustainable option to fossil fuels (Sun et al. 2022). Previous research shows that optimizing REC may contribute considerably to EG (Saidi and Omri 2020; Shahbaz et al. 2020). Therefore, examining the effect of REC on the EG of these countries is an important facet of the current study.

Moreover, international trade (INT) also plays an essential role in the economic fortunes of industrialized nations, and it is intrinsically connected to environmental concerns (Nathaniel et al. 2021). However, in this same context, Malfane (2020) explored trade with Botswana's proxies of total trade, export, and import. The results from the ARDL test confirmed that total trade and exports had a favorable effect on economic growth, while imports had an inverse nexus with economic progress. Therefore, analyzing how international trade practices exacerbate or improve EG is a significant dimension of this research. Moreover, digitalization (DIG) is transforming economies worldwide, affecting various sectors, including green technology (Novikova et al. 2022). More so, the quick progress of digitalization is driving a transformation in the entire socioeconomic system and fostering the emergence of new economic prospects (Ribeiro-Navarrete et al. 2021). Hence, studying how digitalization enhances eco-innovation and green finance in these countries is essential to assess its potential impact on economic growth.

2 Research Objectives and Contributions

In light of this, the primary objective of this research is to illuminate the complex interactions underlying CE, eco-innovation (ECO), international trade (INT), digitalization (DIG), green finance (GF), and renewable energy (REC) and EG. A comprehensive analysis will help policymakers, businesses, and researchers develop initiatives to stimulate sustained economic progress while addressing climate and ecological challenges, improving the long-term sustainability and prosperous future for these nations and the worldwide community.

By examining the panel data from 1990 to 2020, this investigation offers profound details about the comprehensive relationships between these factors and economic growth. The comprehensive analysis helps shed light on the drivers and barriers to sustainable economic development in diverse countries, each with unique characteristics and challenges. From a practical perspective, the evaluation of this investigation

has ramifications for policymakers, businesses, and investors. Understanding the Influence of CE, ECO, INT, DIG, GF, and REC on economic growth can inform policy decisions related to environmental regulations, incentives for eco-friendly innovation, trade agreements, and investment in green technologies. It can also guide businesses in making sustainable investments and adopting eco-friendly practices.

Furthermore, it can provide insights into how international trade and digitalization can be harnessed to boost economic growth while promoting environmental sustainability. The novelty of this assessment lies in its all-encompassing strategy, utilizing advanced econometric methods such as the common correlated effects mean group (CCEG) and augmented mean group (AMG) approaches to analyze a vast dataset spanning 3 decades. Including the ten diverse industrialized countries allows for a more refined perception of the global landscape of sustainable economic growth. By examining these factors in conjunction, this research contributes to the growing body of literary work on the interplay underlying sustainable environmental practices and economic expansion, offering a more holistic view of the challenges and opportunities faced by these countries. This study's contribution is not limited to academia but extends to informing real-world policies and strategies for green and sustainable EG in a rapidly changing society. In addition, this study looks at the transformative effects of renewable energy, green financing, and carbon emission reductions on economic growth in newly industrialized economies, demonstrating the vital intersection of ecological and economic perspectives. By adopting renewable energy and green financing methods, these economies are lowering carbon emissions and paving the way for a more sustainable future. This emphasis on environmental significance and sustainability demonstrates the possibility of a harmonious coexistence of strong economic growth and environmental stewardship, establishing these countries as trailblazers in the global transition to a greener, more resilient economy.

The structure of this paper is organized as follows: Sect. 2 presents the background information and theoretical foundations of the study. Section 3 details the research methodology, including the data sources, collection, and analysis techniques. Section 4 discusses the research findings, with references to previously published literature, and presents the data results. Finally, Sect. 5 concludes the study by offering policy recommendations and discussing the implications for future research and practice.

3 Literature Review

3.1 Carbon Emission and Economic Growth

The study by Uddin et al. (2017) observed the linkage among carbon emission and economic growth between 27 high CO₂

emitters employing panel data from 1991 to 2012. Their outcomes proposed a favorable link between EG and CE. Similarly, Ahmed et al. (2019) assessed the collaboration among economic progress and carbon emissions by evaluating data from 1971 to 2014. Their analysis established that economic growth is a catalyst for CO₂ emissions. Moreover, Akinsola et al. (2022) researched the impact of emissions lev and EG in Brazil. Their study results demonstrate that EG causes an increase in CE and vice versa. Equally, Islam (2022) revealed in his study that carbon emission contributes to ecological deprivation among selected developing economies. The study discovered the occurrence of the EKC pattern within the SSE nations. Their research findings suggest that during the earliest phases of economic expansion, there is an increasing requirement for quality and safety precautions in the economic sector, which correlates to lesser greenhouse emissions.

3.2 Eco-innovation and Economic Growth

The sustainability of resources and society's well-being is the core aim of nations worldwide. Eco-innovation has become the order of sustainability with continuous pollution of the environment by industries. Recent literary investigation has shown researchers' studies on different forms of innovation: green, technological, and eco (Fatma and Haleem 2023; Ojekemi and Ağa, 2023). Ding et al. (2021) investigated G7 eco-innovation and energy productivity between 1998 and 2018. Several analytical approaches were adopted to test the nexus between the constructs. Consistent with literary works, the assessment found that eco-innovation reduces carbon productivity and appreciates economic growth. Ahmad and Wu (2022) explored eco-innovation in 20 OECD nations using the quantile regression approach. The results from the data between 1990 and 2017 indicated that eco-innovation promotes economic growth. Furthermore, Vu et al. (2023) assessed the variables of ECO, globalization, and EG in the MENA regions. The CS-ARDL estimates were adopted to test data from 1990 through 2017. Their research outcome demonstrated that eco-innovation had a material direct effect on economic growth.

3.3 Green Finance and Economic Growth

Eco-friendly financial strategies are an essential part of long-term sustainability. It improves the flow of capital from commercial, governmental, and nonprofit entities into green or sustainable initiatives through investment, credit tools, loans, and insurance. Liu (2023) recommends that banks and other banking facilities lend money to companies to increase their capital and investment ability. Sadiq et al. (2023) selected ASEAN nations to reveal the effect of GF on economic progress. Their outcomes espoused that green credit

was directly related to economic progress. Productivity in China's regional renewable energy enterprises was examined through the GMM model for the data period 2008–2019. The estimated analysis indicated that renewable energy was appreciated, with 16.5% accounting for green finance (Liang et al. 2023). Yikun et al. (2023) also collected data on G7 states from 2000 to 2019. The CS-ARDL analysis indicated that green finance had a favorable impact on EG in the long run. However, the results were immaterial in the short run. Qi et al. (2023) studies show that green finance contributes to adopting REC and improving EG.

3.4 Digitalization and Economic Growth Affiliation

Alina-Petronela et al. (2023) examined panel data from 2010 to 2018 with multiple linear and OLS regression approaches on the digitalization of European nations. The results depicted that digitalization is a significant contributor to economic growth. Balsalobre-Lorente et al. (2023) investigated digitalization in Mexico, Indonesia, Nigeria, and Turkey (MINT) regions on mobile use through international tourism and natural resources rent. This will include an analysis of data for the period of 1971 up to 2019 and the adoption of the FMOL and DOLS models. The findings revealed that tourists' mobile subscriptions had a material impact on economic growth. Criveanu (2023) also explored electronic commerce and digitalization to attain sustainable development goals in EU communities. The paper revealed that digital transformation had a stronger link to the GDP of EU nations. Previous researchers have mainly focused on digitalization and climate change or digitalization and financial inclusion, ignoring its significance to economic progress (Cao 2023; Pérez-Martínez et al. 2023; Wang et al. 2023).

3.5 International Trade and Economic Growth

For centuries, research has indicated that international trade should be how emerging and developed nations can appreciate economic progress (Jun et al. 2020; Tachie et al. 2020). Theoretically, empirical assessment has shown that the INT favorably affected economic progress (Feng et al. 2023). Using an international dataset, Katrakilidis and Madas (2020) studied the affiliation between INT and EG of logistics enterprises for the years 2007 through 2018. Analysis through the stochastic and granger causality produces a positive relationship. In Africa, Abendin and Duan (2021) used the POLS and GMM to investigate the effect of international trade and EG. The findings illustrated a favorable nexus among the variables. The ARDL model examined Morocco's international trade and its effects on economic progress from 1980 to 2019. The Toda–Yamamoto estimate illustrated that in the short run, INT positively impacts economics growth. Within the emerging economies of Kazakhstan, Akhter et al.

(2022) confirmed a negative nexus between trade and economic progress.

3.6 Renewable Energy Consumption and Economic Growth

REC sources comprising geothermal energy, wind, solar and hydropower have gained significant attention as potential catalysts for economic growth in recent years (Segbefia et al. 2023). The switch from fossil fuels to renewables has been driven by environmental apprehensions, energy security, and the quest for sustainable EG (Wiredu et al. 2023). The nexus between REC and EG was examined within the E7 nations for 1995–2018. The analysis from feasible generalized least squares (FGLS) and panel-corrected standard errors (PCSE) illustrated a positive affiliation (Hye et al. 2023). Raihan (2023) explored an assessment of renewable energy and economic progress within the emerging economy of Mexico. The findings demonstrate that REC and EG had a favorable relation through the ARDL test. The quantile MMR was used to evaluate REC and EG in N-11 economies. The econometrics analysis presented a two-way affiliation between the indicators (Xie et al. 2023). Appiah-Otoo, Chen, and Ampah (2023) explored the economic growth of fifteen West African countries using renewable energy as a means of productivity. The findings from the Feasible GLS test showed an immaterial coefficient nexus between REC and EG.

4 Research Gap

Despite a comprehensive investigation, there remains a need for a more elaborated understanding of the heterogeneous impacts across these diverse countries, potentially driven by variations in policy implementation, technological capabilities, and market structures. In addition, the research may not

adequately capture evolving dynamics over time, such as the rapid acceleration of digitalization and the changing global policy landscape related to environmental sustainability, suggesting a necessity for more updated data and modeling approaches to address these complexities. In addition, further investigation may be necessary to fully understand the relationships and feedback processes between the variables to present a more complete picture of the nexus among CE, REC, GFR, INT, DIG and EG in the NIEs.

5 Research Methodology

5.1 Data Extraction and Trend Analysis

The paper explores the effect of CE, eco-innovation (ECO), digitization (DIG), international trade (INT), renewable energy consumption (REC), and green finance (GF) on economic growth (EG) among ten NIE. The study explored annual panel data for more than 30 years (1990–2020), and the data was retrieved from WDI (2024) and OECD (2024) databases. The explanatory indicator of this research is EG, and the regressors are comprised of CE, ECO, DIG, INT, and REC. The data about each of the indicators are displayed in Table 1. Similarly, Fig. 1 illustrates the evolution and trend assessment associated with each indicator examined in this research. The diagrams revealed an increase in these indicators over the last decades. Thus, all the indicators keep rising from 1990 to 2020, among the understudied nations.

5.2 Theoretical Background and Model Estimation

The conceptual framework of this analysis is grounded on the Cobb–Douglas production (C-DP), which has been expanded via prior studies (Ghosh et al. 2023; Raihan 2023; Sultana et al. 2022). According to this model, economic output is based on three key indicators: human capital, physical,

Table 1 Description of study indicators

Acronyms	Indicators description	Unit of measurement	Source
EG	Economic growth	GDP growth per (annual %)	WDI (2024)
CE	Carbon emission	Metric tons per capita	WDI (2024)
ECO	Eco-innovation	Measured with % of all technologies	OECD (2024)
DIG	Digitization	DIG measures the aggregation of ICT based on (mobile cellular subscriptions)	WDI (2024)
INT	International trade	Export and import of goods and sources (% of GDP)	WDI (2024)
REC	Renewable energy consumption	Measured with (% of overall cleaner energy consumption)	WDI (2024)
GF	Green finance	GF evaluates the ecological protection of products from residents and non-residents	OECD (2024)

EG Economic growth; CE Carbon emission; ECO Eco-innovation; DIG Digitization; INT International trade; REC Renewable energy consumption; GF Green finance; GDP Gross domestic product; WDI World development indicators; OECD Organization for economic co-operation and development

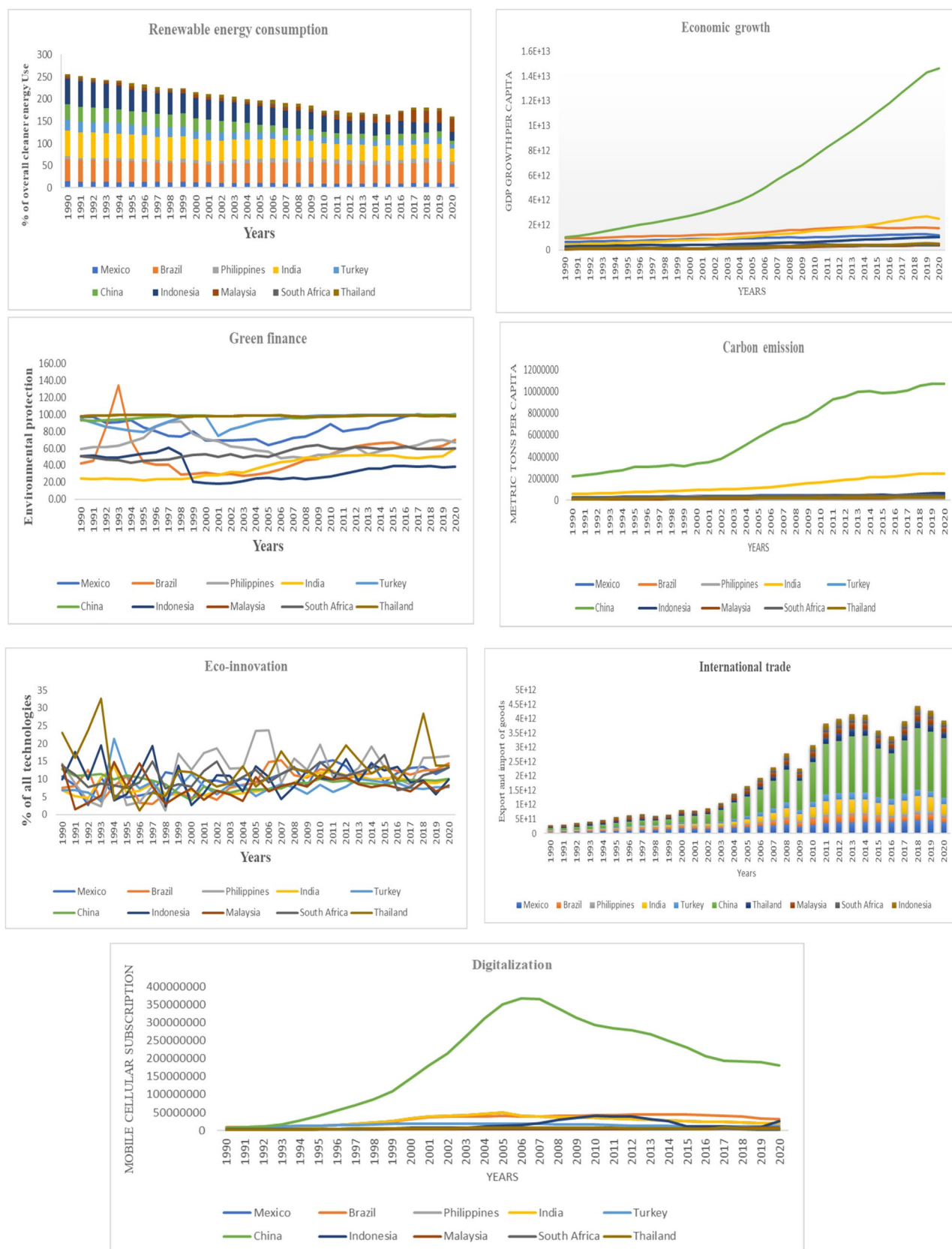


Fig. 1 Trend assessment of the various variables explored in the study. Clockwise from top left: renewable energy consumption, economic growth, carbon emissions, international trade, digitalization, eco-innovation, and green finance

and labor. Equation 1 presents the per capital output of the C-DP model:

$$Y_t = A_{it} K_{it}^\alpha H_{it}^\beta L_{it}^{1-\alpha-\beta} \varepsilon_{it} \quad (1)$$

Here, Y denotes the EG measured with GDP, Y represents the technological level, H depicts the indicators for human capital, and L indicates the labor force. The error term of the model is depicted with ε_{it} .

Moreover, the C-DP model is defined by the invariant return to scale module, meaning that if a certain percentage increases all inputs, output will increase by the same percentage. This model has been influential in comprehending the dynamics of EG and productivity, and it offers a useful paradigm for analyzing the contributions of labor and capital to overall production in various industries and economies. Therefore, this research enriches this theory by evaluating the Influence of CE, ECO, DIG, INT, GF, and REC on EG. Therefore, the following liner model has been developed to examine these indicators' time-varying impact on EG. Thus, Eq. 2 presents the logarithm form for this model:

$$\ln ECG_{it} = \alpha_i + a \ln CE_{it} + b \ln ECO_{it} + c \ln DIG_{it} + d \ln INT_{it} + e \ln GF_{it} + f \ln REC_{it} + \mu_{it} \quad (2)$$

Here, α_i signifies the model's constant, and the coefficient of the independent indicators is identified by $a - f$. The term $\ln$ showcases the logarithm function for the indicators, and the error term of the model is depicted with ε_{it} . In addition, economic growth (EG), carbon emissions (CE), green finance (GF), digitalization (DIG), eco-innovation (ECO), and renewable energy consumption (REC). Similarly, i demonstrates the ten NIEs, and t reflects the time-span of the study.

5.3 Panel Estimation Approaches

5.3.1 CSD and SHT

Cross-sectional dependency (CSD) encompasses the potential correlation or interdependence within the distinct units or entities that make up a cross-sectional dataset. In panel data analysis, neglecting or ignoring CSD can result in skewed estimates and erroneous statistical conclusions. Detecting and addressing CSD is crucial for obtaining reliable and unbiased estimates in panel data analysis. Failing to account for such dependency can lead to incorrect inferences about the relationships between variables, potentially impacting the validity of research findings and policy recommendations (Li et al. 2022; Sun et al. 2022). As a result, the paper applied CSD tests and methods to thoroughly examine and correct for cross-sectional

dependency in their panel datasets. The Pesaran CSD, in particular, uses the linear model as provided in Eq. 3:

$$CSD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{n-1} \sum_{j=i+1}^n \sigma_{ij}^t \right) \quad (3)$$

Moreover, the slope homogeneity test (SHT) outlined by Pesaran and Yamagata (2008) is designed to assess whether the coefficients of explanatory indicators are consistent across different groups or periods in panel data. This test is essential when examining the homogeneity of slopes, providing insights into the stability of interconnection over diverse conditions. If the effect of variables is found to vary significantly across subgroups, this test guides researchers in refining their models to capture better the dynamics discovered in the data (Bersvendsen and Ditzen 2021). Understanding the homogeneity of slopes is crucial for making accurate predictions and policy recommendations based on panel data analyses, especially in contexts where relationships may change across different dimensions or time intervals. The two tests Pesaran and Yamagata (2008) presented are captured in 5 and 6 as follows, which show the adjusted delta ($\tilde{\Delta}D$) and the delta tide $\tilde{\Delta}D$:

$$\tilde{\Delta}AD = (n)^{\frac{1}{2}} \left(\frac{2p(t-p-1)^{\frac{-1}{2}}}{t+1} \right) \left(\frac{1}{n} (\tilde{S} - P) \right) \quad (4)$$

$$\tilde{\Delta}D = (n)^{\frac{1}{2}} (2P) \left(\frac{1}{n} (\tilde{S} - P) \right) \quad (5)$$

Here, $\tilde{\Delta}SHT$ denotes the delta of the slope and $\tilde{\Delta}ASHT$ implies the adjusted slope homogeneity.

5.3.2 Panel Stationarity Assessment

The panel data evaluation relies heavily on panel root model tests, such as CADF and CIPS. These tests determine whether the structures being examined are constant throughout the model's sectional units (Abbasi et al. 2022). In the presence of non-stationarity, these tests help the analysis to identify the incorporation of the integration order of the indicators, ensuring that subsequent analyses are based on appropriate transformations. These tests are essential diagnostic tools that provide insights into indicators' time series features and enable the estimation process. Equation 6 provides the test equation CIPS in its linear form:

$$CADF = \gamma x_{it} = \alpha_{it} + \beta_{it-1} + \delta_I T + \sum_{j=1}^N \gamma_{ij} \gamma x_{it-j} + \varepsilon_{it} \quad (6)$$

Here, γ represents the disparities among the indicators, x_{it} captures the variables assessed in this research, where $\tilde{\Delta}Y_{it}$

represents the first difference of the indicators and Y_{it-1} is the lagged level of the variables.

Another method specifically designed for panel data that addresses CSDT is the CADF test. Conventional ADF regression techniques are strengthened by incorporating the cross-sectional mean of the lagged level and the first differences of the series. Equation 7 presents the linear as follows:

$$\text{CIPS} = \frac{1}{N} \sum_{i=1}^N \text{CADF}_i \quad (7)$$

Equation 7 evaluates the stationarity propositions through the Pesaran (2007) simulation, with the derived CIPS values assessed against a reference table of critical values.

5.3.3 Inspection of Cointegration Test

Westerlund (2007) approach is specifically tailored for panel data, offering a means to evaluate long-term interaction within the variables. Cointegration is a critical concept in time series analysis, indicating a common stochastic trend between variables. The Westerlund (2007) test accounts for CSD in panel data settings, allowing the study to examine whether a set of variables share a cointegrating relationship. This is particularly valuable when studying economic phenomena with long-term equilibrium dynamics, as it helps identify co-movements among variables that persist over time and across different entities. Equations 8–11 capture the linear model for the cointegration test:

$$G_\tau = \frac{1}{N} \sum_{i=1}^N \frac{\eta_i}{S.E(\hat{\eta}_i)} \quad (8a)$$

$$G_a = \frac{1}{N} \sum_{i=1}^N \frac{T\eta_i}{1 - \sum_{j=1}^k \hat{\eta}_{ij}} \quad (8b)$$

$$P_\tau = \frac{\hat{\eta}_i}{S.E(\hat{\eta}_i)} \quad (8c)$$

$$P_a = T\eta_i \quad (8d)$$

Here, $(G_t - G_a)$ reflects the statistics for the group, while $(P_t - P_a)$ reflect the statistics for the panel.

5.3.4 Long-Term Estimation Models

The CCEG estimator is a powerful method in panel data analysis designed to address potential CSD, as espoused by Pesaran (2006). The CCEG model assumes that the common shocks influencing the cross-sectional units are correlated and introduces a factor structure to capture these shared

effects (Sun et al. 2022). By incorporating information from the entire panel, the CCEG estimator yields more efficient coefficient estimates than traditional MG estimators, making it particularly useful when dealing with economic phenomena that exhibit cross-sectional interdependence (Li et al. 2021; Voumik et al. 2023). This approach provides an understanding of how common factors influence individual units over time, offering improved model accuracy and mitigating potential biases associated with neglecting cross-sectional dependence. The AMG estimator is another valuable tool in panel data analysis, specifically developed to handle the problem of heterogeneity across cross-sectional units. Introduced by Eberhardt and Bond (2009), the AMG estimator extends the traditional models by allowing for individual-specific fixed effects. This accounts for unobserved heterogeneity among units, providing a more adaptive and practical approach for panel data analysis. The AMG technique is particularly relevant when examining economic phenomena that vary across entities, such as industries or regions. By accommodating both time-specific and unit-specific effects, the AMG estimator enhances the accuracy of parameter estimates and contributes to more robust and reliable econometric analyses (Doğan et al. 2021; Yang et al. 2022).

Two mechanisms can be applied to the dataset to estimate the AMG approach. Equations 9 and 10 reflect the functional expression for these stages.

The initial stage of the AMG method:

$$\Delta Y_{it} = \omega_i + \varphi_i \varphi X_{it} + \gamma_i \theta_t \sum_{t=2}^T \theta_t \Delta D_t + \mu_{it} \quad (9)$$

Stage two of the AMG method:

$$\text{AMG}_{\text{Estimator}} = N^{-1} \sum_{i=1}^N \hat{\beta}_i \quad (10)$$

Such that ω_i signify the intercept, Y_{it} and X_{it} specify the regressors with unforeseen common effects. The initial operator of the equation is reflected by Δ , and t reflects the time-span of the study.

The CCEG method was incorporated to evaluate the effect of the regressors on EG. Equation 15 outlines the function of this estimation model:

$$Y_{it} = \alpha_{1i} + \delta_i X_{it} + \theta_i n_{it} + \mu_{it} \quad (11)$$

such that Y_{it} and X_{it} are shown as observed indicators, α_{1i} specify the definite group effect, δ_i denotes the CSD of the estimates for the slope. The uncommon features in the model are depicted with n_i . The heterogeneous nature is denoted with θ_i . In addition, the augmented form for the model, which is factored in the CSD issues, is articulated in Eq. 12:

$$Y_{it} = \alpha_{1i} + \beta_i Z_{it} + \varphi_i \bar{y}_{it} + \bar{z}_{it} + \theta_i n_{it} + \mu_{it} \quad (12)$$

This regression was computed by applying the OLS approach for each cross-section. Equation (14) provides a rigorous solution for estimating the country-wise coefficient used by linear models:

$$\text{CCEMG} = N^{-1} \sum_{i=1}^N \hat{\theta}_i \quad (13)$$

5.3.5 Robustness Analysis

The Driscoll and Kraay (1998) standard error (DSK) estimation approach serves as a robustness test for this analysis, particularly when considering the (CCEG and AMG) models. These estimators are widely used to address common correlated effects and heterogeneous slopes in panel data models. The DSK method offers a diagnostic tool to assess the sturdiness of results to potential misspecifications in the covariance structure. It involves computing robust standard errors that allow for heteroscedasticity and contemporaneous correlation within panel data.

5.3.6 Panel Causality Test

Dumitrescu and Hurlin (2012) (D–H) introduced an innovative model to panel data analysis through their causality assessment. This method extends traditional causality tests to a panel setting, allowing for a more comprehensive

examination of causal relationships across multiple entities simultaneously. The D–H methodology has been widely adopted, providing valuable insights into dynamic interactions within diverse datasets and contributing to the refinement of econometric causal inference techniques (Baydoun an.,d Aga 2021; Islam 2022). The assumption of the D–H approach is stipulated on the assumption of non-causal interplay among indicators contrarily to the alternate proposition, which affirms the prevalence of causal connection in the model. The liner function for this technique is captured in Eq. 14:

$$Y_{it} = \alpha_i + \sum_{m=1}^M \psi_i^m, Y_{i(m-t)} + \sum_{m=1}^M \lambda_i^m, Z_{i(m-t)} \quad (14)$$

Here, m depicts the lag's length in the archetype, and the autoregressive nature of the parameters is denoted by ψ_i^m .

6 Results and Discussion

6.1 Descriptive Test

Table 2 projects the statistical properties of the parameters analyzed in the theoretical framework. Thus, Table 2 illustrates that the largest average is identified in EG, with INT and DIG following. CE, GF, REC, and ECO averages are relatively lower than the remaining three indicators. As a

Table 2 Descriptive and correlation analysis

Descriptive	InEG	InECO	InGF	InINT	InCE	InDIG	INREC
Mean	27.007	2.196	4.176	25.381	12.846	16.295	2.529
Median	26.929	2.251	4.254	25.303	12.669	16.125	2.530
Maximum	30.313	3.484	4.898	28.389	16.186	19.723	4.071
Minimum	24.508	0.139	2.898	23.277	10.607	13.321	− 1.924
Std. Dev	1.180	0.470	0.451	1.056	1.174	1.310	1.134
Skewness	0.329	− 1.033	− 0.911	0.586	1.049	0.572	− 0.788
Kurtosis	3.104	5.611	2.884	3.234	4.059	3.098	3.454
Jarque–Bera	5.710	141.881	42.695	18.298	70.692	16.868	34.473
Probability	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
Observations	307	307	307	307	307	307	307
<i>Correlation analysis</i>							
InEG	1						
InCE	− 0.421***	1					
InECO	− 0.464	0.121***	1				
InGF	0.714	0.125	0.249***	1			
InDIG	0.833	0.646	− 0.322	0.725***	1		
InINT	0.859	− 0.030	0.804	0.717	0.813***	1	
InREC	0.481	− 0.994	− 0.310	0.156	0.270	0.418***	1

EG Economic growth; CE Carbon emission; ECO Eco-innovation; DIG Digitization; INT International trade; REC Renewable energy consumption, GF Green finance

***Indicates a significance level of 1%

result, in contrast with the remaining parameters, the standard deviation for DIG, EG, and CE also seems greater. Moreover, the statistical mean for CE is 12.846, while the maximum value is 16.186, indicating greater ecological pollution among the selected economies. In addition, the coefficient of the average EG is 27.007, indicating the accelerating nature of economic expansion activities in the ten NIEs. The second section of Table 2 displays the correlation assessment for the indicators. The results confirm a positive and substantial connection between the regressors and EG with the expectation of CE, which had an inverse link with EG.

6.2 Result of CSD and SHT Analysis

Table 3 displays the findings from the CSD and SHT approaches for all the indicators explored in this paper. The finding from the CSD test discovered that the null hypothesis suggesting no CSD within the variables was rejected, indicating that the alternate position's acceptance of otherwise. The inferences from this outcome are that the ten NIEs are connected in-terms of trading activities, financial issues, economic, language, and other externalities. Likewise, the finding confirms the presence of SHT features among the research indicators. Thus, both the SHT and adjusted SHT are significant at a 1% significance level in this paper.

6.3 Finding of Unit Root Test

The CADF and CIPS are vital tools used to ensure that the data employed in panel models are stationary, which is a prerequisite for reliable and valid regression analysis, eventually leading to more robust and precise consequences in econometric studies (Oteng et al. 2023; Wiredu

et al. 2023). The stationarity assessment result validates the indicators' stationarity at the first difference, as displayed in Table 4.

6.4 Cointegration Analysis

It is critical to assess whether there is a common stochastic trend between several cross-sectional units, which can be important in analyzing economic associations in a panel context. Table 5 delineates the findings of the cointegration model examined in this study. This test established that both groups—($G_t - G_a$) for group statistics and ($P_t - P_a$) for panel analysis—were acceptable. Therefore, the study could discover that the indicators under deliberation are long-term interconnected.

Table 4 Finding of stationarity test

Series	CIPS		CADF		Remarks
	Level	First Diff	Level	First Diff	
InEG	2.551	5.695***	2.879	10.785***	I (1)
InCE	− 1.109	− 6.277***	− 0.434	− 5.460***	I (1)
InECO	− 1.587	− 14.031***	− 0.402	− 4.210***	I (1)
InGF	− 1.672	− 8.856***	− 0.560	− 6.474***	I (1)
InDIG	− 0.650	− 8.411***	− 0.716	− 9.353***	I (1)
InINT	− 1.364	− 7.893***	4.463	− 8.439***	I (1)
InREC	3.761	− 12.776***	1.659	− 9.720***	I (1)

***Represents a 1% significance level

EG Economic growth; CE Carbon emission; ECO Eco-innovation; DIG Digitization; INT International trade; REC Renewable energy consumption; GF Green finance

Table 3 Findings of SHT and CSD

	Pagan LM coefficient	Scaled LM coefficient	Corrected scaled coefficient
InEG	879.185***	89.850***	89.764***
InCE	139.693***	25.930***	25.763***
InECO	100.427***	15.842***	15.675***
InGF	264.515***	23.189***	23.233***
InDIG	717.550***	70.893***	70.726***
InINT	227.897***	24.688***	24.521***
InREC	434.220***	41.024***	40.860***
SHT analysis	Δ statistic		P value
$\bar{\Delta}$ SHT	8.557**		0.000
$\bar{\Delta}$ ASHT	8.990***		0.001

***Indicates a significance level of 1%

EG Economic growth; CE Carbon emission; ECO Eco-innovation; DIG Digitization; INT International trade; REC Renewable energy consumption; GF Green finance

Table 5 Outcome of cointegration test

Test	Value	Z value	P value
G_t	− 5.668***	2.128	0.000
G_a	− 4.113	4.339	0.320
P_t	− 6.884***	2.448	0.000
P_a	− 2.041	4.131	0.290

***Represents a 1% significance level

6.5 Results of Estimation Models

The study incorporated the novel AMG and CCEG approaches to comprehensively analyze the series to establish the proposed model's elasticities. The empirical findings from these econometric techniques have been outlined in Table 6. The summary of the estimates demonstrated that besides CE, all the other indicators (ECO, GF, DIG, INT, and REC) positively and substantially improved EG among the NIEs. The discussion of this research is based on the CCEG coefficient estimates.

6.6 Discussion

The empirical findings from the AMG and CCEG models revealed that CE negatively affects economic growth. More precisely, the outcome showed that a 1% rise in CE will reduce EG by 0.593% in the NIEs. The inference is that carbon emissions contribute to climate alteration, which can result in increased frequency and severity of natural disasters such as hurricanes, floods, and droughts. These occurrences can severely compromise distribution networks, disrupt infrastructure activities, and decline EG. Moreover, the long-term effects of warming temperatures, such as shifting agricultural conditions and increasing sea levels, can further hamper economic productivity and stability in these countries. CE can also lead to health problems, resulting in increased healthcare costs and decreased labor productivity, ultimately impacting economic growth (Xu, Zhang,

and Mehmood, 2023). Moreover, CE can increase energy costs because governments and international bodies impose stricter regulations on CE. Udeagha and Ngepah (2022) asserted that enterprises in these economies might have to pay more to adopt pollution mitigation measures or switch to greener power sources. These costs can reduce the competitiveness of their products in the global market. Furthermore, dependence on fossil fuels, frequently linked to elevated emission levels, can lead to energy price volatility, harming economic stability. These challenges can discourage foreign investment and potentially stifle innovation in industries critical for economic growth economies (Ahmad et al. 2020). Hence, CE's negative and substantial effects on economic growth in these ten industrialized countries are diverse and necessitate concerted efforts to mitigate through sustainable and cleaner economic practices. The result of this paper collaborates with these studies (Jebabli et al. 2023; Kartal et al. 2023; Khan et al. 2023a, b).

Furthermore, the study espoused that ECO positively impacts EG, implying that a 1% upsurge in ECO will improve EG by 0.451%. Thus, the finding confirmed that the ten NIEs have recognized the importance of sustainability and are increasingly investing in eco-innovation. This shift towards more sustainable practices enhances economic growth in several ways. Thus, ECO fosters resource efficiency, reducing waste and lowering production costs. As a result, businesses become more competitive and profitable. Moreover, Yurdakul and Kazan (2020) espoused that ECO opens up new markets and export opportunities for green products and services, expanding the scope of economic activities. This boosts overall GDP, particularly in countries such as India and China, which have large populations. Furthermore, ECO leads to minimized environmental externalities, such as air and water pollution, which can otherwise burden the healthcare system and diminish the quality of life for citizens (Puertas and Marti 2021). It also addresses the global demand for sustainable products, creating export potential for these countries. Improved environmental stewardship enhances the attractiveness of these

Table 6 Findings of long-term estimators (AMG and CCEG)

Series	AMG estimates			CCEG estimates		
	Coeff.	Std. error	P value	Coeff.	Std. error	P value
InCE	− 0.372***	0.044	0.000	− 0.593***	0.218	0.007
InECO	0.816***	0.063	0.003	0.451***	0.071	0.000
InGF	0.667***	0.070	0.008	0.303***	0.146	0.000
InDIG	0.326***	0.042	0.000	0.227***	0.063	0.000
InINT	0.175***	0.045	0.000	0.303***	0.101	0.003
InREC	0.208***	0.029	0.000	0.246***	0.056	0.000

***Represents a 1% significance level

EG Economic growth; CE Carbon emission; ECO Eco-innovation; DIG Digitization; INT International trade; REC Renewable energy consumption; GF Green finance

nations to foreign investors and tourists, further fueling economic growth (Vence and Pereira 2019). Most importantly, the adoption of eco-innovation positively and significantly impacts the economic growth of these ten industrialized countries by promoting sustainability, driving innovation, increasing competitiveness, and creating new economic opportunities.

In addition, the findings revealed in this study proved that GF has a beneficial and strong effect on EG. Specifically, the result approves that a 1% up rise in GF will enhance EG by 0.303%. The inference from this analysis is that green finance contributes to economic growth by fostering innovation and deploying clean facilities and technologies (Nawaz et al. 2021). Thus, GF enhances the competitiveness of these nations in the global market and helps create new industries. For example, countries such as China and India have invested heavily in REC projects, leading to the growth of their green energy sectors and creating millions of jobs, ultimately boosting their economic output (Tu et al. 2021). Furthermore, green finance can reduce environmental risks and long-term economic costs, particularly in countries such as South Africa and Brazil, where natural resources play a vital role in their economies (Sampene et al. 2022). By promoting sustainable practices and environmentally friendly investments, these countries can dissipate the negative effect of CE, reduce resource depletion, and safeguard their long-term economic stability (Wang et al. 2021). Shang et al. (2023) also established that GF can attract foreign investment, as it aligns with global sustainability goals and ethical investing principles, making these countries more attractive for international capital flows. This research confirms that GF is a powerful driver of EG in these ten industrialized nations, offering economic benefits and a robust EG. The outcome of this paper collaborates with erstwhile analysis on the need to invest in GF to promote EG and ecological stability (Cai et al. 2022; Li et al. 2022; Rasoulinezhad and Taghizadeh-Hesary 2022; Sampene et al. 2022).

The CCEG analysis also established that DIG has a favorable and substantial influence on EG. Consequently, a 1% upsurge in DIG will lead to a 0.227% rise in EG in the NIEs region. A possible explanation for the study result is that adopting digital technologies has accelerated productivity and efficiency across various sectors, leading to improved economic performance in the NIEs. For instance, Ribeiro-Navarrete et al. (2021) observed that digitizing financial services in India has expanded financial inclusion, allowing millions of previously unbanked individuals to access and participate in the formal economy, thus boosting overall economic output. Similarly, the widespread use of e-commerce platforms in China has opened up new opportunities for small businesses to reach larger markets, fueling entrepreneurship (Ju and Tang 2023). Moreover, in Brazil, for example, the growth of the technology sector has fostered

innovation and diversification, reducing the country's historical reliance on commodity exports. Implementing smart manufacturing and supply chain solutions in countries such as Malaysia and Thailand has made their manufacturing sectors more competitive globally, attracting foreign investments and driving economic growth (Novikova et al. 2022). Furthermore, the availability of data-driven insights and analytics tools has enabled these nations to make informed policy decisions, allocate resources more efficiently, and better address societal challenges. DIG has proven to be a powerful driver of EG in these ten industrialized nations, and this outcome aligns with these prior articles (Alina-Petronela et al. 2023; Novikova et al. 2022; Pérez-Martínez et al. 2023).

The study's empirical result further indicates that INT positively impacts EG, suggesting that a 1% increase in INT will improve EG by 0.303%. This result implies that international trade promotes EG by expanding markets for these countries' products and services. Thus, INT allows these economies to access a global customer base, which increases their sales and revenues (Anwar et al. 2020). This encourages domestic businesses to produce more and fosters competition, which can lead to higher efficiency and innovation. Udeagha and Ngepah (2022) noted the influx of foreign capital and technology through international trade often results in improved production processes and increased productivity. For instance, China has experienced outstanding EG over the past few years due to its momentous role in global trade, attracting foreign investment and facilitating technology transfer, leading to the expansion of its manufacturing sector and export capabilities (Zhou et al. 2020). In addition, Nathaniel et al. (2021) asserted that these nations can become more productive and successful by specializing in manufacturing commodities and services in which they have an edge attributable to INT. As a result, they can allocate their resources more effectively and achieve higher levels of economic growth. For instance, Malaysia and Thailand have focused on electronics manufacturing, while Brazil and South Africa have emphasized commodities and natural resources (Rienda et al. 2021). This specialization enables them to reap the benefits of economies of scale and produce goods at lower costs, making them more attractive to both domestic and international markets (Anwar et al. 2020).

Furthermore, the study analyses also discovered that REC positively and significantly impacts EG. Thus, a 1% rise in REC will lead to a 0.246% increase in EG in the NIEs region. The result of this research implies that adopting REC technologies has led to substantially increased investment opportunities in these nations, affecting their EG agenda. The development and maintenance of REC infrastructure, like solar panels, wind turbines, and hydropower facilities, have created a surge in employment opportunities, boosting income and contributing to overall EG (Asrani and Kar 2022). In addition, the shift towards renewable energy has

reduced these countries' dependence on costly and volatile fossil fuel imports, which, in turn, has led to improved trade balances and reduced energy-related expenditure. This enhanced energy security and reduced import bills free up capital that can be redirected into other productive sectors, further fueling economic expansion (Ali et al. 2023). Moreover, Habiba and Xinbang (2023) indicated that using REC has reduced environmental externalities and health-related costs. The mitigation of air and water pollution from burning fossil fuels has improved public health, decreased healthcare expenditures, and increased productivity (Yu et al. 2023). The positive environmental impact has also positioned these

countries as leaders in sustainability and clean technology, attracting foreign investments and fostering a burgeoning green industry. The finding of this research enriches this analysis that demonstrated REC helps stimulate sustainable EG (Wang et al. 2022; Yu et al. 2022; Yunzhao 2022).

6.7 Robustness Analysis

This paper further incorporated the DSK technique to assess the robustness of the AMG and CCEG approaches. The outcome from the DSK, as captured in Table 7 and Fig. 2, confirms a positive connection between ECO, GF, DIG, INT, REC, and EG. Contrastingly, the DSK model confirms an inverse nexus between CE and EG.

6.8 Outcome of Causality Assessment

Table 8 presents the outcomes from the D–H causality methods. The D–H estimates showed a one-directional relationship between CE, ECO, GF, INT, and EG. The implication is that every change in CE, ECO, GF, and INT directly impacts EG in NIEs. The result supports this (Akinsola et al. 2022; Chopra et al. 2022; Koengkan et al. 2020). The causality assessment also demonstrated a two-way connection between DIG, REC, and EG. A bi-directional causality from DIG and REC shows that initiatives and programs related to these parameters are determinants of improving EG and promoting environmental stability in the NIEs region. These

Table 7 Results of robustness models (DSK)

Series	DSK estimates		
	Coeff	Std. error	P value
InCE	− 0.740***	0.267	0.000
InECO	0.680***	0.097	0.000
InGF	0.438***	0.150	0.000
InDIG	0.109***	0.055	0.002
InINT	0.408***	0.101	0.000
InREC	0.381***	0.115	0.001
Constant	12.044***	0.331	0.000

***Represents a 1% significance level

EG Economic growth; CE Carbon emission; ECO Eco-innovation; DIG Digitization; INT International trade; REC Renewable energy consumption; GF Green finance

Fig. 2 Graphical representation of empirical findings

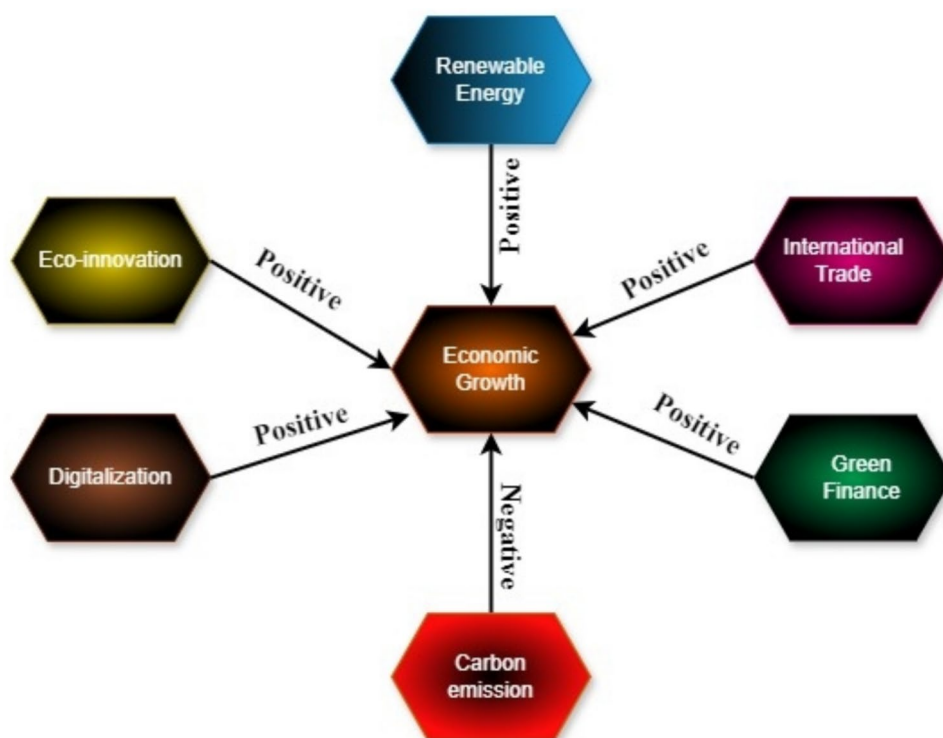


Table 8 Findings from causality analysis (D–H approach)

Null hypothesis	<i>W</i> – stats	<i>Z</i> – bar stats.	<i>P</i> value	Remarks
InCE ⇌ InEG	12.419***	13.533	0.000	CE → EG
InEG ⇌ InCE	1.689	0.652	0.514	
InECO ⇌ InEG	7.022***	6.397	0.000	ECO → EG
InEG ⇌ InECO	1.104	0.425	0.153	
InGF ⇌ InEG	6.867***	6.192	0.000	GF → EG
InEG ⇌ InGF	1.061	0.826	0.138	
InDIG ⇌ InEG	9.077***	9.869	0.000	DIG ↔ EG
InEG ⇌ InDIG	6.144***	6.187	0.000	
InINT ⇌ InEG	9.370***	9.163	0.000	INT → EG
InEG ⇌ InINT	1.909	− 0.360	0.718	
InREC ⇌ InEG	7.683***	9.373	0.000	REC ↔ EG
InEG ⇌ InREC	6.494**	6.043	0.000	

EG Economic growth; *CE* Carbon emission; *ECO* Eco-innovation; *DIG* Digitization; *INT* International trade; *REC* Renewable energy consumption; *GF*: Green finance

***Signifies a 1% significance level, ⇌ implies it does not homogeneously cause, ↔ represents bi-directional causality, and → identifies un-directional causality

results align with Özpölat (2021), Usman et al. (2020), and Usman and Makhdom (2021).

7 Research Implications and Conclusion

7.1 Policy Implications

In context to the empirical evidence presented in this investigation, the study provides the following policy ramifications for stakeholders, governments, and international bodies. First, the detrimental influence of carbon emissions on economic growth is a global concern. The ten industrialized countries should collectively commit to a comprehensive carbon reduction strategy to address this issue. This should include implementing stringent emissions targets, investing in clean energy technologies, and adopting strategies for regulating carbon, such as cap-and-trade schemes or tariffs on carbon. In addition, governments should incentivize businesses to depreciate their carbon footprint through tax breaks for green initiatives, encouraging energy-efficient practices, and supporting research and development in clean technologies. By reducing carbon emissions, these states can mitigate the immaterial effects on their economies and promote global environmental sustainability.

Second, governments and other stakeholders need to implement a complete set of policies to maximize the benefits of eco-innovation on economic growth. First, governments should provide grants, tax breaks, and subsidies to

businesses that invest in eco-innovation. These incentives might reduce the financial barriers to adopting sustainable practices and technologies. Strong regulatory frameworks that protect environmental norms may also incentivize companies to innovate to comply with the law. Stakeholders—including those in the corporate sector and non-governmental organizations—should collaborate to develop and share best practices for eco-innovation. Partnerships between the public and private sectors can aid in disseminating technology and information, increasing the acceptability and scalability of discoveries.

Third, the finding from the analysis espoused that international trade can boost economic growth, and the ten industrialized countries should continue to pursue trade liberalization policies. Reducing trade barriers and tariffs can benefit these nations while fostering open and fair trade. Encouraging international partnerships and co-operation in technology transfer and sustainable production practices can further enhance economic growth. However, it is vital to monitor and address any adverse effects on domestic industries and employment through well-crafted policies and safety nets to ensure that the benefits of international trade are widely distributed. Moreover, embracing digitalization is crucial for economic growth in the modern era. Policymakers should support digital transformation by investing in digital infrastructure, promoting digital literacy, and fostering innovation in the technology sector. Regulations should balance encouraging innovation and ensuring data security and privacy.

Fostering green finance mechanisms and expanding renewable energy sources are crucial for sustainable economic growth. Policymakers should establish a financial ecosystem that supports investments in renewable energy projects, sustainable businesses, and green infrastructure. This can be achieved through tax incentives, green bonds, and encouraging financial institutions to integrate environmental and social factors into their investment decisions. Furthermore, industrialized nations should prioritize the transition to renewable energy by setting specific targets for the proportion of energy generated from renewables. This approach will help reduce greenhouse gas emissions, create jobs, and drive economic growth within the clean energy sector. These countries must adopt a comprehensive strategy to mitigate the negative impacts of carbon emissions while enhancing the positive effects of eco-innovation, international trade, digitalization, green finance, and renewable energy on their economies. A coordinated effort to lower carbon emissions, promote sustainable practices, and invest in cutting-edge technologies, trade alliances, and digital advancements will pave the way for a more sustainable and prosperous future.

7.2 Conclusions

This study analyzed panel data from 1990 to 2020 using the CCEG and AMG econometric methodologies. The examination produced useful data regarding the complex interplay between variables and economic growth in ten developed countries. The study findings indicated that carbon emissions have consistently shown an inverse effect on economic growth in these nations, underscoring the urgent need for sustainable environmental policies. On a more positive note, eco-innovation, international trade, digitalization, green finance, and renewable energy have all contributed positively to economic growth. These findings highlight the importance of embracing environmentally friendly practices and adopting innovative technologies to foster sustainable economic development. Moreover, the illustrations emphasize the significance of international trade, digitalization, green finance, and renewable energy in stimulating economic growth across the selected industrialized nations. The positive impact of international trade reflects the benefits of global economic integration, while digitalization has enabled greater efficiency and competitiveness. Green finance and renewable energy have also been proven to stimulate economic growth in the NIEs. The results from this paper highlight the importance of aligning economic policies with sustainability goals. The study's findings highlight the environmental significance and sustainability components, illustrating how renewable energy and green financing may dramatically reduce carbon emissions while supporting economic growth in newly industrialized economies. This study emphasizes the critical role that sustainable practices play in sustaining long-term ecological balance and economic resilience, calling for policy frameworks that combine environmental stewardship with economic development methods to build sustainable growth in these emerging economies.

Though the research has produced valuable insights into these economies and their addenda for economic transformation, it is imperative to acknowledge certain limits. First, the available panel data spanning 1990–2020 may not include recent events and policy changes in these countries. Future research projects could broaden the scope of the data analysis to include modern policy changes and national technological innovations. Examining these countries' regional and sectoral disparities would further explain how these factors impact economic growth. A deeper understanding of how these nations' economies grow sustainably may also be possible by examining how institutional and political factors affect green investments and laws. In addition, future research will consider conducting a country-wise analysis to provide a more granular understanding of the impact of renewable energy, green finance, and carbon emissions on economic growth. This approach will allow for a more detailed assessment of each country's unique circumstances

and the specific role of these indicators in their economic development.

Author Contribution Agyemang Kwasi Sampene: conceptualization, methodology, and formal analysis. Takyi Kwabena Nsiah: investigation and visualization. John Wiredu: validation and investigation.

Funding No funding was received.

Data Availability WID: <https://databank.worldbank.org/source/world-development-indicators#>

Declarations

Conflict of Interest No potential conflict of interest was reported by the author.

Consent to Participate Not applicable.

Consent to Publication All the authors reviewed and approved the manuscript for publication.

Ethical Approval Not applicable.

References

- Abbasi KR, Adedoyin FF, Radulescu M, Hussain K, Salem S (2022) The role of forest and agriculture towards environmental fortification: designing a sustainable policy framework for top forested countries. *Environ Dev Sustain* 24(6):8639–8666. <https://doi.org/10.1007/s10668-021-01803-4>
- Abendin S, Duan P (2021) International trade and economic growth in Africa: the role of the digital economy. *Cogent Econ Finance* 9(1):1911767. <https://doi.org/10.1080/23322039.2021.1911767>
- Ahmad M, Jiang P, Majeed A, Umar M, Khan Z, Muhammad S (2020) The dynamic impact of natural resources, technological innovations and economic growth on ecological footprint: an advanced panel data estimation. *Resour Policy* 69(July):101817. <https://doi.org/10.1016/j.resourpol.2020.101817>
- Ahmad M, Wu Y (2022) Combined role of green productivity growth, economic globalization, and eco-innovation in achieving ecological sustainability for OECD economies. *J Environ Manag*. <https://doi.org/10.1016/j.jenvman.2021.113980>
- Ahmed W, Najmi A, Arif M, Younus M (2019) Exploring firm performance by institutional pressures driven green supply chain management practices. *Smart Sustain Built Environ* 8(5):415–437. <https://doi.org/10.1108/SASBE-04-2018-0022>
- Akhter S, Mir MA, Megits N (2022) The linkage between international trade and economic growth in Kazakhstan. *J East Eur Central Asian Res* 9(6):1021–1033. <https://doi.org/10.15549/JEECAR.V9I6.1019>
- Akinsola GD, Awosusi AA, Kirikkaleli D, Umarbeyli S, Adeshola I, Adebayo TS (2022) Ecological footprint, public-private partnership investment in energy, and financial development in Brazil: a gradual shift causality approach. *Environ Sci Pollut Res* 29(7):10077–10090. <https://doi.org/10.1007/s11356-021-15791-5>
- Alam MS, Shahbaz M, Paramati SR (2016) The role of financial development and economic misery on life expectancy: evidence from post financial reforms in India. *Social Indic Res* 128(2):481. <https://doi.org/10.1007/s11205-015-1040-4>
- Ali K, Jianguo D, Kirikkaleli D, Mentel G, Altuntaş M (2023) Testing the role of digital financial inclusion in energy transition and

- diversification towards COP26 targets and sustainable development goals. *Gondwana Res* 121:293–306. <https://doi.org/10.1016/j.gr.2023.05.006>
- Alina-Petronela H, Mirela Ș, Ionela BG, Cristina BR (2023) Climate neutrality through economic growth, digitalization, eco-innovation and renewable energy in European countries. *Kybernetes*. <https://doi.org/10.1108/K-09-2022-1254>
- Andabaka A, BasaracSertić M, Harc M (2019) Eco-innovation and economic growth in the European Union. *Zagreb Int Rev Econ Bus* 22(2):43–54. <https://doi.org/10.2478/zireb-2019-0019>
- Anwar A, Younis M, Ullah I (2020) Impact of urbanization and economic growth on CO₂ emission: a case of far east Asian countries. *Int J Environ Res Public Health* 17(7):2531. <https://doi.org/10.3390/ijerph17072531>
- Appiah-Otoo I, Chen X, Ampah JD (2023) Exploring the moderating role of foreign direct investment in the renewable energy and economic growth nexus: evidence from West Africa. *Energy*. <https://doi.org/10.1016/j.energy.2023.128346>
- Asrani C, Kar AK (2022) Diffusion and adoption of digital communications services in India. *Inf Technol Dev* 28(3):488–510. <https://doi.org/10.1080/02681102.2022.2046536>
- Balsalobre-Lorente D, Luzon LI, Usman M, Jahanger A (2023) The relevance of international tourism and natural resource rents in economic growth: fresh evidence from MINT countries in the digital era. *Environ Sci Pollut Res* 30(34):81495–81512. <https://doi.org/10.1007/s11356-022-25022-0>
- Baydoun H, Aga M (2021) The effect of energy consumption and economic growth on environmental sustainability in the GCC countries: does financial development matter? *Energies* 14(18):5897. <https://doi.org/10.3390/en14185897>
- Bersvendsen T, Ditzén J (2021) Testing for slope heterogeneity in Stata. *Stata J* 21(1):51–80. <https://doi.org/10.1177/1536867X211000004>
- Cai L, Sampene AK, Khan A, Agyeman FO, John W, Brenya R (2022) The dynamic nexus between biocapacity, renewable energy, green finance, and ecological footprint: evidence from South Asian economies. *Int J Environ Sci Technol*. <https://doi.org/10.1007/s13762-022-04471-7>
- Cao F (2023) Digital financial innovation and renewable electrification: a step toward zero carbon nexus. *Renew Energy* 215:118910. <https://doi.org/10.1016/j.renene.2023.118910>
- Chopra R, Magazzino C, Shah MI, Sharma GD, Rao A, Shahzad U (2022) The role of renewable energy and natural resources for sustainable agriculture in ASEAN countries: do carbon emissions and deforestation affect agriculture productivity? *Resour Policy* 76(February):102578. <https://doi.org/10.1016/j.resourpol.2022.102578>
- Criveanu MM (2023) Investigating digital intensity and e-commerce as drivers for sustainability and economic growth in the EU Countries. *Electronics (Switzerland)* 12(10):2318. <https://doi.org/10.3390/electronics12102318>
- Ding Q, Iqbal S, Ahmad M (2021) Towards sustainable production and consumption: assessing the impact of energy productivity and eco-innovation on consumption-based carbon dioxide emissions (CCO₂) in G-7 nations. *Sustain Prod Consump* 27:254–268. <https://doi.org/10.1016/j.spc.2020.11.004>
- Doğan B, Driha OM, BalsalobreLorente D, Shahzad U (2021) The mitigating effects of economic complexity and renewable energy on carbon emissions in developed countries. *Sustain Dev* 29(1):1–12. <https://doi.org/10.1002/sd.2125>
- Driscoll JC, Kraay AC (1998) Consistent covariance matrix estimation with spatially dependent panel data. *Rev Econ Stat* 80(4):549–560. <https://doi.org/10.1162/003465398557825>
- Dumitrescu E-I, Hurlin C (2012) Testing for Granger non-causality in heterogeneous panels. *Econ Model* 29(4):1450–1460. <https://doi.org/10.1016/j.econmod.2012.02.014>
- Eberhardt M, Bond S (2009) Cross-section dependence in nonstationary panel models: a novel estimator. MPRA Paper 17692, University Library of Munich, Germany. <https://mpra.ub.uni-muenchen.de/id/eprint/17692>
- Fatma N, Haleem A (2023) Exploring the nexus of eco-innovation and sustainable development: a bibliometric review and analysis. *Sustainability (Switzerland)* 15(16):12281. <https://doi.org/10.3390/su151612281>
- Feng C, Ye G, Zeng J, Zeng J, Jiang Q, He L, Zhang Y, Xu Z (2023) Sustainably developing global blue carbon for climate change mitigation and economic benefits through international cooperation. *Nat Commun* 14(1):6144. <https://doi.org/10.1038/s41467-023-41870-x>
- Feng MQ, Morake O, Sampene AK, Agyeman FO (2024) Trade openness, human capital, natural resource, and carbon emission nexus: a CS-ARDL assessment for Central Asian economies. *Environ Sci Pollut Res* 31(21):31424–31442. <https://doi.org/10.1007/s11356-024-33059-6>
- Ghosh S, Adebayo TS, Abbas S, Doğan B, Sarkodie SA (2023) Harnessing the roles of renewable energy, high tech industries, and financial globalization for environmental sustainability: evidence from newly industrialized economies. *Nat Resour Forum*. <https://doi.org/10.1111/1477-8947.12356>
- Habiba U, Xinbang C (2023) The contribution of different aspects of financial development to renewable energy consumption in E7 countries: the transition to a sustainable future. *Renew Energy* 203:703–714. <https://doi.org/10.1016/j.renene.2022.12.088>
- Hye QMA, Ul-Haq J, Visas H, Rehan R (2023) The role of eco-innovation, renewable energy consumption, economic risks, globalization, and economic growth in achieving sustainable environment in emerging market economies. *Environ Sci Pollut Res* 30(40):92469–92481. <https://doi.org/10.1007/s11356-023-28945-4>
- Islam MS (2022) Does financial development cause environmental pollution? Empirical evidence from South Asia. *Environ Sci Pollut Res* 29(3):4350–4362. <https://doi.org/10.1007/s11356-021-16005-8>
- Jebabli I, Lahiani A, Mefteh-Wali S (2023) Quantile connectedness between CO₂ emissions and economic growth in G7 countries. *Resour Policy* 81:103348. <https://doi.org/10.1016/j.resourpol.2023.103348>
- Ju S, Tang H (2023) Competition and operating efficiency of manufacturing companies in E-commerce environment: empirical evidence from Chinese garment companies. *Appl Econ* 55(19):2113–2128. <https://doi.org/10.1080/00036846.2022.2102126>
- Jun W, Mahmood H, Zakaria M (2020) Impact of trade openness on environment in China. *J Bus Econ Manag* 21(4):1185–1202. <https://doi.org/10.3846/jbem.2020.12050>
- Kartal MT, KılıçDepren S, Ali U, Nurgazina Z (2023) Long-run impact of coal usage decline on CO₂ emissions and economic growth: evidence from disaggregated energy consumption perspective for China and India by dynamic ARDL simulations. *Energy Environ*. <https://doi.org/10.1177/0958305X231152482>
- Katrakylidis I, Madas M (2020) Catching-up effects in the logistics industry and the dynamic linkages with international trade and economic growth: empirical evidence from an international panel dataset. *Econ Bus Lett* 9(3):197–205. <https://doi.org/10.17811/ebl.9.3.2020.197-205>
- Khan A, Hussain S, Sampene AK (2023a) Investing in green intellectual capital to enhance green corporate image under the influence of green innovation climate: a case of Chinese entrepreneurial SMEs. *J Clean Prod* 418:138177. <https://doi.org/10.1016/j.jclepro.2023.138177>
- Khan H, Weili L, Khan I (2023b) The effect of political stability, carbon dioxide emission and economic growth on income inequality:

- evidence from developing, high income and Belt Road initiative countries. *Environ Sci Pollut Res* 30(3):6758–6785. <https://doi.org/10.1007/s11356-022-22675-9>
- Koengkan M, Fuinhas JA, Santiago R (2020) The relationship between CO₂ emissions, renewable and non-renewable energy consumption, economic growth, and urbanization in the Southern Common Market. *J Environ Econ Policy* 9(4):383–401. <https://doi.org/10.1080/21606544.2019.1702902>
- Li C, Sampene AK, Agyeman FO, Brenya R, Wiredu J (2022) The role of green finance and energy innovation in neutralizing environmental pollution: empirical evidence from the MINT economies. *J Environ Manag*. <https://doi.org/10.1016/j.jenvman.2022.115500>
- Li K, Hu E, Xu C, Musah M, Kong Y, Mensah IA, Zu J, Jiang W, Su Y (2021) A heterogeneous analysis of the nexus between energy consumption, economic growth and carbon emissions: evidence from the Group of Twenty (G20) countries. *Energy Explor Exploit* 39(3):815–837. <https://doi.org/10.1177/0144598720980198>
- Liang S, Wang P, Jia C, Zhu J (2023) Studying green financing, factor allocation efficiency, and regional productivity growth in renewable energy industries. *Renew Energy* 214:130–139. <https://doi.org/10.1016/j.renene.2023.05.072>
- Liu D (2023) Does green finance and natural resources agglomeration have potential for green economic growth? Evidence from Asian perspective. *Resour Policy*. <https://doi.org/10.1016/j.resourpol.2023.103720>
- Malefane MR (2020) Trade openness and economic growth in Botswana: evidence from cointegration and error-correction modelling. *Cogent Econ Finance* 8(1):1783878. <https://doi.org/10.1080/23322039.2020.1783878>
- Nadiri A, Gündüz V, Adebayo TS (2024) The role of financial and trade globalization in enhancing environmental sustainability: evaluating the effectiveness of carbon taxation and renewable energy in EU member countries. *Borsa Istanbul Rev*. <https://doi.org/10.1016/j.bir.2024.01.004>
- Nathaniel SP, Murshed M, Bassim M (2021) The nexus between economic growth, energy use, international trade and ecological footprints: the role of environmental regulations in N11 countries. *Energy Ecol Environ* 6(6):496–512. <https://doi.org/10.1007/s40974-020-00205-y>
- Nawaz MA, Seshadri U, Kumar P, Aqdas R, Patwary AK, Riaz M (2021) Nexus between green finance and climate change mitigation in N-11 and BRICS countries: empirical estimation through difference in differences (DID) approach. *Environ Sci Pollut Res* 28: 6504–6519. <https://doi.org/10.1007/s11356-020-10920-y>
- Novikova O, Khandii O, Shamilova L, Olshanskyi O (2022) The impact of digitalization on ensuring economic growth. *Manag Theory Stud Rural Bus Infrastruct Dev* 44(2):223–234. <https://doi.org/10.15544/mts.2022.23>
- Odugbesan JA, Rjoub H, Ifediora CU, Iloka CB (2021) Do financial regulations matters for sustainable green economy: evidence from Turkey. *Environ Sci Pollut Res* 28(40):56642–56657. <https://doi.org/10.1007/s11356-021-14645-4>
- OECD (2024) Environmental policy—Patents on environment technologies. OECD, Paris. <https://data.oecd.org/envpolicy/patents-on-environment-technologies.htm>
- Ojekemi OS, Ağa M (2023) In the era of globalization, can renewable energy and eco-innovation be viable for environmental sustainability in BRICS economies? *Environ Sci Pollut Res* 30(36):85249–85262. <https://doi.org/10.1007/s11356-023-28299-x>
- Oteng F, Adu E, Kedjanyi G, Akwasi A, Frimpong M, Razak A, Buabeng P, Carlos G, Samekong G (2023) Heliyon exploring the nexus link of environmental technology innovation, urbanization, financial development, and energy consumption on environmental pollution: evidence from 27 emerging economies. *Heliyon* 9(6):e16423. <https://doi.org/10.1016/j.heliyon.2023.e16423>
- Özpolat A (2021) How does internet use affect ecological footprint?: an empirical analysis for G7 countries. *Environ Dev Sustain*. <https://doi.org/10.1007/s10668-021-01967-z>
- Pérez-Martínez J, Hernández-Gil F, Miguel GS, Ruiz D, Arredondo MT (2023) Analyzing associations between digitalization and the accomplishment of the sustainable development goals. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2022.159700>
- Pesaran MH (2006) Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica* 74(4):967–1012. <https://doi.org/10.1111/j.1468-0262.2006.00692.x>
- Pesaran MH (2007) A simple panel unit root test in the presence of cross-section dependence. *J Appl Econometr* 22(2):265–312
- Pesaran MH, Yamagata T (2008) Testing slope homogeneity in large panels. *J Econom* 142(1):50–93. <https://doi.org/10.1016/j.jecon.2007.05.010>
- Puertas R, Martí L (2021) Eco-innovation and determinants of GHG emissions in OECD countries. *J Clean Prod* 319:128739. <https://doi.org/10.1016/j.jclepro.2021.128739>
- Qi H, Huang X, Sheeraz M (2023) Green financing for renewable energy development: driving the attainment of zero-emission targets. *Renew Energy* 213:30–37. <https://doi.org/10.1016/j.renene.2023.05.111>
- Raihan A (2023) Toward sustainable and green development in Chile: dynamic influences of carbon emission reduction variables. *Innov Green Dev* 2(2):100038. <https://doi.org/10.1016/j.igd.2023.100038>
- Rasoulnezhad E, Taghizadeh-Hesary F (2022) Role of green finance in improving energy efficiency and renewable energy development. *Energy Effic*. <https://doi.org/10.1007/s12053-022-10021-4>
- Ribeiro-Navarrete S, Botella-Carrubi D, Palacios-Marqués D, Orero-Blat M (2021) The effect of digitalization on business performance: an applied study of KIBS. *J Bus Res* 126:319–326. <https://doi.org/10.1016/j.jbusres.2020.12.065>
- Rienda L, Ruiz-Fernandez L, Carey L (2021) Analyzing trademark and social media in the fashion industry: tools that impact performance and internationalization for SMEs. *J Fashion Market Manag Int J* 25(1):117–132. <https://doi.org/10.1108/JFMM-03-2020-0035>
- Sadiq M, Le-Dinh T, Tran TK, Chien FS, Phan TTH, Huy PQ (2023) The role of green finance, eco-innovation, and creativity in the sustainable development goals of ASEAN countries. *Econ Res-Ekon Istraz*. <https://doi.org/10.1080/1331677X.2023.2175010>
- Saidi K, Omri A (2020) The impact of renewable energy on carbon emissions and economic growth in 15 major renewable energy-consuming countries. *Environ Res* 186:109567. <https://doi.org/10.1016/j.envres.2020.109567>
- Sampene AK, Li C, Khan A, Agyeman FO, Brenya R, Wiredu J (2022) The dynamic nexus between biocapacity, renewable energy, green finance, and ecological footprint: evidence from South Asian economies. *Int J Environ Sci Technol*. <https://doi.org/10.1007/s13762-022-04471-7>
- Sampene AK, Li C, Nsiah TK (2024a) Catalyzing renewable energy deployment in the Mercosur economies: a synthesis of human capital, technological innovation and green finance. *Energ Strat Rev* 53(April):101388. <https://doi.org/10.1016/j.esr.2024.101388>
- Sampene AK, Li C, Wiredu J (2024b) An outlook at the switch to renewable energy in emerging economies: the beneficial effect of technological innovation and green finance. *Energy Policy* 187:114025. <https://doi.org/10.1016/j.enpol.2024.114025>
- Segbefia E, Dai B, Adotey P, Kwasi A, Timothy S (2023) Renewable energy, technological innovation, carbon emission, and life

- expectancy nexus: experience from the NAFTA economies. *Environ Sci Pollut Res*. <https://doi.org/10.1007/s11356-023-29983-8>
- Shahbaz M, Raghutla C, Chittedi KR, Jiao Z, Vo XV (2020) The effect of renewable energy consumption on economic growth: evidence from the renewable energy country attractive index. *Energy* 207:118162. <https://doi.org/10.1016/j.energy.2020.118162>
- Shang Y, Lingrou Z, Fangbin Q, Yani X (2023) Role of green finance in renewable energy development in the tourism sector. *Renew Energy* 206:890–896. <https://doi.org/10.1016/j.renene.2023.02.124>
- Su C-W, Sun T, Ahmad S, Mirza N (2021) Does institutional quality and remittances inflow crowd-in private investment to avoid Dutch Disease? A case for emerging seven (E7) economies. *Resour Policy* 72:102111. <https://doi.org/10.1016/j.resourpol.2021.102111>
- Sultana T, Dey SR, Tareque M (2022) Exploring the linkage between human capital and economic growth: a look at 141 developing and developed countries. *Econ Syst* 46(3):101017. <https://doi.org/10.1016/j.ecosys.2022.101017>
- Sun D, Kyere F, Sampene AK, Asante D, Kumah NYG (2022) An investigation on the role of electric vehicles in alleviating environmental pollution: evidence from five leading economies. *Environ Sci Pollut Res*. <https://doi.org/10.1007/s11356-022-23386-x>
- Tachie AK, Xingle L, Dauda L, Mensah CN, Appiah-Twum F, Mensah IA (2020) The influence of trade openness on environmental pollution in EU-18 countries. *Environ Sci Pollut Res*. <https://doi.org/10.1007/s11356-020-09718-9/Published>
- Tang K, Li Z, He C (2023) Spatial distribution pattern and influencing factors of relative poverty in rural China. *Innov Green Dev* 2(1):100030. <https://doi.org/10.1016/j.igd.2022.100030>
- Tu Q, Mo J, Liu Z, Gong C, Fan Y (2021) Using green finance to counteract the adverse effects of COVID-19 pandemic on renewable energy investment—the case of offshore wind power in China. *Energy Policy* 158:112542. <https://doi.org/10.1016/j.enpol.2021.112542>
- Uddin GA, Salahuddin M, Alam K, Gow J (2017) Ecological footprint and real income: panel data evidence from the 27 highest emitting countries. *Ecol Indic* 77:166–175. <https://doi.org/10.1016/j.ecoli.2017.01.003>
- Udeagha MC, Ngepah N (2022) Does trade openness mitigate the environmental degradation in South Africa? *Environ Sci Pollut Res* 29(13):19352–19377. <https://doi.org/10.1007/s11356-021-17193-z>
- Usman M, Kousar R, Yaseen MR, Makhdom MSA (2020) An empirical nexus between economic growth, energy utilization, trade policy, and ecological footprint: a continent-wise comparison in upper-middle-income countries. *Environ Sci Pollut Res* 27(31):38995–39018
- Usman M, Makhdom MSA (2021) What abates ecological footprint in BRICS-T region? Exploring the influence of renewable energy, non-renewable energy, agriculture, forest area and financial development. *Renew Energy* 179:12–28. <https://doi.org/10.1016/j.renene.2021.07.014>
- Vence X, Pereira Á (2019) Eco-innovation and circular business models as drivers for a circular economy. *Contaduría y Administración* 64(1):64. <https://doi.org/10.22201/fca.24488410e.2019.1806>
- Voumik LC, Mimi MB, Raihan A (2023) Nexus between urbanization, industrialization, natural resources rent, and anthropogenic carbon emissions in South Asia: CS-ARDL approach. *Anthr Sci* 2(1):48. <https://doi.org/10.1007/s44177-023-00047-3>
- Vu TL, Paramaiah C, Tufail B, Nawaz MA, Xuyen NTM, Huy PQ (2023) Effect of financial inclusion, eco-innovation, globalization, and sustainable economic growth on ecological footprint. *Eng Econ* 34(1):46–60. <https://doi.org/10.5755/j01.ee.34.1.32402>
- Wang Q, Hu S, Li R (2023) Could information and communication technology (ICT) reduce carbon emissions? The role of trade openness and financial development. *Telecommun Policy*. <https://doi.org/10.1016/J.TELPOL.2023.102699>
- Wang S, Sun L, Iqbal S (2022) Green financing role on renewable energy dependence and energy transition in E7 economies. *Renew Energy* 200:1561–1572. <https://doi.org/10.1016/j.renene.2022.10.067>
- Wang X, Huang J, Xiang Z, Huang J (2021) Nexus between green finance, energy efficiency, and carbon emission: Covid-19 implications from BRICS countries. *Front Energy Res* 9:1–11. <https://doi.org/10.3389/fenrg.2021.786659>
- WDI (2024) World development indicator database. The World Bank, NW Washington. <https://datatopics.worldbank.org/world-development-indicators/>
- Westerlund J (2007) Testing for error correction in panel data. *Oxford Bull Econ Stat* 69(6):709–748. <https://doi.org/10.1111/j.1468-0084.2007.00477.x>
- Wiredu J, Yang Q, Inuwa UL, Sampene AK (2023) Energy transition in Africa: the role of human capital, financial development, economic development, and carbon emissions. *Environ Sci Policy* 146:24–36. <https://doi.org/10.1016/j.envsci.2023.04.021>
- Xie P, Zhu Z, Hu G, Huang J (2023) Renewable energy and economic growth hypothesis: evidence from N-11 countries. *Econ Res Ekon Istraz*. <https://doi.org/10.1080/1331677X.2022.2121741>
- Xu P, Zhang J, Mahmood U (2023) How do green investments, foreign direct investment, and renewable energy impact CO₂ emissions? Measuring the role of education in E-7 nations. *Sustainability* 15(19):14052. <https://doi.org/10.3390/su151914052>
- Yang X, Li N, Mu H, Ahmad M, Meng X (2022) Population ageing, renewable energy budgets and environmental sustainability: does health expenditures matter? *Gondwana Res* 106:303–314. <https://doi.org/10.1016/j.gr.2022.02.003>
- Yikun Z, Leong LW, Cong PT, Abu-Rumman A, Shraah AA, Hishan SS (2023) Green growth, governance, and green technology innovation. How effective towards SDGs in G7 countries? *Econ Res Ekon Istraz*. <https://doi.org/10.1080/1331677X.2022.2145984>
- Yu B, Fang D, Xiao K, Pan Y (2023) Drivers of renewable energy penetration and its role in power sector's deep decarbonization towards carbon peak. *Renew Sustain Energy Rev* 178:113247. <https://doi.org/10.1016/j.rser.2023.113247>
- Yu Y, Radulescu M, Ifelunini AI, Ogwu SO, Onwe JC, Jahanger A (2022) Achieving carbon neutrality pledge through clean energy transition: linking the role of green innovation and environmental policy in E7 countries. *Energies* 15(17):6456. <https://doi.org/10.3390/en15176456>
- Yunzhao L (2022) Modelling the role of eco-innovation, renewable energy, and environmental taxes in carbon emissions reduction in E-7 economies: evidence from advance panel estimations. *Renew Energy* 190:309–318. <https://doi.org/10.1016/J.RENENE.2022.03.119>
- Yurdakul M, Kazan H (2020) Effects of eco-innovation on economic and environmental performance: evidence from Turkey's manufacturing companies. *Sustainability (Switzerland)* 12(8):3167. <https://doi.org/10.3390/SU12083167>
- Zhang S, Liu X, Bae J (2017) Does trade openness affect CO₂ emissions: evidence from ten newly industrialized countries? *Environ Sci Pollut Res* 24(21):17616–17625. <https://doi.org/10.1007/s11356-017-9392-8>
- Zhou W, Kong Q, Jiang H (2020) Technology transfer under China's foreign investment regime: does the WTO provide a solution? *J World Trade* 54(3):455. <https://doi.org/10.54648/trad2020021>

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.