Wani et al. Future Business Journal (2024) 10:43
https://doi.org/10.1186/s43093-024-00329-1

Future Business Journal

RESEARCH

Open Access

Impact of green technology and energy on green economic growth: role of FDI and globalization in G7 economies

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Abstract

With the increase in economic growth, the world is facing serious challenges concerning environmental sustainability. Hence, the green economic growth is imperative for sustainable and inclusive development. The objective of this study is to contribute to the existing literature about the factors that influence green economic growth. The study investigates the role of green technology, green energy, foreign direct investment, and globalization on green economic growth in G7 countries. The data of the study is collected from WDI, KOF Swiss Economic Institute, and OECD database and the data period ranges from 1995 to 2020. The existence of cointegration between the variables of the study was tested by Westerlund's (Oxford Bull Econ Stat 69(6):709–748) cointegration test. Due to the presence of cross-sectional dependency, the study employed the cross-sectional autoregressive distributed lag (CS-ARDL) method to estimate the coefficients in the long and short run. The study also used a common correlated effect—mean group (CCEMG) estimator for robustness check. The findings of the study reveal that green energy and FDI positively contribute to green economic growth in the long and short run. The green technology also contributes positively to enhance green economic growth but only in long run. To accelerate green economic growth, G7 countries should incorporate policies promoting green energy and technology, while acquiring more foreign investments to ensure a sustainable development.

Keywords FDI, G7 economics, Green energy, Globalization

Introduction

A significant concern facing the global economy is the issue of environmental degradation, coupled with climate change. This issue not only poses a threat to individuals' well-being but also has negative implications for their financial stability and overall productivity. Economic activity directly correlates with rising energy consumption, leading to a surge in greenhouse gas emissions that significantly harm the environment [48, 58]. Hence, the global community has prioritized the reduction of CO_2 emissions and the enhancement of environmental quality as crucial measures for achieving sustainable development and mitigating the adverse impacts of climate change [49]. Many countries have united under the Paris Agreement, pledging to reduce their greenhouse gas emissions to combat global climate change. In order to guarantee the success of the mission and the achievement of the sustainable development goals, it is crucial for nations to demonstrate unwavering commitment toward the established targets. According to Khan et al. [33], climate change will lead to a significant decline in the global economy, with a loss of more than 18 percent

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of its gross domestic product. Chen et al. [17], climate change is wreaking havoc on both urban and natural systems, with an estimated $500 billion in lost worldwide economic output. However, we can significantly mitigate the potential impact by implementing proactive measures to achieve the goals of the Paris Agreement. In 1987, the Brundtland Report, also known as "Our Common Future," came into publication. It presented a proposal for the concept of "sustainable development" as a response to these concerns [27]. In the realm of economic development, sustainable development is defined as a development that meets the needs of the present generation while safeguarding the ability of future generations to meet their own needs. According to Auty and Brown [10], sustainable development is a global concept comprising three main aspects: social, economic, and environmental. In a recent study, Ahmed et al. [4] identified the need for a new paradigm in global economic growth due to recurring failures in international policy to attain sustainable growth.

Hence, there is a necessity to examine a novel growth model due to the recurrent shortcomings of global strategies to contain environmental degradation and attain sustainable growth. The United Nations has emphasized the importance of environmental sustainability for achieving long-term economic stability. There has been a recent shift toward a new model of growth known as "green economic growth." The notion of "green economic growth" is intricately connected to the sustainable development paradigm and signifies economic expansion that considers the prudent utilization of natural resources, mitigates and prevents pollution, and creates avenues for enhancing social welfare by establishing a carbon–neutral economy [12]. According to the study conducted by Khan et al. [34], green economic growth is an expansion of the economic growth model that promotes economic progress while also prioritizing environmental protection and social sustainability. By enhancing productivity and ensuring macroeconomic stability, a sustainable economic growth strategy can unlock new avenues for growth. Ali et al. [6] argued that it also protects the environment, promotes social progress, and mitigates the barriers to development caused by resource scarcity. The United Nations Production Gap Report 2021 warns that the current production plan is on the verge of exceeding the Paris Agreement's limit (United Nations Environment Program, 2021). Hence, it is crucial for all countries to implement measures to effectively reduce carbon emissions and support the attainment of sustainable development objectives. Although many countries have started adopting renewable and green energy as alternatives, this alone falls short of meeting the global energy demand.

Green technology innovation may offer a potential solution to the environmental problem. This is due to its role in promoting sustainable and balanced economic development, as well as enhancing environmental management [61]. Brunnermeier and Cohen [15] discuss the positive spill over that arises from technological innovation activities. These activities contribute to the development of new goods, processes, and methods that can help mitigate environmental harm. According to Alfaro and Chauvin [5], foreign direct investment (FDI) involves acquiring a lasting stake and controlling ownership in a host nation's commercial enterprise. This phenomenon arises when a company or individual from one nation engages in foreign direct investment (FDI) in another country. Foreign direct investment plays a crucial role in fostering and upholding green economic growth, facilitating the shift toward a low-carbon economy, and attaining sustainable development [40]. Foreign direct investment (FDI) has the potential to foster long-term economic growth through investments in technological innovation, research and development, and renewable energy resources. Implementing these measures can lead to a decrease in gas emissions and mitigate the economic burdens linked to expansion [9].

This research has significantly contributed in numerous ways. With respect to the expansion of green economic growth, the research will provide the policymakers of the G7 countries with a substantial contribution. Due to the rapidity of global change, the G7 nations have a significant impact on the course of world history. This is due to the G7's capability to execute policies, demonstrate technologies, utilize alternative energy sources, and undertake requisite actions to attain net-zero emissions in a manner that is both secure and economically viable. These nations contributed 26.6% of the total global GDP in 2023, which was a substantial proportion. In addition, the G7 significantly contributed to the 14.4% expansion of the global GDP from 2013 to 2023. The preceding research has predominantly concentrated on specific nations. Additionally, it is noteworthy to mention that although considerable research has been conducted on green economic growth, there has been comparatively little emphasis on the contributions of green energy, green technology, and investment. As foreign investment, green energy, and technology gain prominence as viable strategies to mitigate carbon emissions, it is anticipated that green growth activities will increase proportionally. This research endeavors to assess the consequences of this trend. Additionally, the question of how to attain green economic growth remains unresolved, as prior research has failed to effectively ascertain the precise determinants that foster such expansion. This research makes a substantial contribution to the ongoing discourse surrounding green economic growth. The empirical contributions of green technology, energy, foreign direct investment, and globalization to the expansion of the green economy are exhaustively described in this study. Furthermore, the research offers insights into the cointegration that exists among green technology, green energy, investment, and green economic development, with a particular focus on the G7 countries. Amid the G7's attempts to address environmental issues and promote sustainable development, the present period assumes considerable significance for the economies involved.

The G7 countries, including Canada, France, Germany, Italy, Japan, the UK, and the USA, collectively represented a significant portion of the global economy. In 2023, they accounted for 26.6% of the world GDP and contributed to 14.4% of the growth in global GDP from 2013 to 2023.The quantity of carbon emissions has experienced a significant increase in comparison with previous years. In 2022, global CO_2 emissions from energy sources hit a record high of over 36.8 Gt, showing a growth of 0.9% or 321 Mt (IEA 2023). In 2020, the G7 members and the European Union accounted for around 30% of global energy demand and 25% of energy-related CO_2 emissions. However, the increasing cost of imported energy has heightened the urgency surrounding energy consumption. During this process, the ongoing use of fossil fuels leads to increased emissions, resulting in climate change, global warming, reduced agricultural production, and a potential risk to human life. In order to achieve sustainable economic growth and energy consumption, it is crucial to adopt innovative approaches to thinking. Our research will not only examine the economic expansion in these countries, but also explore strategies for sustaining long-term economic growth. Given the significance of economic growth and environmental sustainability in informing policy decisions, it is imperative to examine the impact of energy consumption on green growth. This study utilizes panel data analysis to examine the effects of green energy, green technology, foreign direct investment, and globalization on the green economic growth in G7 countries. The purpose of this study was to address the existing gaps in the literature, as previously identified. This study utilizes a second-generation panel unit root test to check the stationarity of the data, cross-sectional autoregressive distributed lag (CS-ARDL) model to estimate the coefficients. Additionally, we evaluate the robustness of the estimates using a dynamic common correlation effect mean group model.

The present study is organized into the following sections: first, we introduce the entire study, followed by a literature review on the relationship between green energy, technology, foreign direct investment (FDI), globalization, and green economic growth. Subsequently, the research design and methodology portion will be presented, followed by the analysis and discussions. The final section of the study discusses the conclusions drawn from the empirical data pertaining to the variables under investigation.

Literature review and hypothesis development

Green energy and green economic growth

Hypothesis 1: Green energy has significant and positive impact on green economic growth.

The impact of green energy on environmental quality and economic development has been extensively investigated by a number of researchers. The impact of green energy on economic development was studied by Olmo et al. (2020) and findings of the research demonstrated a positive relation between the adoption of green energy consumption and the economic expansion in many European countries. Other studies carried out by Shahbaz et al. [51], Saidi and Omri [50] have also demonstrated the positive association between the renewable energy and economic growth. Renewable energy is essential for advancing the green economic development of a nation [22, 52]. In other words, a rise in renewable energy consumption is associated with a corresponding average acceleration in economic growth. Similar findings were reported by Mohsin et al. [38] for West African States, and the results suggested that a 1% increase in energy (renewable) contributes to an increase in green economic growth by approximately 3%. According to Bhattacharya et al. [14], the correlation between the utilization of renewable energy sources and economic growth is dependent on the level of economic development. A number of researchers have investigated the connection between green energy and economic growth. Nevertheless, the subject of green economic growth in relation to green energy remains a matter of contention.

Additionally, Sohag et al. [55] conducted an analysis on the relationship between green energy and green economic development in Turkey, and the results demonstrated that green energy has a positive impact on green economic expansion. Fang [24] examined the environmental and economic benefits and repercussions of the extensive implementation of green energy sources in China, and the findings revealed that there is a substantial positive impact of renewable energy on green economic growth. The study concluded that environmental protection and green energy use tend to stimulate economic expansion. On the basis of the aforementioned researches, it is hypothesized that green energy contributes substantially to green economic expansion. Limited research has been conducted on the relationship between green energy and green economic growth in the developed countries. The present study endeavors to investigate the impact of green initiatives on green economic growth in G7 countries.

Green technology and green economic growth

Hypothesis 2: There is a significant relationship between Green technology and green economic growth.

The connection between technological progress, environmental quality, and economic growth has been the subject of extensive study. In order to improve environmental quality, technical innovation is essential, according to many academic studies. This is because technological innovation typically leads to a decrease in carbon emissions by making factor production more efficient [54]. Fan et al. [23] asserted that technological progress serves as the most effective means to ensure the efficient, clean, and eco-friendly use of resources. This will improve the environment, people's standard of living, and social sustainability. Omri [41] examined the impact of technological innovation on sustainable economic development, and the results suggest that technological innovation positively affects economic development. Murad et al. [39] looked into the robust relationship between economic development, environmental quality, and technological innovation. The results of the study concluded that economic growth and technological advancement are positively and significantly correlated. According to the study, the results showed a strong relationship between new technologies and environmentally friendly growth.

However, green economic growth is an aspect that has not been extensively studied in the literature, specifically looking at how green technology innovation affects green economic development. This has led to a dearth of studies investigating how environmentally friendly technology affects green economic expansion. However, there are few studies that look at the effects of renewable energy, nonrenewable energy, and technology connected to the environment and green economic growth. For example, Ulucak [56] carried out research in the BRICS countries, and the results showed that green economic growth is positively impacted by renewable energy and technology linked to the environment. Our research attempts to enhance the literature on the topic of green economic growth and the relationship between green technologies. Since the majority of studies are focused on how new technologies work. The current study adds to the existing literature by conducting an empirical investigation into the impact of green technology in promoting green economic growth within the framework of G7 economies.

Green economic growth, foreign direct investment and globalization

Hypothesis 3: There is a significant and a positive relationship between FDI and green economic growth.

Hypothesis 4: There is a significant and negative relationship between green economic growth and globalization.

The effect of foreign direct investment (FDI) on green economic growth has been the subject of various studies in the last decade. According to Hille et al. [28], FDI could be a solid basis for achieving sustainable development. Ghorbal et al. [25] carried out a study in South Korea and found that foreign direct investment (FDI), gross domestic product (GDP), and domestic patents all contribute to the value of foreign patents. Hence, an increase in FDI has a beneficial effect on foreign patents, which in turn leads to more economic growth and less pollution. FDI boosts technological innovation and domestic competitiveness among similar local enterprises, which in turn reduces pollution and improves carbon emission efficiency [53]. However, on the other side, the expertise and contemporary technology that FDI brings to both the upstream and downstream industries in an economy creates a multiplier impact that increases labor productivity, and with respect to green economic development, a disproportionate effect is observed in many countries [57]. Paramati et al. [43] looked at the relationship between foreign direct investment (FDI) and issues like pollution, green growth, carbon emissions, and environmental damage. FDI, trade, and green technology are the main factors that influence the reduction of CO_2 emissions and the advancement of green growth. Zafar et al. [63] carried out a study on OECD economies to look at how green economic growth is affected by FDI, R&D, and trade openness. There is a strong positive correlation between trade openness, foreign investment, and green growth. In conclusion, after considering the significant beneficial effects of FDI such as economic stability, innovations in environmentally friendly technology, efficiency in the use of resources, and the decrease of pollutant emissions.

According to Ahmad and Wu [63], globalization (GLO) helps boost total factor productivity, which in turn leads to economic growth. However, the counterargument, that GLO slows green economic growth by adding to carbon emissions and greenhouse gases, has only been somewhat investigated [13]. The literature does, however, make brief reference to the link between GLO and green economic expansion. Conversely, numerous studies have explored the connection between green economic growth and environmental degradation [37]. Therefore, using the GLO as a focal point, Kirikkaleli et al. [35] calculated ecological imprints. The empirical results show that environmental footprints are positively and significantly associated with GLO. Ahmad and Wu [3] also found a correlation between the rise of green economic growth, ecological innovations, and ecological sustainability. Therefore, considering the environmentally friendly economic growth, i.e., green economic growth, is negatively correlated with GLO, because GLO increases ecological degradation due to the increase in ecological footprints [7, 11].

Theoretical framework of the study

The link between environmentally friendly economic growth, green energy, and technology is left unexplored to a greater extent by the academics in contrast to traditional economic growth. Green energy, green technology, and green growth are expected to be correlated as reported by the previous researches. This section begins by explaining the theoretical foundations that justify this expectation. Hence, this section elaborates on the theories which concluded that green energy and green technology contribute to green economic growth.

An effective technique for boosting economic growth while resolving environmental concerns is green economic growth. The primary concern for the policymakers is to know the factors promoting green economic growth. Macroeconomic theory concludes that renewable energy and related aspects are critical for long-term economic growth. According to Alper and Oguz [8], the reduction of dependency on volatile energy resources like coal, crude oil, and fossil fuels is only possible when the adoption of renewable energy sources is boosted while also reducing the negative externalities linked to energy production. Moreover, it also helps countries' economies grow substantially [51]. The fundamental macroeconomic theory postulates that green energy has a significant impact on the expansion of green economic growth. Additionally, technological innovation is crucial for promoting long-term economic growth, according to the notion of comparative advantage. Moreover, technological progress has a major bearing on economic growth, as economic theory elaborates. Modern technology is able to accomplish a certain amount of output with far less energy consumption. They are also known as "green technologies." Green technologies are highly valued according to Porter's theory. According to the theory [16], green technology helps the environment and the economy at the same time. Chen et al. [17] stated that technological advancements in carbon reduction and energy conservation improve environmental quality and stimulate green economic growth.

The "Pollution Halo" concept states that foreign direct investment (FDI) has the potential to enhance energy and industrial systems by distributing green technology across the host country and optimizing the allocation of resources, leading to a decrease in carbon dioxide emissions and an improvement in environmental quality [42]. So, according to this theory, FDI might improve and strengthen countries' abilities for sustainable long-term economic growth. However, on the contrary, pollution port theory posits that the receiving nation's emissions actually rise as a result of FDI. According to Cole [20], this theory is based on the idea that polluting factories are migrating from highly industrialized nations to underdeveloped industrial nations as a result of foreign direct investment (FDI) flows. This, in turn, stimulates economic growth in nations and leads to a significant increase in carbon dioxide emissions from fossil fuel combustion.

Research methodology

This segment provides an overview of the research design employed in the empirical study. It encompasses particulars regarding the sources and methodologies utilized for data collection, as well as the definition and references of both the dependent and independent variables. Furthermore, it encompasses the research's model specification and the estimation technique utilized in order to accomplish the aims and objectives of the research.

Data collection and research variables

This study analyzes the impact of green energy, green technology, globalization, and foreign direct investment on green economic growth. The study utilizes panel data collected over 26 years (1995–2020) from G7 countries: Canada, France, Germany, Italy, Japan, the UK, and the USA. The variables employed in the study are of secondary nature and are sourced from authentic organizations such as the World Bank's World Development Indicators (2023), the OECD (2023), and the KOF institute (2023). The variables are converted into natural logarithms in order to get normally distributed data by minimizing the variance, and by doing so, the coefficients can be interpreted in a more meaningful way (Table 1).

Model Specification and Research Design

The study analyzes the impact of GT, GE, GLO, and FDI on GG. The model is grounded on the classical production function, a theoretical framework that

Table 1 Variable descriptions

Variable name	Symbol	Definition	Source	Reference
Green economic growth	GG	Adjusted net savings, including particulate emission damage (% of GNI	WDI	Sohag et al. [55], Khan et al. [32]
Green energy	GE	Renewable energy (% of primary energy supply)	WDI	Sharif et al. [52]
Green technology	GT	Environment-related technology (total patents)	OECD	Ahmed et al. [4], Khan et al. [32]
Foreign direct investment	FDI	Net inflow	WDI	Paramati et al. [43]
Globalization	GLO	Overall globalization index	KOF Swiss Economic Institute (2023)	Gygli et al. [26], Huang [30]

establishes economic progress by utilizing labor, capital, and technology as inputs to the output function.

$$Y = f(L, K, A) \tag{1}$$

where Y, L, K, and A represent economic growth, labor input, capital formation, and technology levels, respectively. In accordance with the endogenous growth theory, this study adjusted the model by replacing economic growth (Y) with green economic growth (GG), labor with globalization (GLO) and green energy (GE), capital with foreign direct investment (FDI), and technology with green technology (GT). Based on the theoretical approach, the functional form of the model is specified as:

$$\text{GG} = f(\text{GE, GT, FDI, GLO}) \tag{2}$$

All the variables mentioned are transformed into natural logarithms in order to get precise results. This work modified the methodologies of Ahmed et al. [4] and Khan et al. [32] and developed the subsequent models for the present investigation. Following the functional form of the model, Eq. 2 can be written in the econometric form as follows:

$$GG_{it} = \beta_0 + \beta_1 GE_{it} + \beta_2 GT_{it} + \beta_3 FDI_{it} + \beta_4 GLO_{it} + \varepsilon_{it} \tag{3}$$

where t is the time period, i indicates the number of cross sections (countries), GG (dependent variable) represents green economic growth, whereas GE, GT, FDI, and GLO (explanatory variables). β_0 is the intercept, and β_s are the variable coefficients. The error term is indicated by ε.

In order to understand the relationship between the variables of the study. The study employs various preliminary tests, such as descriptive statistics, correlation, and multicollinearity. Following the preliminary test, the econometric techniques of cross-sectional dependency, unit roots, and cointegration are employed. Based on these test results, the appropriate estimation procedures are carried out.

Econometric techniques

Cross-sectional dependency

Previous studies have stated that panel data usually endures the problem of cross-sectional dependence. The reason being that the cross sections undergo mutual shocks [45]. Hence, ignoring the problem of cross-sectional dependency might lead to biased and misleading results [29]. Therefore, in order to check the cross-sectional dependency, the study employs the Pesaran CD test. The CD test is based on pairwise correlation coefficients and is suitable where the number of cross sections is small and the time period is large. The null hypothesis of the CD test proposes that the panel does not endure cross-sectional dependency, while the alternative hypothesis of the test suggests the occurrence of cross-sectional dependence. Following is the equation (Eq. 4) used to test the cross-sectional dependence [46].

$$\text{CD} = \sqrt{2T/N(N-1} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \widehat{\delta_{i,j}} \tag{4}$$

where N denotes the number of cross sections (countries), T specifies the time period (1995–2020), and δ is the coefficient of correlation which is estimated. Following the cross-sectional dependency test, the study carries a test for slope homogeneity in order to check whether the study variables satisfy the homogeneity condition or the panel is heterogeneous. The study employs the homogeneity test developed by Pesaran and Yamagata [47].

Panel unit root test

We perform the unit root test to verify the stationarity of the data at either a level or a difference.

To avoid spurious regression, it is important that the data be stationary. As we discussed earlier, the panel data usually encounters the problem of cross-sectional dependence. Therefore, the study employs second-generation unit root tests which account for cross-sectional dependence. The presence of cross-sectional dependence leads the study to employ the CIPS and CADF tests rather than the first-generation unit root test, which have been widely used in the majority of studies. However, the inability of first-generation unit roots [31, 36] to deal with the issue of cross-sectional dependency does not make it the appropriate test for our study. Pesaran [45] proposed a second-generation test CIPS, which is established on cross-sectional augmented Dickey–Fuller (CADF) regression. The CIPS test statistics are based on the individual mean of the CADF. CADF computes the cross-sectional lagged average of individuals in order to monitor the effect of common factors.

Panel cointegration

In order to avoid imposing a common-factor limitation, Westerlund [59] created four novel panel cointegration tests that rely on structural rather than residual dynamics. In a conditional panel error-correction model, the goal is to determine if the error-correction term is equal to zero in order to test the null hypothesis of no cointegration. All of the novel tests follow normally distributed distributions and are sufficiently generic to account for cross-sectional dependence, unit-specific trend and slope parameters, and unit-specific short-run dynamics. In order to account for cross-sectional dependence, the study will incorporate the Westerlund cointegration test to confirm the association between the variables. Out of four tests, two panel statistics (Pa and Pt) are employed to examine the alternative hypothesis that the panel as a whole is cointegrated. The remaining two cross-sectional statistics (Ga and Gt) examine the alternative hypothesis that at least one unit is cointegrated.

Cross-sectional autoregressive distributed lag (CS-ARDL)

Once the existence of a long-term relationship has been established using Westerlund's [59] panel cointegration test, this study will utilize a newly created method known as the cross-sectionally augmented autoregressive distributed lags model (CS-ARDL) developed by Chudik and Pesaran [19]. This study employs the CS-ARDL assessment to undertake both long-term and short-term estimations. This test is much more efficient compared to the mean group (MG), pooled mean group (PMG), common correlated effect mean group (CCEMG), and augmented mean group (AMG). Since the reason for obtaining inaccurate estimation results is directly linked to the neglect of unobserved common components. The CS-ARDL model effectively addresses previously unnoticed problems of endogeneity, non-stationarity, mixed-order integration, slope of homogeneity, and cross-sectional dependence. The CS-ARDL model incorporates the mean of cross section of both dependent and independent variables to overcome the issue of cross-sectional dependency [19]. The CS-ARDL equation for the model can be expressed by the following equation (Eq. 5).

$$\text{LnGG} = \alpha_{it} + \sum_{j=1}^{p} \beta_{it} LnGG_{i,t-j} + \sum_{j=0}^{p} \gamma_{it} X_{i,t-j} + \sum_{j=0}^{nl} \delta_{it} \overline{M}_{i,t-j} + \varepsilon_{it} \tag{5}$$

where $\overline{M}_{i,t} = (\Delta\, \overline{LnGG_{it}}, \overline{X_{it}})$, the mean of dependent and independent variables.

$$X_{it} = LnGE_{i,t}, LnGT_{i,t}, LnFDI_{i,t}, LnGLO_{i,t}$$

While *nl* refers to the number of lagged cross-sectional averages for each variable.

Methodological framework

The graphical presentation of the methodology flowchart of the study is presented in Fig. 1.

Findings and discussion

The test results shown in Table 2 show the descriptive statistics of the variables involved in the study. The results specify the mean, median, skewness, dispersion, and distribution of the data curve, along with the standard deviation. The data of green technology (GIT) exhibits the highest volatility with a standard deviation of 1.464, and among the study variables, globalization (GLO) is the least volatile with a standard deviation of 0.131. The data for green growth, green energy, and globalization is negatively skewed, while green technology and foreign direct investment data are positively skewed. All the variables except GIT have a more profound curve with a high peak, and GIT data has a flatter curve.

Table 2 reveals that there is a positive and significant correlation between GE and GG with the coefficient of 0.201 significant at 1%. The correlation between GLO and GG is also positive and significant, with a 0.12 coefficient and statistical significance at 5%. GLO also has a positive correlation with FDI. However, there is a negative correlation between GLO and GIT. The FDI and GIT are also negatively correlated at 1% significance. After the correlation matrix, the study exhibits multicollinearity test results in Table 3 through the VIF test. The results show that no multicollinearity exists between the variables, as the VIF value of each variable is below 5, with the overall mean VIF being 1.34. The VIF value above 5 would have concluded with the presence of multicollinearity.

Table 4 results confirm the presence of cross-sectional dependency. The Pesaran [44] CD test results reject the null hypothesis of no cross-sectional dependency. All the variables have significant coefficients with a p value 0.000. Hence, accepting the alternate hypothesis. Following the CD test, the study tests the homogeneity condition of the

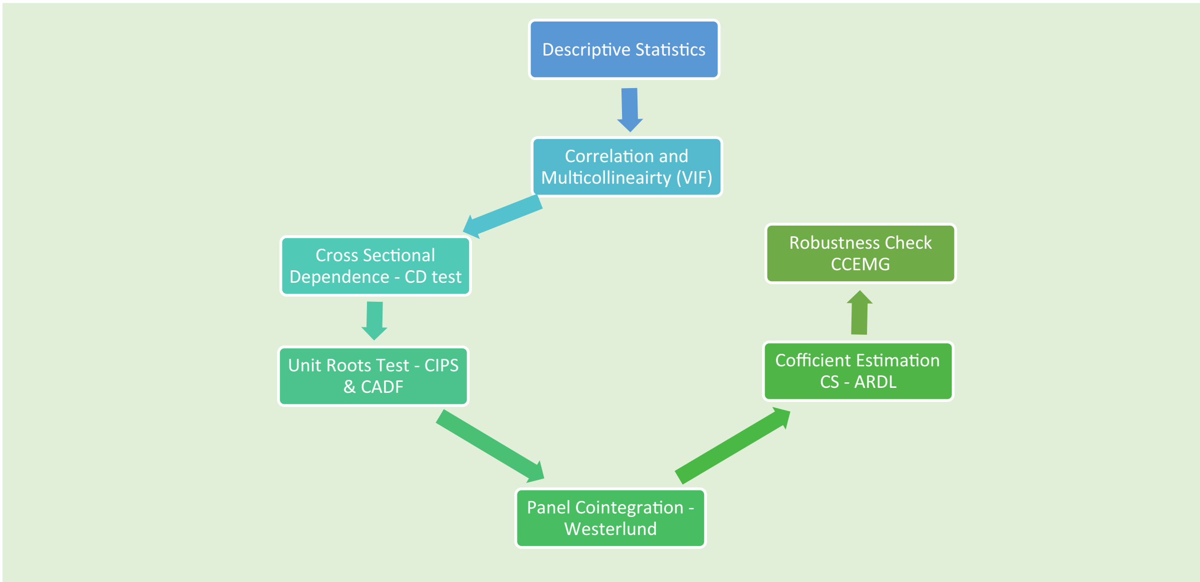

Fig. 1 Methodological Flowchart

Table 2 Summary of descriptive statistics

Variables	GG	GE	GIT	FDI	GLO
Mean	1.883	2.024	8.458	1.355	4.237
Median	2.046	2.163	8.438	1.337	4.243
Std. Dev	0.631	0.806	1.464	0.429	0.131
Skewness	−2.032	−0.754	0.041	0.441	−1.186
Kurtosis	9.977	3.269	1.820	4.067	4.475
	Correlation				
GG	1.000				
GE	0.201* (0.006)	1.000			
GIT	−0.075 (0.312)	−0.017 (0.811)	1.000		
FDI	0.039 (0.594)	0.101 (0.174)	−0.503* (0.000)	1.000	
GLO	0.12*** (0.089)	−0.061 (0.405)	−0.201* (0.006)	0.471* (0.000)	1.000

*, **, and *** indicate statistical significance at 1, 5, and 10%, respectively. Values in the () are the *p* values

variable data. The Pesaran and Yamagata [47] test reveals that the null hypothesis of the cointegration coefficients are homogenous is rejected. The test confirms the presence of heterogeneity. Therefore, based on the above two tests, the study would proceed with a second-generation unit root test and heterogeneous panel estimations.

Due to the presence of cross-sectional dependency, the study employed second-generation unit root tests as they account for such a problem. To check the stationarity of the underlying variables, the CIPS and CADF tests are

Table 3 VIF test for multicollinearity effects

Variable	VIF	Collinearity statistic
GE	1.69	0.590
GIT	1.34	0.743
FDI	1.31	0.763
GLO	1.03	0.972
Mean VIF	1.34	

employed. The findings in Table 5 suggest that the variables have mixed stationarity. Some are stationary at level and some are not. However, all the variables are stationary at the first difference, I(1).

Table 4 The cross-sectional dependency and homogeneity tests

	Statistics	*P* value
Pesaran's CD test		
GG	7.86*	0.000
GE	17.12*	0.000
GIT	17.64*	0.000
FDI	4.93*	0.000
GLO	17.76*	0.000
Pesaran–Yamagata homogeneity test		
$\tilde{\Delta}$	6.004*	0.000
$\tilde{\Delta}$- adjusted	6.846*	0.000

*, **, and *** indicate statistical significance at 1, 5, and 10%, respectively

Table 5 The second-generation panel unit root tests

	At level Constant	At first difference Constant
CIPS test		
GG	−2.122	−3.871*
GE	−1.640	−5.022*
GIT	−2.001	−3.914*
FDI	−3.024*	−5.652*
GLO	−1.879	−4.730*
CADF test		
GG	−2.139	−2.721*
GE	−1.350	−3.513*
GIT	−2.099	−3.276*
FDI	−2.575**	−4.433*
GLO	−2.263***	−3.132*

*, **, and *** indicate statistical significance at 1, 5, and 10%, respectively

Table 6 Westerlund long-run cointegration test results

Statistic	Statistic value	*P* value
G_t	−2.624**	0.049
G_a	−2.208	0.998
P_t	−7.222**	0.010
P_a	−2.275	0.918

*, **, and *** indicate statistical significance at 1, 5, and 10%, respectively

The results of the cointegration test in Table 6 suggest that there exists the cointegration between the variables of the study. The Westerlund cointegration test results reveal that out of four statistical tests two are significant (one from the panel, P_t, and one from cross-sectional statistics, G_t). The null hypothesis of the test proposes that no cointegration exists between the variables of the study. The findings suggest that the null hypothesis of the Westerlund test is rejected at the level of the 5% probability value of P_t and G_t. The study accepts the alternative hypothesis, signifying the presence of a long-term relationship between GG, GE, GIT, FDI, and GLO.

In order to estimate the coefficients of the long and short run, the study utilized the advanced autoregressive distribution lag model, CS-ARDL. The main focus of the research is to understand the relationship between green energy and green economic growth. The study also sheds light on the role of green technology, investment, and globalization and investigates its impact on green economic growth. The relationship between the factors is studied for the G7 countries as they account for major economic powers. To achieve the overall sustainability, the G7 powers can be the driving forces. These economies have enormous and sizeable impacts on the overall economic corridors.

Table 7 CS-ARDL estimation results

Variables	Coefficients	*P* value
Long-run estimates		
GE	1.195**	0.015
GT	0.411**	0.026
FDI	0.258**	0.010
GLO	−4.088	0.276
Short-run estimates		
ect_{t-1}	−0.836*	0.000
ΔGE	0.913**	0.013
ΔGT	0.261	0.428
ΔFDI	0.219**	0.029
ΔGLO	−2.037	0.499

The empirical findings of CS-ARDL in Table 7 suggest that the GE has a positive impact on the GG in the long run as well as in the short run. In the long run, GG will increase by 1.195%, following a 1% increase in GE. In the short run, the increase in GE by 1% increased the GG by 0.913%. The results reveal a positive impact of GE on the GG at the level of 5% statistical significance in both the long and short run. The results indicate that enhancing green energy will push the G7 economic growth toward more sustainable growth which is beneficial for social and environmental sustainability. The attempt to rely more on renewable energy and less on nonrenewable energy can stimulate greener economic growth. The study result is in line with Alper and Oguz [8], Ahmad et al. [3], and Dong et al. [21]. The macroeconomic theory concludes that renewable energy and related aspects are critical for long-term economic growth, the results of the study confirm the theory. Hence, hypothesis of the study that green energy has a positive and significant impact on green economic growth is validated. The studies carried out by Shahbaz et al. [51] and Zafar et al. [63] indicate that the usage of renewable energy source can enhance the sustainable economic growth by reducing the impact on the environment.

The results in Table 7 reveal that GT has a positive impact on the GG in the long and short run. However, the coefficient is significant only in the long run. The economic benefits of green technology primarily stem from increased investment in the initial years. Over time, more growth gains come from cheaper, cleaner energy and more efficient production processes. The findings suggest that with an increase in GT by 1% in the long run, the green economic growth increases by 0.41%. The study is in line with recent studies carried out by Ahmed et al. [4] for South Asian countries and Khan et al. [32] for OECD countries, suggesting that green innovation technology has a favorable and substantial impact on green growth. As suggested by Sohag et al. [55] that green technology is an effective method for enhancing green economic growth. Greener technology significantly reduces the impact on the environment by utilizing resources efficiently and curtailing carbon emissions. Aghion et al. [2] also emphasized the importance of technological advancements in order to decrease the overreliance on nonrenewable energy and increase the usage of green energy for emission mitigation. In order to achieve green development, mitigating carbon emissions is of prime importance [1]. Green technologies are highly valued according to Porter's theory. According to the theory [16], green technology helps the environment and the economy at the same time. Chen et al. [17] stated that technological advancements in carbon reduction and energy conservation improve environmental quality and stimulate green economic growth. The results of the study confirm the theory and hence the hypothesis of the study that green technology has a significant relationship with green economic growth holds true for G7 countries.

The study findings indicate that an increase in FDI in G7 countries results in an increase in green economic growth. An increase of 1% in FDI leads to an increase of GG by 0.219% in the short run and by 0.258% in the long run. The findings are in line with Xiao et al. [60], who also found that the increase in FDI has a positive and significant influence on the green economic growth. The study carried out by Khan et al. [32] emphasized that the investments acquired assist in technological advancements, infrastructure progress, and research development in order to enhance growth while emitting less carbon in OECD nations. Sustainable growth is achieved when economic growth expands while limiting the negative effects on the environment. Similar findings were reported by She and Mabrouk [53] in BRICS countries, wherein FDI positively impacted green economic growth. According to Hille et al. [28] and Xiao et al. [60], there is a positive impact of FDI on green economic growth. FDI mainly contributes to increasing the level of green economic growth through capital effect, environmental effect, technology spill over, improved resource utilization, and reduced pollution emissions. The increase in foreign investments tends to advance the environmental standards of the host nation by reducing environmental damage through the implementation of green production and the utilization of green energy with the help of green technology. The "Pollution Halo" theory states that foreign direct investment (FDI) has the potential to enhance energy and industrial systems by distributing green technology across the host country and optimizing the allocation of resources, leading to a decrease in carbon dioxide emissions and an improvement in environmental quality. On the other hand, pollution port theory posits that the receiving nation's emissions actually rise as a result of FDI. The results of the study confirm the pollution halo theory and contradict the population port theory. Hence, the hypothesis of the study that FDI has a significant relationship with green economic growth is validated for G7 countries. The findings of the study in Table 8 reveal that globalization has a negative impact in the short and long run on green economic growth. However, the coefficients are statistically insignificant. The study done by Ali et al. [7] found that green economic growth is negatively correlated with globalization. However, globalization severely affects the environmental sustainability, which is an important component of green economic growth. Yang [62] also concluded in their study that although globalization contributes to the financial growth globally, it also proves to be detrimental to the ecology and environment. Hence, the hypothesis postulating that globalization has significant and negative relationship with green economic growth is partially validated. Although the coefficient suggests a negative relationship between globalization and economic growth, at the same time the result is insignificant.

In order to verify the strength of the model and the econometric approaches used in the study, we used a dynamic common correlated effect mean growth (DCCE) estimator to conduct a robustness check. The DCCE is an extension of the CCEMG developed by Pesaran and Chudik [19]. This model allows for slope heterogeneity and controls for endogenous regressors. It is also robust against cross-sectional dependence induced by unobserved common factors and shocks that appear at the same time as the result of economic integration between the countries. Table 8 provides the results of DCCE, and the findings are consistent with those of CS-ARDL. The results confirm the positive and significant relationship between GE, GT, FDI, and the GG.

Table 8 Dynamic common correlated effect—mean group (DCCE for robustness check)

Variable	Coefficient	*P* value
GE	0.753*	0.002
GT	0.246***	0.061
FDI	0.065***	0.091
GLO	−0.287	0.847

Conclusion

The aim of this paper is to assess the impact of green energy and technology on green economic growth for G7 countries while incorporating FDI and globalization as explanatory variables. A greener economy means less burden on the environment, which leads to a healthy and improved quality of life. The research used various econometric techniques in order to investigate the relationship between the variables. The study involved CIPS and CADF for the unit root test, the CD test for cross-sectional dependency, the Westerlund test for cointegration, CS-ARDL for estimation of the coefficients, and DCCE for the robustness check.

The study concluded with three main findings; first, the usage of green energy leads to increased green economic growth. Our study reveals a positive impact of green energy on green economic growth, thus validating the hypothesis that green energy has significant and positive impact on green economic growth. As the literature suggests, economic growth can be detrimental to the environment due to overreliance on carbon-emitting energy sources. And on the contrary, green energy lessens the burden on the environment which proves to progress green economic growth. Secondly, the findings revealed that green technology can also contribute to green economic growth, thus validating the hypothesis that green technology has significant and positive impact on green economic growth. Green technology is a constructive force for green energy. Innovation in new technologies directly influences the state of energy. The more technological advancements in energy can lead to greener sources of energy. The increased consumption of green energy due to green technology heavily contributes to green economic growth. Third, the increased FDI positively impacts green economic growth. The study validates the pollution halo hypothesis, which states that FDI promotes green growth. FDI has the ability to improve environmental quality by reducing carbon dioxide emissions through optimum resource allocation and the use of efficient energy by introducing green technology.

This study's findings provide valuable information for policymakers in G7 nations to build frameworks that promote green energy and green technology. The G7 nations are at the forefront of understanding the significance of constructing sustainable economies due to their strong hold on the global economy. Improved energy independence, long-term economic growth, and job creation can result from new policies that the government enacts to promote green technology and remove barriers to the consumption of green energy. The governments of G7 countries should implement green energy systems tailored to local climates, given the growing concerns about climate change and the need to improve energy security. Additionally, governments should consider implementing incentive programs, tax benefits, investment subsidies, incentive programs for technological innovations, and the trading of green energy certificates as ways to encourage the expansion of green energy consumption in order to develop greener economy. By replacing nonrenewable energy with renewable energy, we can lessen the financial strain of importing energy, stabilize energy prices on global markets, and slow the rate of environmental damage caused by carbon emissions. To further enhance environmental quality, lawmakers should invest more in green technology to promote green energy and increase green growth. G7 countries, due to their reputation, can acquire a decent amount of foreign investment and then distribute it to create an ecosystem that is environmentally friendly while at the same time enhancing economic growth. The investment can be utilized in developing infrastructure, technology to displace nonrenewable energy, and replace it with greener energy. Although the cost of replacing nonrenewable and excessive carbon-emitting energy sources is very high and in order to lessen the burden on the local economy, FDI is the most crucial component that can propel this change.

Because this study mostly includes industrialized and developed nations, future studies should look at low-income countries to see how green energy use relates to green economic growth. Furthermore, the present study explored four variables and their contribution to green economic growth. However, future researchers can add in more factors and see their impact on green economic growth. This study contributes to the literature of FDI and its relationship with green growth. Future researchers can incorporate green FDI as an indicator of investment and study its relationship with green economic growth. Another recommendation for future research related to this topic is to include cross-nations, which would provide extensive findings due to their varied characteristics.

Abbreviations

WDI	World Development Indicators
OECD	Organisation for Economic Co-operation and Development
CS-ARDL	Cross-sectional autoregressive distributed lag
CCEMG	Common correlated effect mean group
AMG	Augmented mean group
FDI	Foreign direct investment
GDP	Gross domestic product
CIPS	Cross-sectional Im Pesaran Shim
CADF	Cross-sectional augmented Dickey–Fuller
GE	Green energy
GIT	Green technology
GG	Green economic growth
GLO	Globalization

Acknowledgements
We are grateful to Editor Marianne W. Lewis and the anonymous reviewers for valuable time and considerations.

Author contributions
MJGW contributed to the study conception, research methodology, and data analysis. NL and MJGW wrote the first draft of the manuscript. HE performed data collection and preparation. All authors read and approved the final manuscript.

Funding
No sources of funding were used to conduct this study or prepare this manuscript.

Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors whose names are listed in this paper certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

Received: 16 February 2024 Accepted: 4 April 2024
Published online: 24 April 2024

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