



ARTICLE



<https://doi.org/10.1057/s41599-025-06127-6>

OPEN

Exploring the key role of education in achieving green growth: evidence from group of seven countries

Farah Durani¹, Ali Abbas², Cuihua Xie^{3,4}✉, Kay Hooi Keoy⁵, Qasim Raza Syed⁶ & Ahsan Anwar^{5,7,8,9}✉

Given the detrimental environmental impacts of anthropogenic activities, achieving a higher green growth is inevitable for the whole world. Therefore, this study examines the role of education to enhance green growth in G7 nations (USA, UK, Germany, Italy, France, Canada, and Japan) while controlling the impact of capital, trade, and FDI. To proceed for regression estimations, unit root tests confirm the stationarity of all variables at first difference, while Westerlund cointegration test shows the existence of cointegration. Findings from the augmented mean group (AMG) method reveal that education capital, and trade have a favorable influence on green growth while FDI has an adverse linkage with green growth. Based on empirical outcomes, the study provides policy suggestions for G7 economies to achieve SDG-4 (quality education), SDG-8 (decent work and economic growth), and SDG-13 (climate action). The study suggests G7 economies to implement eco-friendly trade and investment policies, enhancing education, and incentivize sustainable production to improve green growth and meet SDGs.

¹University of Business and Technology, Jeddah, Saudi Arabia. ²National school of public policy, Lahore, Pakistan. ³School of Economics and Management, Wenzhou University of Technology, Wenzhou, China. ⁴Research Centre for Digital Innovation and Global Value Chain Upgrading, Zhejiang Gongshang University, Hangzhou, China. ⁵Centre for Business Informatics and Industrial Management (CBIIM), UCSI Graduate Business School, UCSI University, Kuala Lumpur, Malaysia. ⁶ARUCAD Research Centre, Arkin University of Creative Arts and Design, North Cyprus, Mersin 10, Türkiye. ⁷Advanced Research Centre, European University of Lefke, Mersin TR-10, Northern Cyprus, Turkey. ⁸University College, Korea University, 145 Anam-ro, Seongbuk-gu, Seoul, Republic of Korea. ⁹Department of Business Administration, ILMA University, Karachi, Pakistan. ✉email: xiecuihua@wzu.edu.cn; ahsananwar786@gmail.com

Introduction

The concept of green growth (GG) was emphasized in 2012 by the UNCSO in which focus was made for sustainable economic growth and ensuring the greener economy (Lorek and Spangenberg, 2014; Hickel and Kallis, 2020). In theoretical context, the concept of GG suggests to promote economic growth aligned with reducing environmental pollution through natural resource management to avoid depletion. The theory is considered crucial worldwide to promote environmental sustainability and economic development (Saleem et al., 2022; Zhao et al., 2023). Literature related to GG aims with creation of growth process based on resource efficiency and development of demand for output and green innovative methods (Haberl et al., 2020). Furthermore, GG is a framework to attain SDGs of United Nations presented in 2015. According to Imasiku et al. (2019), GG is closely related with SDG-8 of decent work and economic growth. Implications of GG are explored in numerous studies such as impact of GG on financial stability (Jadoon et al., 2021), corporate sustainability (Saufi et al., 2016), environmental quality (Saleem et al., 2022), carbon neutrality (Chien et al., 2021), and sustainable development (Zaman et al., 2016; Belmonte-Ureña et al., 2021). Conversely, few studies evaluated the responsible factors for green growth including financial inclusion (Dong et al., 2025), green behavior (Awan et al., 2025), energy efficiency (Liu and Chen, 2025), and renewable energy (Murshed, 2024). However, there is significant research gap in literature to analyze the potential influencing factors of GG particularly education, squared education, trade, and capital.

Education plays its role to boost economic growth (Agasisti and Bertolotti, 2022), sustainable economic development (Li et al., 2023), and environmental quality (Zhang et al., 2022; Qamruzzaman, 2025). Education at various levels plays a central role in developing awareness to the society about environmental challenges, such as climate change, global warming, and natural resource depletion (Zhang et al., 2023). It prepares communities for sustainable literacy, contributing positively to enhance sustainable economic growth. According to Yadav et al. (2024) education serves as the key factor for attaining SDGs, particularly in developing and highly populated economies. In such contexts, social literacy of sustainability can enhance the influence of green growth determinants. According to Liu et al. (2023), education contributes to green growth by improving technological advancement and public awareness. Eco-friendly behavior is promoted which causes rise in GG. Education also has favorable effect for reducing fossil fuel consumption and GHG emissions. Romer (1990) explained the education as a potential factor to boost growth of entire society by uplifting labor productivity and production efficiency. Wang et al. (2021) highlighted that GG outcomes of education take place by improving technological advancement. Furthermore, innovative industrial structure is outcome of education which helps in promoting resource efficiency and GG while reducing environmental degradation (Li et al., 2022).

Among economic factors, trade can also effect GG through different channels as highlighted in few studies (e.g., Khan et al., 2024; Ahmad et al., 2022; Liu et al., 2022; Huang and Zhao, 2022). Role of trade for GG is favorable when trade causes increase in economic growth without compromising environmental quality. Numerous studies analyzed the trade contribution for economic growth, environmental quality, and many other socioeconomic challenges. Global trade improves coordination among countries, reduce disputes, and ensure social sustainability which ultimately enhances economic growth (Ahmad et al., 2022). In environmental context, exports reduces carbon emissions while imports leads to high carbon emissions (Khan et al., 2022). Likewise, Majeed and Asghar (2021) explained that trade has mixed effects

for environment and this require to develop and implement green growth policy to attain sustainable development. To enhance trade and economic growth, reliance on energy consumption increases which can effect environmental sustainability through scale effect, composition effect, and technological effect (Grossman and Krueger, 1995). Improving growth results in more output and enhanced energy use which cause more emissions (scale effect). Energy intensive production of primary goods also uplifts emissions (composition effect). While in the presence of trade, transition towards the advanced and green technological innovations improve environmental quality (technological effect).

Besides aforementioned factors, labor and capital are major determinants of economic growth as followed in Cobb-Douglas model. Existing literature intensively considered labor and capital role for growth and sustainability. Educated workforce is found highly supportive for economic growth (Amir et al., 2015; Karadaş, 2020), and sustainable green economy (Ahmed et al., 2022; Naseer et al., 2022). Labor force is further divided into educated and non-educated categories (Lewis and Pattanayak, 2012). Educated female workforce prefers the utilization of modern renewable energy source over biomass energy which can enhance green growth. On the other hand, labor force with low education have weak environmental awareness and relies on conventional energy source which decreases the green growth. Similarly impact of capital formation can also influence green growth in different ways. Use of capital supported by renewable energy source can improve green growth while traditional methods of capital formation can adversely affect sustainable growth (Tran et al., 2020).

This study followed Cobb-Douglas model to examine the labor and capital effects on green growth by including education and trade as GG determinants among G7 economies (USA, UK, Germany, France, Japan, Italy, and Canada). According to dataset published by World Bank (2023), share of G7 countries in world economy is about 50% and in global population 15%. These economies are committed to reduce their carbon emission by 80% by 2050 to attain sustainable development. Among G7 countries, 3 economies are included in the top 10 global carbon emitting nations, emitting carbon emissions (volumes in million tons) 5007 (USA), 1067 (Japan), and 675 (Germany) presented in global carbon emissions report (2021). Several studies focused G7 economies for economic and environmental perspectives (Ali et al., 2023; Rahman et al., 2016). However, there is significant research gap regarding determinants of green growth among G7 countries. Therefore, this research considered G7 nations to conduct empirical analysis and suggest policy measures for attainment of green growth and sustainable development.

The current study makes significant contributions to the existing literature. Previous studies mainly captured the determinants of economic growth and environmental quality. First, the existing literature is scant on the influencing factors of green growth in G7 nations. Thus, we fill this research void by exploring the drivers of GG in G7 countries. Secondly, the literature on the education-green growth nexus is sparse and concludes the vague results. Particularly, impact of squared education on green growth has not been examined in the previous literature. Therefore, we bridge this research lacuna by examining the non-linear role of education for green growth. Finally, the prior literature on green growth adopts an environmentally adjusted multi-factor productivity index or environmental cost-adjusted growth index as the proxy for green growth. These proxies have a limitation as these indices only cover economic and environmental factors. On the contrary, we adopt the novel green growth index put forward by Sarkodie et al. (2023). This index captures deep insights of the green economy by covering five dimensions such as technology,

social inclusion, poverty, natural capital protection, and efficient resource use. Through exploring determinants of green growth, this study can assist policymakers from G7 economies to formulate policies that can attain SDG-4 (quality education), SDG-7 (affordable and clean energy), SDG-8 (decent work and economic growth), SDG-11 (sustainable cities and communities), and SDG-13 (climate action).

Literature review

Theoretical literature

Higher education and green growth nexus. Education can influence positively GG through various mechanisms. First mechanism is promotion of sustainable literacy. Increase in quality education at higher levels improves the awareness of people about circular economy, ecological challenges, and waste management and ultimately enables the individuals to deal with threats of climate change and global warming (Rahai et al., 2023). Secondly, higher education ensures sustainable development through increasing skills and training among individuals and making them as a green job work force that eventually causes green economy. For greening the production environment, development of green job workforce serves as supportive factor of green growth (Sulich et al., 2020). Moreover, Xie et al. (2020) explained that education is more appropriate way to develop green growth and green skills among labor. Spreading the advanced education of green economy in educational institutions could be a source for green growth as society is directly linked with institutes. Furthermore, making aware the household about renewable energy methods and to avoid usage of fossil fuels, education can improve green growth. Another channel is improvement of environmental technologies as a results of higher education which helps to promote green growth (Zhou et al., 2023). Moreover, role of financial development to boost environmental technology innovations, also varies with different levels of higher education. As a conclusion, higher education can improve green growth by improving public awareness about environmental issues, promoting skills and training to develop green labor force, transition towards renewable energy sources, energy efficiency, and green technology. Theoretical mechanism for education and GG nexus is given in Fig. 1.

International trade and green growth. Global trade can reveal both the adverse and supportive impact on green growth. Heckscher-Ohlin theory of trade explains that in the presence of free trade, developed economies converge towards the capital intensive production. While developing nations specialize in production of labor intensive products and rely on natural

resource utilization. During trade process, goods are traded for consumption and production purposes. This highlights that environmental impact of trade occur during production or consumption of goods. In the case when an economy is producing highly energy-oriented commodities then pollution increases and vice versa (Suri and Chapman, 1998). Contradictory theoretical channels are present through which global trade have supportive and adverse impacts for green growth.

For instance, the Pollution Haven Hypothesis (PHH) states that enhanced trade openness may promote environmentally harmful industries in advanced nations to relocate their productive resources to economies with more lenient ecological regulations (Achuo and Ojong, 2025; Al Numan et al., 2025). This relocation is driven by cost-saving objectives, permitting firms to operate with lower compliance costs in host economies. While such trade may increase economic activity in developing countries, it can also lead to environmental degradation, undermining green growth efforts. PHH explains the potential downside of liberalized trade when not supported by uniform environmental standards, making it crucial for economies to balance trade policy with strong environmental governance. Furthermore, in the presence of rapid trade, economies adopt innovative technology to meet the global competitiveness which can reduce emissions and promote sustainable development (Shafik and Bandyopadhyay, 1992). Environmental regulations are also important to consider for nexus between trade and GG. Many studies have provided evidence for significant role environmental regulations for sustainable development. Economies that develop and implement environmental regulations, can get favorable outcomes of trade to boost green growth. While weak environmental policies cause natural resource depletion during trade and production process and reduce green growth. Theoretical link between trade and GG is presented in Fig. 2.

Labor, capital, and green growth. Labor and capital formation have socioeconomic implications. The study draws upon the Cobb-Douglas production function, which models production as a result of labor and capital. In its basic form, $Y = A \cdot L^\alpha \cdot K^\beta$ where Y shows output, while L and K represent labor and capital, respectively. Total factor productivity is symbolized by A, and output elasticities are shown by α and β . In the context of green growth, this framework is followed to evaluate how labor and capital impact the environmentally sustainable economic output, recognizing that increase in productivity can also stem from eco-friendly practices and technological innovation. High capital formation improve labor engagement in economic activities and leads to more economic growth (Aslan and Altinoz, 2021;

Higher Education and Green Growth Linkage

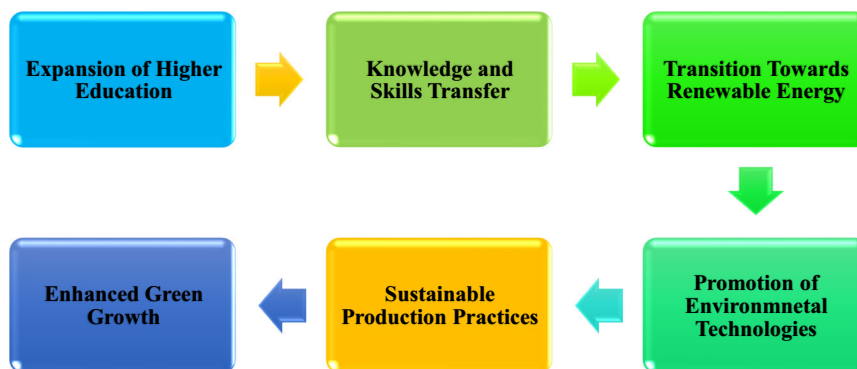


Fig. 1 Higher Education and Green Growth Linkage.

International Trade and Green Growth Linkage

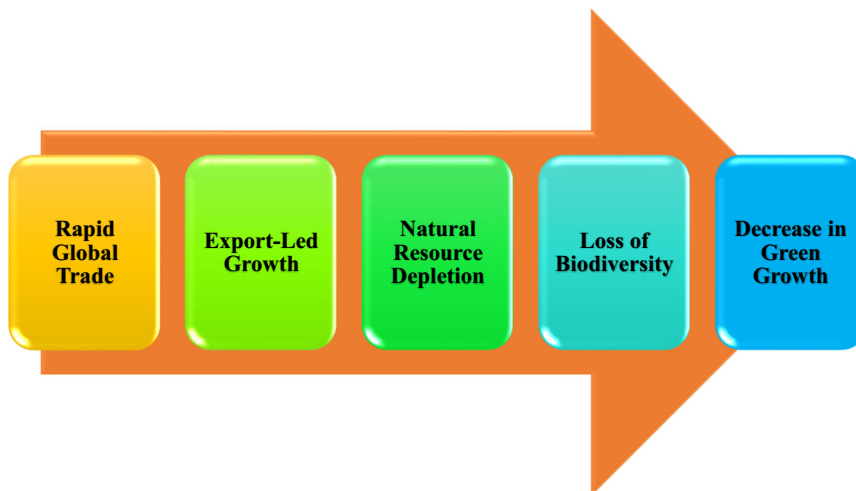


Fig. 2 International Trade and Green Growth Linkage.

Nexus between Labor and Green Growth



Fig. 3 Nexus between labor and green growth.

Olufemi et al., 2022). Intensive labor force utilizations can effect green growth positive and negative both dimensions. For positive dimension, labor force having skills and expertise in renewable energy, green technologies, and sustainable production practices, can support in promoting low carbon economy. Resource conservation, and energy efficiency are also outcomes of well-trained labor force which help in growing GG. While dependence on traditional labor-intensive industries can lower GG. Similarly, rapid capital formation supported by conventional non-renewable energy source can harm GG but if increase in investment is accompanied with renewable energy methods, environment friendly technologies, and sustainable production practices, then ultimately GG improves. Theoretical linkages that how labor and capital can impact the green growth, is given in following Figs. 3 and 4.

FDI and green growth. FDI can impact green growth through both positive and negative channels. On one hand, FDI works as a channel for the transfer of innovative, eco-friendly technologies and managerial practices from advanced to host nations, improving energy efficiency, cleaner production, and innovation, thus supporting sustainable growth (Borensztein et al., 1998). It can also create green employment and stimulate investment in renewable sectors. In contrast, the Pollution Haven Hypothesis

Nexus between Capital and Green Growth



Fig. 4 Nexus between capital and green growth.

advocates that in the absence of strict environmental regulations, FDI may lead to the relocation of pollution-intensive industries to host economies, enhancing environmental degradation and declining green growth. Therefore, the impact of FDI on green growth relies on the environmental standards and regulatory frameworks of the host country. Theoretical linkages for FDI and green growth are shown in Figs. 5 and 6.

Empirical literature

Education and green growth. Implications of education and ecological awareness have been widely analyzed for different global economies and regions. For instance, Kethoilwe (2019) examined the role of climatic knowledge for disaster risk management and showed that climatic awareness can play favorable role to attain sustainable development through ensuring disaster risk management. Ramirez et al. (2019) found significant positive influence of environmental education to boost environmental quality through increasing biodiversity conservation. Gao et al. (2019) analyzed the impact of higher education on conventional economic growth and green growth among 187 global economies by using dataset for time period of 1990–2015. Results depicted significant positive linkage of higher education with growth variables. However, impact on green growth was comparatively high as compared with traditional GDP. Likewise, Ngo et al. (2022) stated that education expenditure and improvement in human capital enhanced the green growth among panel of 36 global nations. Zhao et al. (2023) examined the influence of educational investment and digital economy on environmental quality among 287 cities of China. Regression outcomes showed that rise in educational investment and digital economy provide support to boost sustainable development through improving environmental quality. In contrast, Liu et al. (2022) revealed positive linkage between education and carbon emissions while role of green energy was found supportive to enhance environmental quality. Similarly, Zhang et al. (2022) investigated effect of education,

ICT, and globalization on CO₂ in developing nations for time duration of 1996–2019. Long run outcomes showed emission increasing impact of education and globalization while ICT was found favorable to enhance environmental quality.

International trade, FDI and green growth. Many scholars investigated the effects of global trade on economic growth, environmental quality, sustainable development, and green growth (e.g., Wei et al., 2023; Meng et al., 2022; Wu et al., 2024; Chen et al., 2022). Chu et al. (2025) revealed that digital trade has significant influence to improve inclusive green growth through uplifting industrial structure in China. Individual impact of exports and imports on environmental quality was analyzed among G7 countries (Khan et al., 2022). Results revealed that exports improved sustainable development by reducing CO₂ and imports caused rise in CO₂. Study advocated the promotion of exports, renewable energy, and institutional quality to ensure sustainable development. Using load capacity factor as proxy for environmental quality, Wu et al. (2024) evaluated the environmental role of trade openness among fast growing nations for time span of 1996–2019. Results showed that trade adversely affect the sustainable development by decreasing load capacity factor. Udeagha and Ngepah (2022) investigated short term and long term environmental influence of trade using ARDL method in South Africa for the time period of 1960–2020. Results revealed that trade improved environmental quality in short term but not in the long term. Zhang and Choi (2025) analyzed the linkage of digital trade and technological innovation with green productivity of 52 global nations for the time period of 2005–2001. Using panel ARDL, study showed that digital trade and technological innovation enhance the green growth but FDI has impeding impact for green growth. Derindag et al. (2023) concluded that effect of trade on CO₂ emissions mainly depends on prevailing intensity of CO₂ emissions in the economy. Their estimations showed that trade openness increases CO₂ emissions when economy is facing weak CO₂ intensity and decreases environmental pollution in the presence of strong CO₂ emissions intensity. Omri and Saadaoui, (2023) found harming influence of trade on sustainable development by uplifting CO₂ emissions in France. Findings of causality test depicted bidirectional causality linkage between trade and CO₂ emissions.

Capital, labor, and green growth. Socioeconomic implications of capital and labor are analyzed in several studies depicting varying outcomes. Apinran et al. (2022) estimated the effects of capital, labor, and carbon emissions on economic growth in Nigeria for time period of 1981 to 2019. Using novel dynamic ARDL method,

Foreign Direct Investment Promoting Green Growth

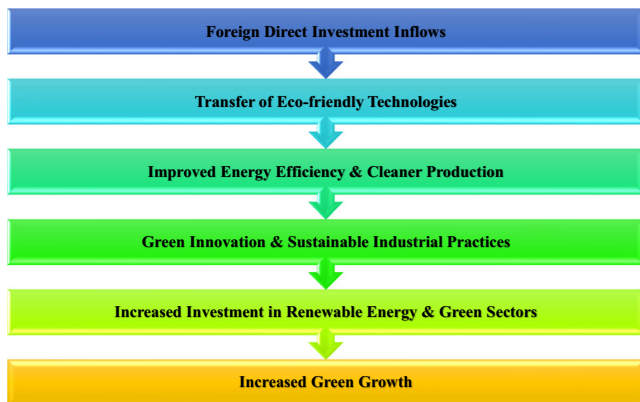


Fig. 5 Foreign direct investment promoting green growth.

Foreign Direct Investment Hindering Green Growth



Fig. 6 Foreign Direct Investment Hindering Green Growth.

Table 1 Variables specification.

Sign	Variables	Measures	Sources
GGDP	Green Growth	Green Growth Index	(Sarkodie et al., 2023)
EDU	Education	Human capital index, based on year of schooling and return to education	PWT 11.0 (Penn World Table Version 11) (https://www.rug.nl/ggdc/productivity/pwt/?lang=en)
CAP	Capital	Gross Fixed Capital Formation	World Bank, (2023)
EMP	Labor	Employment Ratio	World Bank, (2023)
TRD	Trade	Trade as Percentage of GDP	World Bank, (2023)
FDI	Foreign Direct Investment	Net Inflows (Percent of GDP)	World Bank, (2023)

All variables are used after taking natural logarithm.

Table 2 Descriptive statistics.

	GGDP	EDU	TRD	CAP	EMP
Mean	0.603354	1.762880	48.82428	21.80676	72.53427
Median	0.601476	1.778276	50.87614	21.34853	73.98000
Maximum	0.895946	1.984474	88.51987	36.05232	80.34300
Minimum	0.298458	1.427463	15.81031	14.97762	57.97600
Std. Dev.	0.111331	0.111511	18.40795	3.409786	5.299912
Skewness	0.017771	-0.602174	0.019940	1.294929	-1.041499
Kurtosis	2.879276	3.473562	2.267683	6.062558	3.409173
Jarque-Bera	0.142538	15.07245	4.840907	144.7796	40.55674
Probability	0.931211	0.000533	0.088881	0.000000	0.000000

study revealed that capital and labor have favorable role for economic growth while carbon emissions have adverse impact. For sustainable growth, reduction of carbon emissions was suggested. Likewise, Soava et al. (2020) also explained that labor and capital formation had significant supportive influence on economic growth in economies of European Union. In case of Bangladesh, Khalid and Abdul (2025) found significant role of FDI and financial development on green growth and study concluded that human capital growth has favorable role to enhance green growth. Fedulova et al. (2019) stated that labor productivity, technological innovations, and industrial advancement are significant supportive factors of sustainable economic development. Role of capital formation for energy demand was analyzed by Rafindadi and Mika'Ilu (2019). Using ARDL method study depicted that rise in capital formation results in higher energy demand. To meet that energy demand through renewable sources can ultimately ensure green growth (Sohag et al., 2021). Explained that CO₂ emissions varies more closely with changes in capital formation instead of GDP. Study also showed that investment structure was more favorable tool among developing economies as compared with developed nations to attain sustainable development.

Research gap. The existing literature have examined the individual linkages of education, labor, capital, trade, and FDI on economic growth or environmental quality, limited focus has been made to their joint impact on green growth, particularly within developed nations. Most prior studies are either focused on developing economies or addresses isolated components of sustainable development. Additionally, studies rarely employ dynamic econometric techniques like AMG method to capture the long term equilibrium among these factors in the framework of green growth. This study fills this substantial gap by jointly analyzing these variables across G7 nations, offering comprehensive policy suggestions aimed at achieving sustainable and inclusive green growth.

Methods

Models. The present study considered the Cobb-Douglas production function and added trade as additional explanatory variables for panel of G7 nations. Education is included in model as key concerned factor of the study as given in Eqs. 1, 2, and 3 (model 1, 2, and 3). The study uses green growth as a comprehensive measure of sustainable development instead of using traditional GDP growth.

$$GGDP = EDU + EDU2 + CAP + EMP \tag{1}$$

$$GGDP = EDU + EDU2 + CAP + EMP + FDI \tag{2}$$

$$GGDP = EDU + EDU2 + CAP + EMP + TRD \tag{3}$$

In above given Eqs. 1–3, GGDP is green growth. Furthermore, green growth index introduced by Sarkodie et al. (2023) is used as proxy for green growth.

Econometric form of three aforementioned models, is presented below in Eqs. 4, 5, and 6.

$$GGDP_{it} = \alpha + \beta_1 EDU_{it} + \beta_2 EDU2_{it} + \beta_3 CAP_{it} + \beta_4 EMP_{it} + \epsilon_{it} \tag{4}$$

$$GGDP_{it} = \alpha + \beta_5 EDU_{it} + \beta_6 EDU2_{it} + \beta_7 CAP_{it} + \beta_8 EMP_{it} + \beta_9 FDI_{it} + \epsilon_{it} \tag{5}$$

$$GGDP_{it} = \alpha + \beta_{10} EDU_{it} + \beta_{11} EDU2_{it} + \beta_{12} CAP_{it} + \beta_{13} EMP_{it} + \beta_{14} TRD_{it} + \epsilon_{it} \tag{6}$$

Data. Specification of variables is given in Table 1. Green growth (GGDP) is dependent variable and measured as green growth index calculated by Sarkodie et al. (2023). Independent variables are education (EDU) measured as human capital index, based on year of schooling and return to education, capital (CAP) measured as gross fixed capital formation, labor (EMP) measured as

Table 3 Correlation matrix.

Variable	GGDP	CAP	EMP	FDI	TRD	EDU
GGDP	1.000					
CAP	0.037	1.000				
EMP	0.012	0.054	1.000			
FDI	-0.001	-0.259	0.284	1.000		
TRD	-0.243	-0.436	0.201	0.369	1.000	
EDU	0.040	-0.051	0.837	0.250	0.087	1.000

Table 4 Pesaran CSD test.

Variables	p-value
GGDP	0.02**
EMP	0.00***
CAP	0.06*
TRD	0.00***
EDU	0.00***

***, **, and * show significance level 1%, 5%, and 10% respectively.

employment ratio, trade (TRD) measured as total trade as percentage of GDP, and foreign direct investment (FDI) measured as net inflows as percentage share of GDP. The data Education collected from PWT 11.0 (Penn World Table Version 11), whereas the data for other independent variables is taken from World Bank (2023). Time period for the dataset is 1990–2020.

Descriptive specifications of variables are presented in Table 2 including mean, median, standard deviation, maximum, minimum, Kurtosis, Skewness, Jarque-Bera, and p-value. Mean values are 0.603 (GGDP), 1.763 (EDU), 48.824 (TRD), 21.807 (CAP), and 72.534 (EMP). Median values in same sequence of variables are 0.601, 1.779, 50.876, 21.348, and 73.98. Maximum values of variables are 0.896 (GGDP), 1.984 (EDU), 88.519 (TRD), 36.052 (CAP), and 80.343 (EMP). Minimum values are 0.298, 1.427, 15.81, 14.978, and 57.976. The GGDP, TRD, and CAP are positively skewed with 0.0178, 0.0199, and 1.295 respectively. While EDU and EMP are negatively skewed with -0.602 and -1.041. Values of Jarque-Bera (test for goodness of fit) are 0.142 (GGDP), 15.072 (EDU), 4.84 (TRD), 144.779 (CAP), and 40.556 (EMP).

The descriptive statistics show that green growth (GGDP) among G7 nations averaged around 0.60, depicting moderate performance, with limited variability (Std. Dev. = 0.11). Education (EDU), based on year of schooling and return to education, also highlights a low standard deviation (0.11), indicating relatively consistent education levels across nations. The trade variable (TRD) exhibits wide variation (Std. Dev. = 18.41), reflecting diverse trade openness across nations. Capital (CAP) has a positively skewed distribution with notable dispersion (Skewness = 1.29, Std. Dev. = 3.41), showing that in some cases, capital formation is significantly greater than the average. Employment (EMP) is negatively skewed (Skewness = -1.04), suggesting most values cluster at the higher end, but a few lower observations pull the mean down. The Jarque-Bera test assures that CAP, EDU, and EMP are not normally distributed ($p < 0.05$), which has implications for the choice of estimation methods.

Methodology

Augmented Mean Group (AMG). Traditional panel regression methods may produce biased and inconsistent long-run results when cross-sectional dependence exists among units in the panel (Pesaran and Smith, 1995; Paramati et al., 2017; Dumitrescu and

Hurlin, 2012). The Augmented Mean Group (AMG) estimator developed by Eberhardt and Teal (2010) is employed, as it effectively addresses cross-sectional dependence and parameter heterogeneity. The AMG method is appropriate technique for models with heterogeneous slope coefficients and remains consistent even in the existence of endogeneity, non-stationarity, and unobserved common factors. Its robustness under these conditions makes it a valuable tool for panel data estimations (Dumitrescu and Hurlin, 2012). AMG is suitable for panels with moderate time dimensions and a limited number of cross-sectional units, such as the G7 nations, making it more consistent than traditional estimators in such contexts. Additionally, AMG method operates under less restrictive assumptions as it does not require slope homogeneity or cross-sectional independence, confirming robustness even when these conditions are violated. These features make AMG a flexible and robust choice for long term panel estimations.

Equation (7) shows the common dynamic effect parameter, which represents the unobserved common factors (f_t) captured by the AMG estimator. This is explained through the first-difference OLS equation given below, which forms a key step in the AMG estimation process.

$$\Delta y_{it} = \alpha_i + \beta_i \Delta X_{it} + \sum_{t=0}^T \theta_t D_t + \varphi f_t + \varepsilon_{it} \tag{7}$$

In Eq. (7), y_{it} and X_{it} represent the dependent and independent variables, respectively. β_i shows the country-specific slope coefficients, while f_t represents unobserved common factors with heterogeneous impacts. α_i and ε_{it} are the intercept and error terms, respectively. The symbol Δ indicates the first-difference operator, β_i reflects cross-sectional heterogeneity, and θ_t represents time-specific effects. The AMG estimator is then derived by averaging the group-specific parameters across all panel units.

$$AMG = \frac{1}{N} \alpha_i + \sum_{i=1}^N \tilde{\beta}_i \tag{8}$$

In Eq. (8), $\tilde{\beta}_i$ represents the estimator of β_i from Eq. (7). The AMG technique is used to estimate long-run parameters due to its demonstrated unbiasedness and efficiency across various sample sizes (N) and time dimensions (T) in Monte Carlo simulations.

Data transformations and panel unit root test (CIPS) is conducted to ensure stationarity. Cross-sectional dependence and Westerlund (2007) Cointegration are used to assess the validity of the model’s assumptions.

Results and discussion

Correlation matrix of the variables of the study, is given in Table 3. The correlation matrix shows that green growth (GGDP) has low correlations with all independent factors, showing low multicollinearity. Employment (EMP) and education (EDU) are highly correlated (0.837), suggesting high multicollinearity. Trade (TRD) is negatively correlated with capital (CAP) and green growth (GGDP), while foreign direct investment (FDI) has a moderate positive correlation with trade (0.369) and employment (0.284) but a negative correlation with capital (-0.259). Overall, no extreme correlations suggest serious multicollinearity concerns among the variables. However, we drop EMP from models 1, 2, and 3 due to its high multicollinearity with EDU.

Findings of CSD test are given in Table 4. To proceed for cointegration and regression estimations, this is crucial to assess the CSD because using conventional techniques in the existence of CSD reveal invalid conclusions and inconsistent estimators (Mao and Shen, 2019). The CSD test is significant for all the variables of the study. The CSD outcomes rejects the null

Table 5 Slop heterogeneity test.

Test Statistic	Value	p-value
Delta	0.485	0.628
Adj. Delta	0.540	0.589

Table 6 CIPS unit root.

Variables	I(0)	I(1)
GGDP	-1.01	-5.27***
EMP	-1.14	-4.95***
CAP	-1.23	-4.82***
TRD	-0.94	-5.21***
EDU	-1.36	-6.14***

***shows significance level at 1%.

Table 7 Westerlund cointegration.

Variable	p-value
G _t	0.01**
G _a	0.12
P _t	0.16
P _a	0.06*

** and * show significance level 5%, and 10% respectively.

hypothesis of non-existence of cross-section dependence and accepts the alternative hypothesis.

The slope heterogeneity test (Table 5) shows p-values greater than 0.05, showing that cannot be rejected the null hypothesis of slope homogeneity. This reveals that the model assumes similar slope coefficients across panel units. Such homogeneity depicts that the influence of independent variables on green growth is consistent across the G7 nations, supporting the use of pooled estimators. To assess the stationarity of variables, the study employs CIPS unit root test and outcomes are shown in Table 6. The CIPS unit root test is more suitable test in the presence of CSD among the variables. All variables are found stationary at first difference with 1% significance level.

Cointegration among the variables is evaluated by applying Westerlund Cointegration method. Results are given in Table 7. This method presents four statistics (G_t, G_a, P_t, and P_a) with null hypothesis and alternative hypothesis for absence and existence of cointegration among the variables respectively. Estimations show two statistics (G_t and P_a) as significant which provide confirmation to reject the null hypothesis and confirm the presence of cointegration among the variables.

Empirical outcomes of AMG method regarding impact of capital, education, squared education, and trade on green growth are given in Table 8. Findings show that capital has positive but insignificant link with green growth among all three models. Findings also reveal that education has positive but insignificant influence on green growth in all three AMG models. This depicts that, while education may usually contribute to environmentally sustainable development, its direct influence alone is not strong enough to bring significant improvement in green growth. While in squared education has favorable and significant impact on green growth with 0.15 coefficient value in all three models which reveals that 1% rise in squared education improves the green growth by 0.15%. This non-linear linkage shows that the impact of education becomes more impactful beyond a particular threshold level. In other words, initial or lower levels of education may not be

Table 8 Models estimated through Augmented Mean Group (AMG).

Dependent Variable = Green Growth (GGDP)		
Independent Variables	Coefficients	p-value
Model 1		
EDU	0.250	0.190
EDU2	0.1542	0.000
CAP	0.0001	0.354
Diagnostic Test: Root mean squared error = 0.0009		
Model 2		
EDU	0.270	0.140
EDU2	0.1545	0.000
CAP	0.0002	0.257
FDI	-0.0002	0.064
Diagnostic Test: Root mean squared error = 0.0009		
Model 3		
EDU	0.1123	0.350
EDU2	0.1542	0.000
CAP	0.0001	0.351
TRD	0.00005	0.060
Diagnostic Test: Root mean squared error = 0.0010		

sufficient, but as education levels rise, particularly in terms of higher education, research capacity, and environmental awareness, then its contribution to green growth becomes significant. This supports the argument that investments in advanced and targeted educational programs are essential to foster long-term sustainable development. Literature provides evidence positive impact of education on green growth (Ngo et al., 2022; Liu et al., 2022). Endogenous growth theory shows that boost in sustainable growth can be outcome of rising knowledge levels (Benos and Zotou, 2014; Zhou et al., 2023). Policymakers should prioritize education reforms that integrate sustainability into curricula and enhance innovation in clean technologies, as these measures can directly work for attaining long-term green growth.

The findings also show that trade has a direct and insignificant impact on green growth across all three AMG models, as the p values are greater than 5% significance level. This shows that while trade openness may be associated with improvements in green growth, the linkage is not strong or consistent enough to be considered statistically impactful in this study. This finding could be due to the nature of trade in the G7 nations, which may not be sufficiently oriented towards environmentally sustainable goods and technologies (Wu et al., 2024). It also suggests that without complementary ecological policies or green trade practices, enhanced trade alone may not significantly improve green growth. Moreover, FDI has negative association with green growth. Numerous studies confirmed the validity of pollution haven hypothesis which shows that in the presence of weak environmental regulations, rise in FDI increases environmental degradation in the host economy (Esmaili et al., 2023; Bashir, 2022; Huang et al., 2023) which ultimately reduces the green and sustainable growth. Policymakers should emphasize on attracting green FDI by offering incentives for sustainable projects and ensuring environmental compliance, which can improve domestic capacity for low carbon development. The adverse influence of FDI on green growth aligns with the pollution majhaven hypothesis, highlighting that environmentally harmful investments may be flowing into sectors with weaker environmental oversight.

Conclusion and policy suggestions

Conclusion. Green growth has become very pressing phenomenon for researchers and policymakers since 20th century. This

study investigates the empirical influence of education, squared education, capital, and trade on green growth among G7 nations using annual data for time period of 1990–2020. The study utilizes AMG method to long run coefficients. Findings of Westerlund cointegration test ensure the existence of long run cointegration among all the variables in the model. Findings of the AMG method reveal that education has positive and insignificant impact on green growth while squared education has positive significant impact on green growth, that environmental awareness improves with rise in advanced levels of education which leads to green and sustainable growth. Outcomes show positive association of trade with GGDP. While capital has positive but insignificant association with GGDP. Moreover, study shows that FDI proves adverse factor for green growth among G7 nations which supports the pollution haven hypothesis.

Policy implications. Based on findings of the study following policy suggestions are advocated to the governments of G7 nation for boosting the quality education (SDG-4), decent work and economic growth (SDG-8), and climate action (SDG-13).

1. Given the positive but insignificant impact of capital on green growth, G7 nations should focus on redirecting capital investment toward ecologically sustainable sectors. This can be attained by promoting incentives for clean energy, green infrastructure, and eco-innovation, confirming that capital contributes more efficiently to green growth. For example, economies like the U.S. and Germany could boost capital flow into sustainable manufacturing and energy-efficient technologies through green bonds, tax benefits, and public-private partnerships. Such measures would improve the productivity of capital in uplifting environmental sustainability.
2. G7 nations should invest in advanced and higher-level education programs that integrate sustainability-focused curricula and promote green skills development. Collaboration with research institutions and universities should be supported to grow green innovation hubs and support public-private R&D initiatives. Economies like UK and Japan can further scale up their efforts by improving university-led research clusters dedicated to sustainable technologies and environmental solutions.
3. To strengthen the positive contribution of trade to enhance green growth, G7 nations should adopt proactive eco-friendly trade measures. These may consist of incentivizing the export of green technologies, integrating environmental standards into trade agreements, and facilitating low-carbon supply chains. Italy and Japan, as leading trading economies, can further support sustainability by promoting green exports, encouraging environmentally responsible imports, and aligning trade policies with global climate goals.
4. Governments of G7 economies should provide green investment incentives to avoid adverse ecological impact of FDI. A transparent reporting framework for monitoring the environmental impact of FDI can ensure that global investments contribute positively to the host country's SDGs. Economies like the U.S. and Canada, which receive high volumes of FDI, can improve ecological screening criteria to attract only sustainability-oriented investments.

Limitations of the study. Following are some limitations of the present study.

1. The study emphasizes solely on G7 nations, limiting the applicability of results to other regions with different economic and environmental conditions.
2. The analysis excludes other potentially significant factors such as environmental policies, renewable energy adoption, and technological innovation beyond trade and FDI.
3. The adverse linkage of capital and trade on green growth may be context-specific, requiring further investigation into sectoral or industry-level differences.

Data availability

The data sources are provided in this study.

Received: 24 October 2024; Accepted: 21 October 2025;

Published online: 27 November 2025

References

- Achuo E, Ojong N (2025) Foreign direct investment, economic growth and environmental quality in Africa: revisiting the pollution haven and environmental Kuznets curve hypotheses. *J Econ Stud* 52(4):673–691
- Agasisti T, Bertolotti A (2022) Higher education and economic growth: a longitudinal study of European regions 2000–2017. *Socio-Econ Plan Sci* 81:100940
- Ahmad M, Jabeen G, Shah SAA, Rehman A, Ahmad F, Isik C (2022) Assessing long-and short-run dynamic interplay among balance of trade, aggregate economic output, real exchange rate, and CO2 emissions in Pakistan *Environ Dev Sustain* 24:7283–7323
- Ahmed F, Kousar S, Pervaiz A, Trinidad-Segovia JE, del Pilar Casado-Belmonte M, Ahmed W (2022) Role of green innovation, trade and energy to promote green economic growth: a case of South Asian Nations. *Environ Sci Pollut Res* 29(5):6871–6885
- Ahmed N, Sheikh AA, Hassan B, Khan SN, Borda RC, Huamán JMC, Senkus P (2022) The role of educating the labor force in sustaining a green economy in MINT Countries: panel symmetric and asymmetric approach. *Sustainability* 14(19):12067
- Al Numan A, Tahrim F, Esquivias MA, Biswas MK, Pramanthi MR (2025) Testing the pollution haven and inverted N-shaped EKC hypotheses in the ASEAN region: the impact of FDI and energy mix on environmental quality. *Env Sustain Indic* 26:100698
- Ali Q, Anwar S, Khan MTI, Yaseen MR, Ashfaq M (2023) Estimation of economic, environmental, and social efficiency for sustainable development in G-8 and SAARC countries: a data envelopment analysis. *Environ Sci Pollut Res* 30(10):26819–26842
- Amir H, Khan M, Bilal K (2015) Impact of educated labor force on Economic growth of Pakistan: a human capital perspective. *Eur Online J Nat Soc Sci* 4(4):814–831
- Apinran MO, Usman N, Akadiri SS, Onuzo CI (2022) The role of electricity consumption, capital, labor force, carbon emissions on economic growth: implication for environmental sustainability targets in Nigeria. *Environ Sci Pollut Res* 29(11):15955–15965
- Aslan A, Altinöz B (2021) The impact of natural resources and gross capital formation on economic growth in the context of globalization: evidence from developing countries on the continent of Europe, Asia, Africa, and America. *Environ Sci Pollut Res* 28:33794–33805
- Awan A, Hussain K, Zafar M, Butt MJ, Yaghmour S (2025) Impact of nations' green behavior on green growth by considering the moderating role of environmental policy stringency. *Manag Environ Qual: Int J* 36(2):309–328
- Bashir MF (2022) Discovering the evolution of pollution haven hypothesis: a literature review and future research agenda. *Environ Sci Pollut Res* 29(32):48210–48232
- Belmonte-Ureña LJ, Plaza-Úbeda JA, Vazquez-Brust D, Yakovleva N (2021) Circular economy, degrowth and green growth as pathways for research on sustainable development goals: a global analysis and future agenda. *Ecol Econ* 185:107050
- Benos N, Zotou S (2014) Education and economic growth: A meta-regression analysis. *World Development* 64:669–689
- Borensztein E, De Gregorio J, Lee JW (1998) How does foreign direct investment affect economic growth? *J Int Econ* 45(1):115–135
- Chen S, Zhang H, Wang S (2022) Trade openness, economic growth, and energy intensity in China. *Technol Forecast Soc Change* 179:121608
- Chien F, Ananzeh M, Mirza F, Bakar A, Vu HM, Ngo TQ (2021) The effects of green growth, environmental-related tax, and eco-innovation towards carbon neutrality target in the US economy. *J Environ Manag* 299:113633

- Chu Y, Du Y, Yang Y (2025) The impact of digital trade on inclusive green growth—evidence from China's experience. *Front Environ Sci* 13:1559586
- Derindag OF, Maydybyura A, Kalra A, Wong WK, Chang BH (2023) Carbon emissions and the rising effect of trade openness and foreign direct investment: evidence from a threshold regression model. *Heliyon*, 9:e17448
- Dong Q, Balsalobre-Lorente D, Syed QR (2025) The critical role of financial inclusion in green growth: Evidence from BRICS countries. *Res Int Bus Finance* 76:102847
- Dumitrescu EI, Hurlin C (2012) Testing for Granger non-causality in heterogeneous panels. *Econ Model* 29(4):1450–1460
- Eberhardt M, Teal F (2010) Productivity analysis in global manufacturing production (Economics Series Working Paper No. 515). University of Oxford, Department of Economics
- Esmaceli P, Lorente DB, Anwar A (2023) Revisiting the environmental Kuznetz curve and pollution haven hypothesis in N-11 economies: fresh evidence from panel quantile regression. *Environ Res* 228:115844
- Fedulova I, Voronkova OY, Zhuravlev P, Gerasimova E, Glyzina M, Alekhina NA (2019) Labor productivity and its role in the sustainable development of economy: on the example of a region. *Entrep Sustain Issues* 7(2):1059
- Gao W, Ding X, Chen R, Min W (2019) An empirical study of the role of higher education in building a green economy. *Sustainability* 11(23):6823
- Grossman GM, Krueger AB (1995) Economic growth and the environment. *Q J Econ* 110(2):353–377
- Haberl H, Wiedenhofer D, Virág D, Kalt G, Plank B, Brockway P, Creutzig F (2020) A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II: synthesizing the insights. *Environ Res Lett* 15(6):065003
- Hickel J, Kallis G (2020) Is green growth possible? *N. political Econ* 25(4):469–486
- Huang L, Zhao W (2022) The impact of green trade and green growth on natural resources. *Resour Policy* 77:102749
- Huang Y, Xu F, Abbas A, Zhang Y, Kim E (2023) Empirical impact of China-Pak business cycle synchronization on environmental degradation in Pakistan. *Front Environ Sci* 10:1030408
- Imasiku K, Thomas V, Ntagwirumugara E (2019) Unraveling green information technology systems as a global greenhouse gas emission game-changer. *Adm Sci* 9(2):43
- Jadoon IA, Mumtaz R, Sheikh J, Ayub U, Tahir M (2021) The impact of green growth on financial stability. *J Financial Regul Compliance* 29(5):533–560
- Karadaş HA (2020) Effect of labor force education level on growth: an analysis on fragile five countries. *Contemp Approaches Field Econ Finance Manag* 43–58
- Kethlhoilwe MJ (2019) Building community resilience through environmental education: a local response to climate change. *Building Sustainability Through Environmental Education*. IGI Global pp. 1–21
- Khalid MA, Abdul M (2025) Green growth and human Capital in Bangladesh: evaluating the roles of financial development and foreign direct investment in reducing carbon emissions. *J Energy Environ Policy Options* 8(1):1–13
- Khan AA, Khan SU, Ali MAS, Safi A, Gao Y, Luo J (2022) Identifying impact of international trade and renewable energy consumption on environmental quality improvement and their role in global warming. *Environ Sci Pollut Res* 29(23):33935–33944
- Khan KA, Cong PT, Thang PD, Uyen PTM, Anwar A, Abbas A (2024) From brown to green: are Asian economies on the right path? Assessing the role of green innovations and geopolitical risk on environmental quality. *Environ Sci Pollut Res* 1–13
- Lewis JJ, Pattanayak SK (2012) Who adopts improved fuels and cookstoves? A systematic review. *Environ health Perspect* 120(5):637–645
- Li X, Ma L, Ruman AM, Iqbal N, Strielkowski W (2023) Impact of natural resource mining on sustainable economic development: the role of education and green innovation in China *Geosci Front* 15:101703
- Li X, Shaikh PA, Ullah S (2022) Exploring the potential role of higher education and ICT in China on green growth. *Environ Sci Pollut Res* 29(43):64560–64567
- Liu H, Alharthi M, Atil A, Zafar MW, Khan I (2022) A non-linear analysis of the impacts of natural resources and education on environmental quality: green energy and its role in the future *Resour. Policy* 79:102940
- Liu D, Wang G, Sun C, Majeed MT, Andlib Z (2023) An analysis of the effects of human capital on green growth: effects and transmission channels. *Environ Sci Pollut Res Int* 30:10149–10156
- Liu W, Chen X (2025) Evaluating the impact of energy efficiency on green growth in Chinese cities: a spatial Durbin model approach. *Energy* 322:135298
- Lorek S, Spangenberg JH (2014) Sustainable consumption within a sustainable economy—beyond green growth and green economies. *J Clean Prod* 63:33–44
- Majeed MT, Asghar N (2021) Trade, energy consumption, economic growth, and environmental quality: an empirical evidence from D-8 and G7 countries. *Environ Sci Pollut Res* 28(43):61302–61316
- Mao G, Shen Y (2019) Bubbles or fundamentals? Modeling provincial house prices in China allowing for cross-sectional dependence. *China Econ Rev* 53:53–64
- Meng Y, Wu H, Wang Y, Duan Y (2022) International trade diversification, green innovation, and consumption-based carbon emissions: the role of renewable energy for sustainable development in BRICST countries. *Renew Energy* 198:1243–1253
- Murshed M (2024) Can renewable energy transition drive green growth? The role of good governance in promoting carbon emission-adjusted economic growth in Next Eleven countries. *Innov Green Dev* 3(2):100123
- Naseer S, Song H, Chupradit S, Maqbool A, Hashim NAAN, Vu HM (2022) Does educated labor force is managing the green economy in BRCS? Fresh evidence from NARDL-PMG approach. *Environ Sci Pollution Res* 29:20296–20304
- Ngo T, Trinh HH, Haouas I, Ullah S (2022) Examining the bidirectional nexus between financial development and green growth: International evidence through the roles of human capital and education expenditure. *Resour Policy* 79:102964
- Olufemi J, Asaleye AJ, Popoola O, Awe AA, Ojo J (2022) Implications of Human Capital Formation on Output and Employment: Evidence from Nigeria. *Asian Econ Financial Rev* 12(1):47–57
- Omri E, Saadaoui H (2023) An empirical investigation of the relationships between nuclear energy, economic growth, trade openness, fossil fuels, and carbon emissions in France: fresh evidence using asymmetric cointegration. *Environ Sci Pollut Res* 30(5):13224–13245
- Paramati SR, Mo D, Gupta R (2017) The effects of stock market growth and renewable energy use on CO₂ emissions: evidence from G20 countries. *Energy Econ* 66:360–371
- Pesaran MH, Smith R (1995) Estimating long-run relationships from dynamic heterogeneous panels. *J Econ* 68(1):79–113
- Qamruzzaman M (2025) The effects of natural resources, education, and financial inclusion in achieving environmental sustainability in resources-abundance nations. *Discov Sustain* 6(1):136
- Rafindadi AA, Miki'llu AS (2019) Sustainable energy consumption and capital formation: empirical evidence from the developed financial market of the United Kingdom. *Sustain Energy Technol Assess* 35:265–277
- Rahai R, Wells NM, Evans GW (2023) School greenspace is associated with enhanced benefits of academic interventions on annual reading improvement for children of color in California. *J Environ Psychol* 86:101966
- Rahman MS, Noman AHM, Shahari F, Aslam M, Gee CS, Isa CR, Pervin S (2016) Efficient energy consumption in industrial sectors and its effect on environment: A comparative analysis between G8 and Southeast Asian emerging economies. *Energy* 97:82–89
- Ramírez F, Santana J, Ramírez F, Santana J (2019) Environmental education and biodiversity conservation. *Environ Educ Ecotourism* 7–11. https://link.springer.com/chapter/10.1007/978-3-030-01968-6_2
- Romer PM (1990) Endogenous technological change. *J Political Econ* 98(5, Part 2):S71–S102
- Saleem H, Khan MB, Mahdavian SM (2022) The role of green growth, green financing, and eco-friendly technology in achieving environmental quality: evidence from selected Asian economies. *Environ Sci Pollut Res* 29(38):57720–57739
- Sarkodie SA, Owusu PA, Taden J (2023) Comprehensive green growth indicators across countries and territories. *Sci Data* 10(1):413
- Saufi NAA, Daud S, Hassan H (2016) Green growth and corporate sustainability performance. *Proc Econ Financ* 35:374–378
- Shafik N, Bandyopadhyay S (1992) Economic growth and environmental quality: time-series and cross-country evidence (Vol. 904). World Bank Publications
- Soava G, Mehedintu A, Sterpu M, Raduteanu M (2020) Impact of employed labor force, investment, and remittances on economic growth in EU countries. *Sustainability* 12(23):10141
- Sohag K, Husain S, Hammoudeh S, Omar N (2021) Innovation, militarization, and renewable energy and green growth in OECD countries. *Environ Sci Pollut Res* 28:36004–36017
- Sulich A, Rutkowska M (2020) Green jobs, definitional issues, and the employment of young people: an analysis of three European Union countries. *J Environ Manag* 262:110314
- Suri V, Chapman D (1998) Economic growth, trade and energy: implications for the environmental Kuznets curve. *Ecol Econ* 25(2):195–208
- Tran T, Do H, Vu T, Do N (2020) The factors affecting green investment for sustainable development. *Decis Sci Lett* 9(3):365–386
- Udeagha MC, Ngepah N (2022) Does trade openness mitigate the environmental degradation in South Africa? *Environ Sci Pollut Res* 29(13):19352–19377
- Wang M, Xu M, Ma S (2021) The effect of the spatial heterogeneity of human capital structure on regional green total factor productivity. *Struct Change Econ Dyn* 59:427–441
- Westerlund J (2007) Testing for error correction in panel data. *Oxford Bulletin of Economics and statistics*, 69(6):709–748
- Wei S, Jiandong W, Saleem H (2023) The impact of renewable energy transition, green growth, green trade and green innovation on environmental quality: evidence from top 10 green future countries. *Front Environ Sci* 10:1076859
- World Bank (2023). World Development Indicators, World Bank, Online Database. <https://data.worldbank.org/>

- Wu Y, Anwar A, Quynh NN, Abbas A, Cong PT (2024) Impact of economic policy uncertainty and renewable energy on environmental quality: testing the LCC hypothesis for fast growing economies. *Environ Sci Pollut Res* 31:36405–36416
- Xie X, Zhu Q, Qi G (2020) How can green training promote employee career growth? *J Clean Prod* 259:120818
- Yadav V, Kumar V, Gahlot P, Mittal A, Kaswan MS, Garza-Reyes JA, ... Owad AA (2024) Exploration and mitigation of green lean six sigma barriers: a higher education institutions perspective. *The TQM Journal* 36:2132–2153
- Zaman K, bin Abdullah A, Khan A, bin Mohd Nasir MR, Hamzah TAAT, Hussain S (2016) Dynamic linkages among energy consumption, environment, health and wealth in BRICS countries: green growth key to sustainable development. *Renew Sustain Energy Rev* 56:1263–1271
- Zhang C, Khan I, Dagar V, Saeed A, Zafar MW (2022) Environmental impact of information and communication technology: unveiling the role of education in developing countries. *Technol Forecast Soc Change* 178:121570
- Zhang M, Wei X, Xu A (2023) Impact of investment in quality language education on green economic growth: case study of 23 Chinese provinces. *Human Soc Sci Commun* 10(1):1–7
- Zhang T, Choi CH (2025) Will digital trade be friend or foe of the green economy? Unveiling the complexities of green growth. *J Appl Econ* 28(1):2464591
- Zhao J, Taghizadeh-Hesary F, Dong K, Dong X (2023) How green growth affects carbon emissions in China: the role of green finance. *Economic Res -Ekonomiska istraživanja* 36(1):2090–2111
- Zhao Y, Kong X, Ahmad M, Ahmed Z (2023) Digital economy, industrial structure, and environmental quality: assessing the roles of educational investment, green innovation, and economic globalization. *Sustainability* 15(3):2377
- Zhou X, Hu X, Duan M, Peng L, Zhao X (2023) Go for economic transformation and development in China: financial development, higher education, and green technology evolution. *Eval Rev* 48:32–62
- Zhou Y, Tian L, Yang X (2023) Schumpeterian endogenous growth model under green innovation and its enculturation effect. *Energy Econ* 127:107109

Acknowledgements

This research has been supported by Key Project of Zhejiang Provincial Philosophy and Social Sciences Planning (No.25NDJC030Z). This research has been funded by the research funds of University of Business and Technology, Jeddah, Saudi Arabia.

Author contributions

F.D. wrote main manuscript. A.A. wrote main manuscript. C.X. wrote main manuscript. K.H.K. wrote results and discussion. Q.R.S. done data analysis. A.A. wrote original draft and supervision.

Competing interests

The authors declare no competing interests.

Ethical approval

Ethical consent was not a prerequisite as the current study did not incorporate human respondents.

Informed consent

This research paper does not include any studies with human respondents performed by any of the authors.

Additional information

Correspondence and requests for materials should be addressed to Cuihua Xie or Ahsan Anwar.

Reprints and permission information is available at <http://www.nature.com/reprints>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Open Access This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by-nc-nd/4.0/>.

© The Author(s) 2025