Gondwana Research 121 (2023) 472–485

Contents lists available at ScienceDirect

Gondwana Research

journal homepage: www.elsevier.com/locate/gr

Investigating the impact of financial development on carbon emissions: Does the use of renewable energy and green technology really contribute to achieving low-carbon economies?

Umme Habiba [1], Cao Xinbang *,[1], Shahid Ali [1]

School of Management Science and Engineering, Nanjing University of Information Science and Technology, PR China

ARTICLE INFO

Article history:
Received 19 September 2022
Revised 17 April 2023
Accepted 28 May 2023
Available online 1 June 2023
Handling Editor: A. Vasanthi

Keywords:
Renewable energy
Financial development
Green technology
Emerging countries

ABSTRACT

Global warming has become one of the most serious and hotly debated global issue in recent years, despite increasing international agreements requiring urgent action. Therefore, many countries are striving to achieve carbon neutrality. To achieve decarbonization, renewable energy and green technologies can play a significant role. Thus, it is worth noting the connection between renewable energy consumption, green technology, and carbon emissions. We explore the effects of financial development (FD), renewable energy consumption, and green technology on carbon emissions (CE) in seven emerging countries between 1990 and 2020. To assess the empirical data, a wide range of econometric techniques from second-generation were employed, including cross-sectional dependence test, heterogeneity test, Westerlund cointegration test, augmented mean group (AMG) heterogeneous panel estimator, and Panel Granger causality test. The empirical findings revealed that FD increases the level of CE, which results in environmental degradation. In contrast, renewable energy usage and green technology decline CE in the long-run. Furthermore, when combined with renewable energy, FD tends to be less detrimental to the environment. The findings also unveiled that FD improves environmental quality through the green technology channel. The findings of causality tests demonstrated that policies related to renewable energy and green technology will affect carbon emissions in one direction, but not in the other. Our outcomes have significant implications. Our recommendation is to promote green technology and renewable energy usage, especially in emerging economies. By doing so, we will be able to attain the sustainable development goals.

1. Introduction

Climate change and global warming have become prominent issues around the world. The burning of fossil fuels, such as coal, oil, and natural gas, releases large amounts of greenhouse gases (GHGs), particularly carbon emissions (CE), into the atmosphere and degrades the environment (Vural, 2020). Recently, the need to reduce CE has become increasingly critical. To address this issue, during the UN climate conference in Paris in December 2015, all nations committed to jointly reducing global GHGs and curbing climate change. Under the 2015 Paris Agreement, states agreed to keep global warming below 2 °C and become carbon neutral by 2050.

Towards carbon neutrality, renewable energy is a viable option, since recent studies have demonstrated that renewable energy consumption (RNEC) can mitigate CE (Gielen et al., 2019; Vural, 2020; Habiba et al., 2021). Also, emphasizes the importance of using renewable energy instead of fossil fuels and maximizing energy efficiency for achieving carbon neutrality by 2050. Therefore, we urgently need to implement a global energy transition in order to achieve sustainable development goal 7 (SDG 7), which consists of three key objectives: to make modern energy services affordable, reliable, and accessible; to make renewable energy a more prominent part of energy systems; and to speed up the pace of energy efficiency improvements worldwide (McCollum et al., 2017). The switch to low-carbon energy is fundamental, as fossil fuel-related CE account for two-thirds of all GHGs (IPCC, 2014). A crucial part of this energy transition depends on technological advancements, particularly those related to renewable energy.

Renewable energy deployment is dependent on financial development (FD), due to its capital-intensive characteristics.

* Corresponding author.
E-mail addresses: Habi512@yahoo.com (U. Habiba), Caoxinbang@163.com (C. Xinbang), shahidali24@hotmail.com (S. Ali).
[1] Address: 219 # Ninglu Road, Nanjing City, Jiangsu Province 210044, PR China

https://doi.org/10.1016/j.gr.2023.05.013
1342-937X/

An efficient financial system encourages more investment in renewable energy projects while reducing their costs, which in turn stimulates the quest for clean energy. However, numerous studies have suggested that FD has various environmental implications (Zafar et al., 2019; Acheampong et al., 2020). For instance, a sound and well-functioning financial system makes it possible for individuals and businesses to acquire affordable credit, enabling individuals to purchase energy-consuming equipment, and businesses to enhance their current operations by purchasing energy-consuming equipment which contributes to the growth of CE (Sadorsky, 2010; Acheampong, 2019; Habiba and Xinbang, 2022). On the other hand, FD could enhance environmental sustainability by reducing CE through technological development, research and development (R&D) (Tamazian et al., 2009). Furthermore, the capital markets could facilitate R&D in renewable energy by attracting overseas companies capable of transferring these technologies to local firms (Ahmad et al., 2021).

Along with renewable energy consumption and FD, green technology is integral to the accomplishment of sustainable development without causing environmental damage (Lin et al., 2018; Shan et al., 2021). Green technology refers to increasing energy efficiency and reducing adverse effects on the environment by using technologies to generate and use energy. An international energy agency report (2021) states that if the globe is to achieve carbon neutrality by 2050, further oil, natural gas, and coal extraction and development need to cease by 2021. To this end, green technologies are critical for the transition from conventional to renewable energy. They are also instrumental toward bridging the rhetorical and real world realities of net-zero CE. In recent studies, a number of researchers highlight the necessity to enhance innovation in this transition (Ganda, 2019; Chien et al., 2021; Zafar et al., 2021). Researchers contend that R&D of green technologies are not always carried out uniformly across countries. In this regard, the specific impact of green technology is likely to vary across countries based on specific circumstances (Du et al., 2019; Paramati et al., 2021).

In this regard, we make an attempt to explore the effect of FD on CE with the role of green technology and RNEC based on data from emerging seven countries (E-7 countries). For a number of reasons, the current study considers these emerging economies. Firstly, E-7 countries, including Indonesia, Brazil, India, China, Russia, Turkey and Mexico, are regarded as emerging markets that will experience rapid economic growth in the future. It is predicted that global economic growth will double by 2042, growing by 2.6% on average annually between 2016 and 2050. This expansion is expected to be fueled primarily by emerging markets, with E7 countries projected to rise by an average of nearly 3.5% annually over the next 34 years, unlike the advanced G7 nations, which will only grow by 1.6% annually. In the coming years, we will continue to see the global economy shift away from developed economies, particularly European economies, towards emerging economies in Asia and elsewhere. By 2050, the E7 could account for almost 50% of world GDP, while the G7 will account for only about 20% (PWC, 2017).

It is also predicted that E-7 countries will dominate the top economies of the world by 2050, and their economic strength is also predicted to double. (Hawksworth et al., 2017). Secondly, by 2020, these economies accounted for 47.1% of global population, 36.15 % of global GDP, 41.2% of global 61 growing at an accelerated rate, 54% of total global carbon emissions, these countries are extremely vulnerable to climate change and pollution (see Fig. 1). It is therefore essential to know what drives environmental degradation in these economies in order to switch to a greener economies and achieve sustainable development goals (SDGs). Thirdly, research on the impact of FD on CE with the combined role of green technology and RNEC is scant and displays dissent in E-7 blocks. Additionally, past studies have used traditional FD proxies, possibly yielding to biased outcomes. Svirydzenka (2016) claims that conventional FD measures such as stock market capitalization and domestic credit are not able to capture the full range of financial system dimensions. Unlike previous studies, the current study incorporates a new proxy for FD to assess its efficiency, accessibility, and depth of financial markets and institutions. Due to the fact that the traditional FD measures ignored these dimensions. Lastly, this study uses a set of analysis techniques based on second-generation panel methods, i.e., Pesaran (2007) panel unit root test, Westerlund (2007) panel cointegration, and augmented mean group (AMG) for long-run analysis. For this study, estimation techniques are important to avoid misleading results due to the existence of cross-sectional dependence and heterogeneity which may make conventional econometric techniques irrelevant to the conditions. Thus, to secure solid empirical coefficients and provide direction for future policy, robust econometric methods are used.

2. Literature review

The literature review consists of the following sections. (1) The connection between FD and CE (2) The connection between RNEC and CE (3) The connection between green technology and CE.

2.1. The connection between FD and CE

The literature on the connection between FD and CE is extensive, but the findings are contradictory. Researchers have noted that FD affects carbon emissions both directly and indirectly, including Farhani et al. (2014), Kayani et al. (2020), Ahmad et al. (2021), and Habiba et al. (2021). Based on existing research, two main schools of thought exist regarding the relationship between FD and the environment. Some believe that FD can contribute to the protection of the environment by using eco-friendly technologies (Tamazian et al., 2009; Pata, 2018; Acheampong et al., 2020). To support this argument, Abbasi and Riaz, (2016) revealed that FD improved environmental quality in Pakistan between 1988 and 2011 (period of financial liberalization). Likewise, Nasreen et al. (2017) found that the stability of the financial sector reduces CE in Bangladesh, Sri Lanka, India, Nepal, and Pakistan. Likewise, Xing et al. (2017) examined the association between CE and FD in China by using ARDL approach, and concluded that FD reduces CE. For Turkey, Gokmenoglu and Sadeghieh (2019) found that FD contributed to environmental protection through a reduction in CE.

The others point out that FD increases environmental degradation through the following mechanisms. Firstly, FD enables consumers to borrow money at a lower cost to purchase high-priced items that consume large amounts of energy and produce high CE. Secondly, once a country's stock market has developed, listed companies can access low-cost financing, which they can use for expansion and purchase highly energy-consuming machinery and equipment, thereby causing a rise in CE (Sadorsky, 2010; Acheampong, 2019; Habiba and Xinbang, 2022). In the case of India, Boutabba (2014) observed that FD increases CE. In the same way, Hao et al. (2016) investigated the effect of financial development on CE across 29 provinces of China applying the system-GMM. They discovered that financial depth increases CE. Likewise, Ehigiamusoe and Lean (2019) employed FMOLS and DOLS methodologies to explore the association between FD and CE in 122 countries. They concluded that FD significantly increased CE for the entire sample. Using FMOLS approach, Kayani et al. (2020) assessed the effect of FD on CE by using the panel data of top ten emitter countries for the period 1990 to 2016 and found that FD has a positive effect on CE in the long-term. Researchers believe that different indicators of FD adopted by different studies have

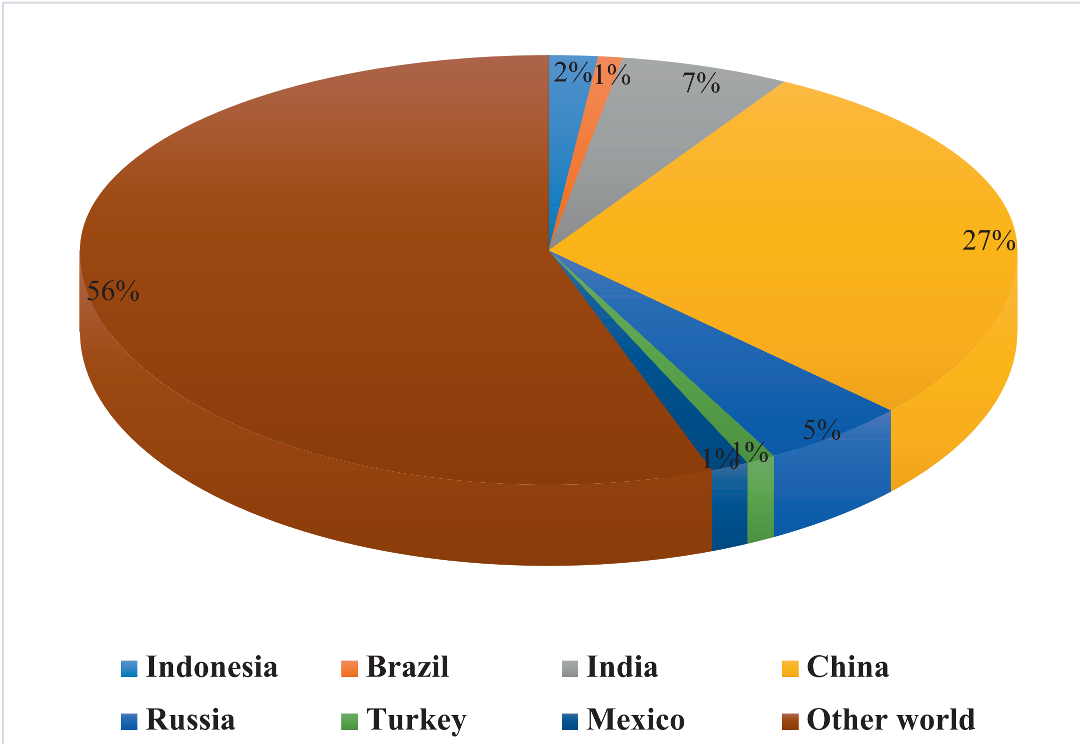

Fig. 1. Global carbon emissions from emerging countries.

distinguished effect on the environment through energy consumption (Levine and Zervos, 1998; Kakar 2016; Acheampong, 2019). Most previous studies have measured FD by using domestic credit to the private sector and deposit money banks relative to GDP (Al-Mulali et al., 2015a; Maji et al., 2017; Jamel and Maktouf, 2017; Saud et al., 2019; Bilgili et al., 2020). These measures of FD are simple and ignore the complicated nature of FD. Most recent studies indicate that the new financial development indicator developed by the IMF is more comprehensive (Acheampong, 2019). This index is not extensively used in current literature. In Table 1, the literature is summarized on the connection between FD and carbon emissions. In light of current literature, it is hypothesized that FD strongly influences carbon emissions in E-7 countries.

2.2. The connection between RNEC and CE

The use of renewable energy is essential for achieving a sustainable environment, and has emerged as a mainstream concern recently (Zhang et al., 2017; Waheed et al., 2018; Sinha and Shahbaz, 2018; Nathaniel and Iheonu, 2019). Many studies demonstrate that RNEC reduces CE level and reduces dependence on fossil fuels, in turn, improving the environment. For instance, Shafiei and Salim (2014) discovered a positive association between RNEC and environmental quality by applying the AMG approach for Economic Cooperation and Development (OECD) countries from 1980 to 2011. Bölük and Mert (2015) investigated the impact of RNEC on CE for Turkey. The study employed ARDL approach and concluded that RNEC is an effective way to reduce CE. Alternatively, (Bulut, 2017) explored the effect of both conventional and clean energy sources on CE in Turkey employing panel estimation techniques spanning 1970–2013. The study estimates showed that RNEC has no impact on the reduction of CE. Based on panel data for 30 countries from 1980 to 2014, Chen and Lei (2018) studied the effect of clean energy utilization on environmental quality using panel quantile regression. Researchers found that the higher usage of clean energy improves environmental quality. By employing panel estimation techniques, Inglesi-Lotz and Dogan (2018) reached the similar conclusion for the top-10 electricity-producing nations in sub-Saharan Africa. Likewise, Charfeddine and Kahia (2019) studied the correlation between RNEC and CE for 12 MENA countries. In this context, they applied the panel vector autoregressive model from 1980 to 2012 and showed that RNEC lowers CE. With respect to the top-10 carbon emitting countries, the outcomes are similar. RNEC has a negative and significant connection with CE as discovered by Kayani et al. (2020) using FMOLS and VECM between 1990 and 2016. Similarly, Sharif et al. (2020) explored the impact of RNEC and conventional energy on environmental degradation in Turkey over the period 1990–2017 using quantile ARDL. The findings of the long-run estimation revealed that green energy decreases the footprint of the environment, whereas conventional energy increases it. For Turkey, Shan et al. (2021) studied the linkage between renewable energy and CE using a bootstrapping ARDL-bound testing technique. The research reported that the prevalence of renewable energy is diminishing in CE. In light of existing research, it is hypothesized that RNEC negatively impacts CE in E-7 countries. Most recently, Khan et al. (2022) utilized linear regression methods to examine the effects of energy transitions and RNEC on ecological footprint across OECD countries between 1990 and 2015. Their empirical findings revealed a negative association between RNEC and ecological footprint.

2.3. The connection between green technology and CE

A growing body of research supports the argument that technological advancements drive energy-efficient technologies that cause less environmental damage (Feng et al., 2009; Weber and Neuhoff, 2010; Samargandi, 2017; Cheng and Yao, 2021). However,

Table 1
Summary of the literature on the FD-CE nexus.

Author	Time-frame	Country	approach	FD measure	Main findings
Habiba et al. (2021)	From 1981 to 2017	G20 countries	CCEMG	SMD index	SMD reduces CE
Saud et al. (2020)	From 1990 to 2014	Forty nine countries	PMG	DCPS/GDP	FD increases EF
Kayani et al. (2020)	From 1990 to 2016	Top ten emitter countries	FMOLS	DCPS/GDP	FD increases CE
Yao and Tang (2021)	From 1971 to 2014	G20 countries	Two-way fixed effect	Stock market value/ private credit	FD reduces CE in the case of developed economies FD increases CE in the case of developing economies
Acheampong (2019)	From 2000 to 2015	Forty six Sub-Saharan Africa countries	System-GMM	Broad money, DCPS/ GDP, DCPS/banks	FD increases CE
Saud et al. (2019)	From 1990 to 2016	Fifty nine countries	dynamic seemingly unrelated co-integrating regression	DCPS/GDP	FD improves EQ
Gokmenoglu and Sadeghieh (2019)	From 1960 to 2011	Turkey	Error correction model	Ratio of bank credit to bank deposits	FD reduce CE in the short-run
Shahbaz et al. (2018)	From 1955 to 2016	France	Bootstrapping bound testing	DCPS/GDP	FD reduces CE
Maji et al., 2017	From 1980 to 2014	Malaysia	ARDL	DCPS/banks	FD decreases CE from construction and manufacturing sectors. FD increase CE from the transportation and oil and gas sector.
Abbasi and Riaz (2016)	From 1971 to 2011	Pakistan	Granger causality, VECM	DCPS/GDP, SMC/GD	FD increases CE
Nasreen et al. (2017)	From 1980 to 2012	Five South Asia countries	Granger causality, ARDL	Financial stability index	Financial stability improves EQ
Al-Mulali et al. (2015a)	From 1990 to 2013	Twenty three European countries	FMOLS	DCPS	FD increases CE
Shahbaz et al. (2015)	From 1970 to 2012	India	ARDL, co-integration test	DCPS/GDP	FD reduces EQ
Boutabba (2014)	From 1971 to 2008	India	VECM, ARDL	DCPS/GDP	FD increases CE
Jalil and Feridun (2011)	From 1953 to 2006	China	ARDL	LL/GDP	FD reduces CE

Abbreviations: SMD index = stock market development index, DCPS/GDP = domestic credit to the private sector to GDP, CCEMG = common correlation effect-mean group, PMG = pooled mean group, EF = ecological footprint, FMOLS = fully modified ordinary least squares, System-GMM = system-generalized method of moments, EQ = environmental quality, ARDL = autoregressive distributed lag, DCPS/banks = domestic credit to private sector by banks, VECM = vector autoregressions error correction mechanism, SMC/GD = stock market capitalization to GDP, LL/GDP = liquid liabilities to GDP.

the empirical findings for the effects of green technology on sustainability of the environment are mixed. For example, Lee and Min (2015) evaluated the role of eco-friendly R&D investment in green innovation and discovered a negative relationship between eco-friendly R&D and CE in Japanese manufacturing entities during 2001–2010. The nexus between green technology and CE across four Nordic countries was examined by Andoust (2016), applying a vector autoregression model and Granger non-causality test. This study found that green technology contributes significantly to improving environment quality. For OECD countries, Ganda (2019) examined the impact of technological innovation on CE using a system-GMM analysis. Study results indicated that technological innovation reduces the amount of CE. Petrović and Lobanov (2020) stated the same conclusion based on data from 16 OECD countries. The researchers argued that R&D expenditures can lead substantially to a reduction in the amount of CE without hindering economic development. In the same vein, Paramati et al. (2020) evaluated the effect of green technology on CE based on data on 25 OECD economies utilizing the AMG estimator. In this study, the findings suggested that green technologies play a major role in reducing CE in these economies. With regard to Turkey, Shan et al. (2021) explored the role of green technology in carbon neutrality. The investigation used the bootstrapping ARDL-bound testing technique and concluded that green technology is crucial to strengthening environmental sustainability. A study by Xu et al. (2022) also concluded that technological innovations contribute to the improvement of environmental quality in Turkey by applying a dynamic ARDL model based on a dataset spanning the years 1980 to 2019. Similarly, Usman et al. (2022) noted that technological innovations have a detrimental effect on greenhouse gas emissions in Mercosur countries by using the Driscoll and Kraay approach for the period 1990–2018.

Some authors contend that technological innovation does not lead to significant reductions in CE. Among others, Wang and Wang (2018) explored the relationship between environmental degradation and imported technology in China by using the ARDL model and the VECM approach from 1980 to 2011. The authors found that imported technology raises environmental degradation. For the next-11 economies, Sinha et al. (2020) analyzed the interaction between technological innovation and CE. Using Principle Component Analysis (PCA), the researchers developed an index for measuring technological innovation. Their panel analysis findings indicated that technological innovation adversely affects the environment. Similar effects were obtained by Bai et al. (2020) by using a panel data regression method for low-income economies from 2000 to 2015. Taking into account existing research, it is hypothesized that green technology reduces CE in E-7 countries.

In conclusion, despite the growing number of studies exploring the influence of FD on carbon emissions, there is still a need for further research in view of the following considerations. To begin with, the majority of previous studies have employed single or conventional indicators of financial development. These indicators are insufficient to capture a broad range of aspects and segments within the financial sector. Moreover, besides direct effects, FD can indirectly affect carbon emissions through renewable energy consumption and green technology. Lastly, there are very few empirical studies available that investigate the connection among FD, renewable energy consumption, green technology, and CE for the panel of emerging seven economies. These research gaps in the literature motivate us to conduct this investigation. In addition, we formulate the following framework in light of the literature review and the discussion above, as Fig. 2 illustrates the effects of financial development directly and indirectly on CE.

3. Research methods and data

3.1. Models and data

Our investigation aims to quantify the role that FD, RNEC, and green technology play towards achieving carbon neutrality in the E-7 countries. To begin, this paper extends the theoretical framework of Dietz and Rosa (1997), known as STIRPAT (Stochastic Impacts on Population, Affluence and Technology), which is described below:

$$I_{it} = \alpha P_{it}^{\delta_1} A_{it}^{\delta_2} T_{it}^{\delta_3} \varepsilon_{it} \tag{1}$$

Where, I indicates the environment impact as a function of population (P), affluence (A) and technology (T) for country i and time t. α stands for the constant term, while ε represents the random stochastic error. Eq. (1) can be expressed in logarithmic form in the following way:

$$lnI_{it} = \alpha_{it} + \delta_1 lnP_{it} + \delta_2 lnA_{it} + \delta_3 lnT_{it} + \varepsilon_{it} \tag{2}$$

Various investigations have drawn attention to the significance of factors such as FD, RNEC, and green technology. This study examines the combined effects of these important factors in achieving carbon neutrality. To this end, we expand the basic STIRPAT model by adding new variables. It is modeled as follows:

$$lnCE_{it} = \alpha_0 + \delta_1 lnFD_{it} + \delta_2 lnRNEC_{it} + \delta_3 lnGRT_{it} + \delta_4 C_{it} + \varepsilon_{it} \tag{3}$$

Where CE denotes carbon emissions. FD, RNEC, and GRT refer to financial development, renewable energy consumption, and green technology, respectively. C relates to other factors, including trade openness (Abid 2017; Paramati et al., 2021; Le et al., 2020), and economic growth (Wang et al., 2011; Acheampong et al., 2020).

To measure the indirect influence of FD on CE via the channel of renewable energy consumption, equation (3) is extended by including the interaction term (lnFD*lnRNEC).

$$lnCE_{it} = \alpha_0 + \delta_1 lnFD_{it} + \delta_2 lnRNEC_{it} + \delta_3 lnGRT_{it} + \delta_4 C_{it} + \delta_5 (\mathrm{lnFD} * \mathrm{lnRNEC})_{it} + \varepsilon_{it} \tag{4}$$

Furthermore, green technology may act as a moderator of the interaction between FD and CE. Therefore, for estimating the contribution of green technology to the relationship between FD and CE, the equation (3) is extended by adding the interaction term (lnFD*lnGRT).

$$lnCE_{it} = \alpha_0 + \delta_1 lnFD_{it} + \delta_2 lnRNEC_{it} + \delta_3 lnGRT_{it} + \delta_4 C_{it} + \delta_5 (\mathrm{lnFD} * \mathrm{lnGRT})_{it} + \varepsilon_{it} \tag{5}$$

To conduct this research, we select a sample of countries from the E-7 group following the reasons and rationale provided in the introduction. The E-7 consists of Brazil, Indonesia, India, China, Russia, Turkey and Mexico, and data covers the years 1990–2020. The graphs in Figs. 3 and 4 show the carbon emissions and renewable energy consumption per capita trends for the E-7 countries. Three different sources are used to collect the required data. One of them is the World Development Indicators (WDI), which provide a set of macroeconomic variables, including a dependent variable (carbon emissions), an independent variable (renewable energy consumption), and other control variables. Data on the other important variable of interest, green technology, is taken from the OECD statistics. Lastly, we use the IMF database to obtain data on the most important financial development index regressor. There is a detailed description of each variable in Table 2, whereas Table 3 presents summary statistics on each variable.

3.2. Empirical estimation framework

A six-step estimation process is presented in Fig. 5. Each step is thoroughly explained in the subsequent sections.

3.2.1. Cross-sectional dependence test

Cross-sectional dependence (CD) is common for panel data because of the connectivity among countries and regions. Approaches that ignore cross-sectional dependence may yield inaccurate results. For this reason, cross-sectional analysis of panel data is essential. To investigate CD in series, this research employs the CD test introduced by Pesaran (2004). Following is the test equation:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \widehat{P_{ij}} \right) \tag{6}$$

Where, a sample size is specified by N, T denotes the sample duration, and Pij is the residual coefficient.

3.2.2. Slope homogeneity test

Following the CD's analysis, issue of slope homogeneity between countries is analyzed, given that economics, socio-economic, and demographics structures may differ from nation to nation. In this regard, we employ the Pesaran and Yamagata (2008) slope homogeneity test. Following are the test equations:

$$\widetilde{\Delta_{SH}} = (N)^{\frac{1}{2}} (2K)^{-\frac{1}{2}} \left(\frac{1}{2} \widetilde{S} - k \right) \tag{7}$$

$$\widetilde{\Delta_{ASH}} = (N)^{\frac{1}{2}} \left(\frac{2k(T-k-1)}{T+1} \right)^{-\frac{1}{2}} \left(\frac{1}{2} \widetilde{S} - k \right) \tag{8}$$

Where the delta tilde is represented by $\widetilde{\Delta_{SH}}$ and the delta tilde adjusted by $\widetilde{\Delta_{ASH}}$.

3.2.3. Unit root test

A third step consists of identifying the integrated properties of the variables under consideration. This step is imperative before applying cointegration and regression techniques. First-generation unit root tests were previously used to determine the unit root of a dataset, but it ignores CD in the dataset (Bhattacharya et al., 2017). For this reason, we rely on unit root tests of the second-generation that incorporate CD concerns. In this study, I'm Pesaran-Shin (CIPS) and cross-sectional augmented Dickey-Fuller (CADF) unit root tests of Pesaran (2007) are conducted to evaluate unit roots in the dataset. Tests of this type produce consistent outcomes for subsequent statistical evaluation.

3.2.4. Cointegration test

Following our check for stationarity, we next investigate cointegration between variables. A panel cointegration test of Westerlund (2007) is employed, which depends on error correction mechanism (ECM). This test is designed to adjust for CD and slope heterogeneity underlying panel data and provide efficient results. The Westerlund test can be expressed in equation (7) as follows:

$$\gamma X_{i,t} = \theta \prime_i n_t + \delta_i \left(X_{i,t-1} - \pi \prime_i Y_{i,t-1} \right) + \sum\nolimits_{j=1}^{p} \delta_{i,j} \gamma X_{i,t-j} + \sum\nolimits_{j=0}^{p} \eta_{i,j} \gamma Y_{i,t-j} + \varepsilon_{it} \tag{9}$$

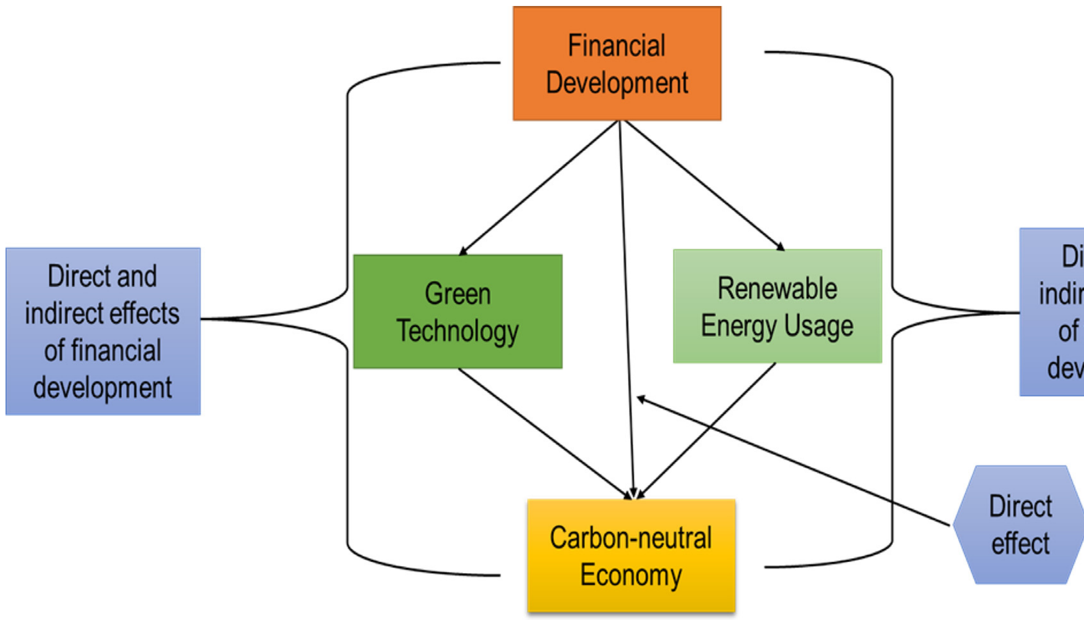

Fig. 2. Conceptual framework for achieving carbon neutrality through financial development.

Where n_t= (1-t)', δ_i are deterministic components, while $\theta\prime_i$ is $(\theta_{1i}, \theta_{2i})\prime$ which indicates the parameters vector. Tests can be demonstrated empirically as follows:

$$G_\tau = \frac{1}{N}\sum_{i=1}^{N}\frac{\alpha_i'}{SE(\alpha_i)} \tag{10}$$

$$G_\alpha = \frac{1}{N}\sum_{i=1}^{N}\frac{T\alpha_i}{\delta_i'(1)} \tag{11}$$

$$P_\tau = \frac{\alpha}{SE(\alpha)} \tag{12}$$

$$\alpha = \frac{P_a}{T} \tag{13}$$

3.2.5. Panel estimates of long-run elasticity

For estimating the long-run elasticity of the variables mentioned above, the panel estimators should take into account the CD concerns. We therefore apply two robust methods that allow us to address the latter concern. The augmented mean group (AMG) heterogeneous panel estimator proposed by Eberhardt and Bond (2009) is employed in this study. This method consists of two stages as follows:

The 1st stage of the AMG:

$$\theta Y_{it} = \tau_i + \varphi_i \theta X_{it} + \delta_i B_t + \sum_{t=2}^{T}\mu_i \theta C_t + \varepsilon_{it} \tag{14}$$

The 2nd stage of the AMG:

$$\widehat{\varphi}_{AMG} = N^{-1}\sum_{i=1}^{N}\widehat{\varphi_i} \tag{15}$$

Where Y_{it} and X_{it} stand for the dependent and independent variables. B_t represents the common unobserved dynamics, and ε_{it} is the error term. For checking robustness of outcomes, we employ the common correlated effects mean group (CCEMG) estimator developed by Pesaran (2006). Using this method, consistent coefficients are generated even when CD, endogeneity, and heterogeneity are included in the sample (Kapetanios et al., 2011). CCEMG estimator is modeled as follows:

$$Y_{it} = \tau_i + \varnothing_i X_{it} + \pi_i h_{it} + \varepsilon_{it} \tag{16}$$

Where X_{it} and Y_{it} measure the unknown common effects,$\varnothing_i$ he slope of the cross-section across all predictor variables, and h_{it} identifies the possible common effects with heterogeneous factors.

3.2.6. Granger causality

Even though long-term estimation approaches provide valuable insights, they are not able to establish causal links between variables, which is crucial for formulating policy recommendations. To do so, we use a second-generation Dumitrescu and Hurlin (2012) test to evaluate the causality between variables. The vector autoregressive (VAR) method is used on stationary results in order to adjust for non-observed heterogeneity in the data.

4. Empirical results and discussions

In the first place, we need to determine whether the data series are cross-sectionally dependent. For this, we employ two CD tests (Pesaran CD and Pesaran scaled LM). Table 4 summarizes the outcomes of these CD tests. The findings of Pesaran CD and LM tests reveal that the null hypothesis that there is no CD across countries is rejected. It follows that the environmental and economic changes that occur in one place can easily spread to others due to convergence and globalization. A summary of the slope homogeneity test results is provided in Table 5. It is apparent from the results that data exhibit heterogeneity across cross-sections. Therefore, it is important to employ advanced panel unit root tests to counteract the common-effect.

Table 6 presents the results of the second-generation stationarity tests (i.e. CADF and CIPS). The findings suggest that the underlying data series comprise the unit root problems. However, when the first difference is taken into consideration, the data series become stationary. Next, we need to evaluate whether datasets are interconnected in the long-run. It is recommended that panel cointegration tests not be used to investigate cointegration as they are not able to incorporate cross-country interdependence. Accord-

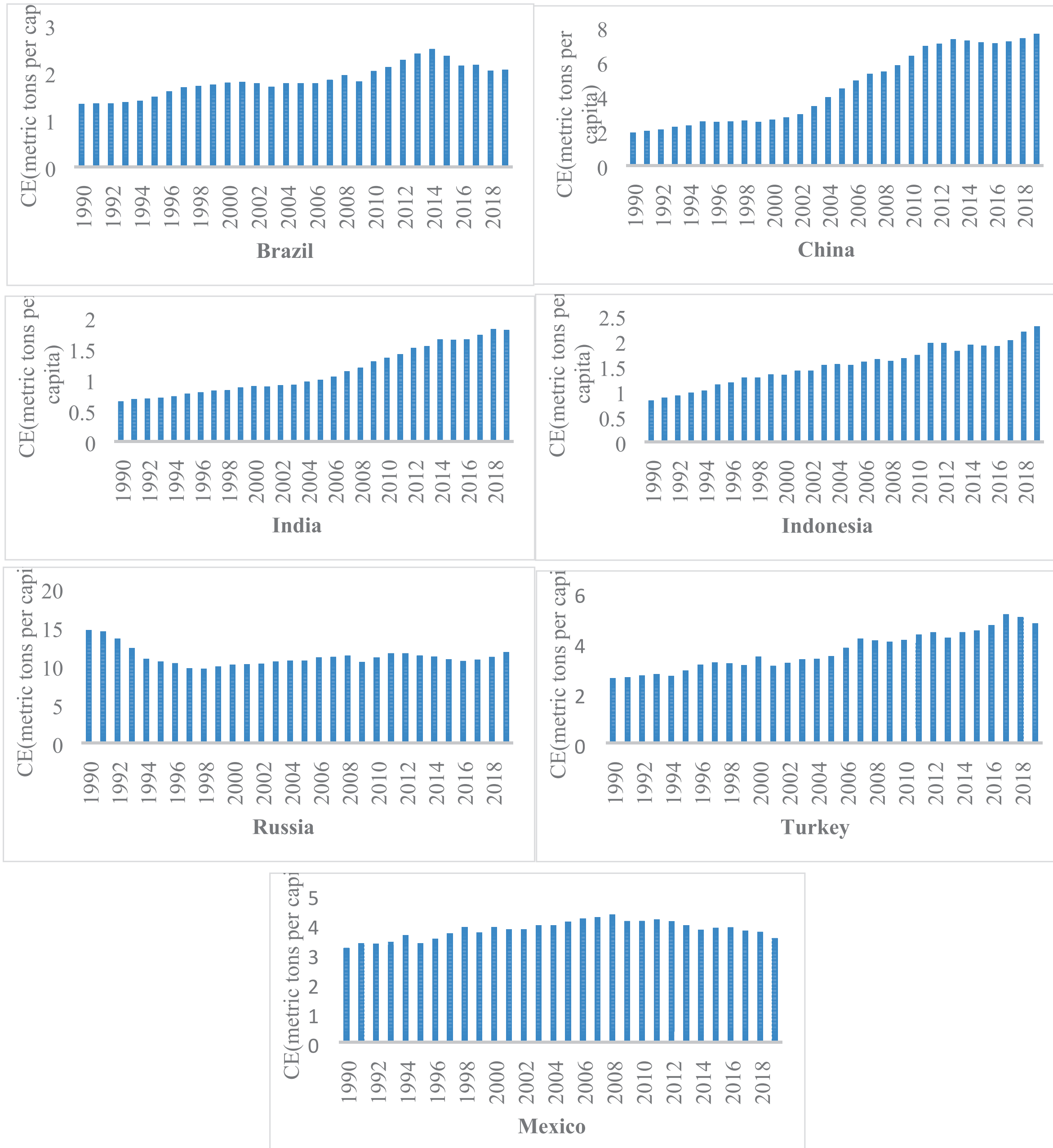

Fig. 3. This figure shows carbon emissions trends for E-7 countries.

ingly, we employ the Westerlund (2007) test, which is robust since it is capable of handling cross-country interdependence. Table 7 summarizes the result of the cointegration test. The results of this test substantiate the long-term correlation between the data series, and the error correction parameter (α) is calculated by −14. 702/31 = −0.47. In view of this value, approximately 47 percent of annual carbon emissions will return to their equilibrium level.

It is necessary to estimate the long-run coefficients of variables after confirming long-term cointegration. In Table 8, the long-run coefficients obtained from the AMG estimator are summarized. For key estimation, the AMG estimator is used, which was developed by Eberhardt and Bond (2009). It is a more effective method among the available approaches because it provides robust results even in the presence of CD and heterogeneity problems in the dataset. The empirical results show that the long-run coefficient of FD is positive and significant in all models, suggesting that financial markets and institutions lead to an increase in CE, thereby compromising environmental quality. This finding supports the argument that FD makes it easier for people to borrow money to buy energy-intensive household items such as cars, refrigerators, and other large appliances, which consume lots of energy and emit carbon emissions (Sadorsky, 2011). Our findings may also be attributed to the fact that financial markets and institutions in emerging economies fund projects that do not adhere to environmental sustainability and provide resources to polluting industries. Furthermore, the positive impact of FD on carbon emissions is in accordance with Boutabba (2014); Al-Mulali et al. (2015b); Maji et al. (2017); Acheampong (2019), and Kayani et al. (2020). However, these findings do not agree with those of Nasreen and Anwar (2015) and Shahbaz et al. (2018), who found that FD lowers carbon emissions. Such contradiction may be due to the fact that economies with sustainable financial systems can play a significant

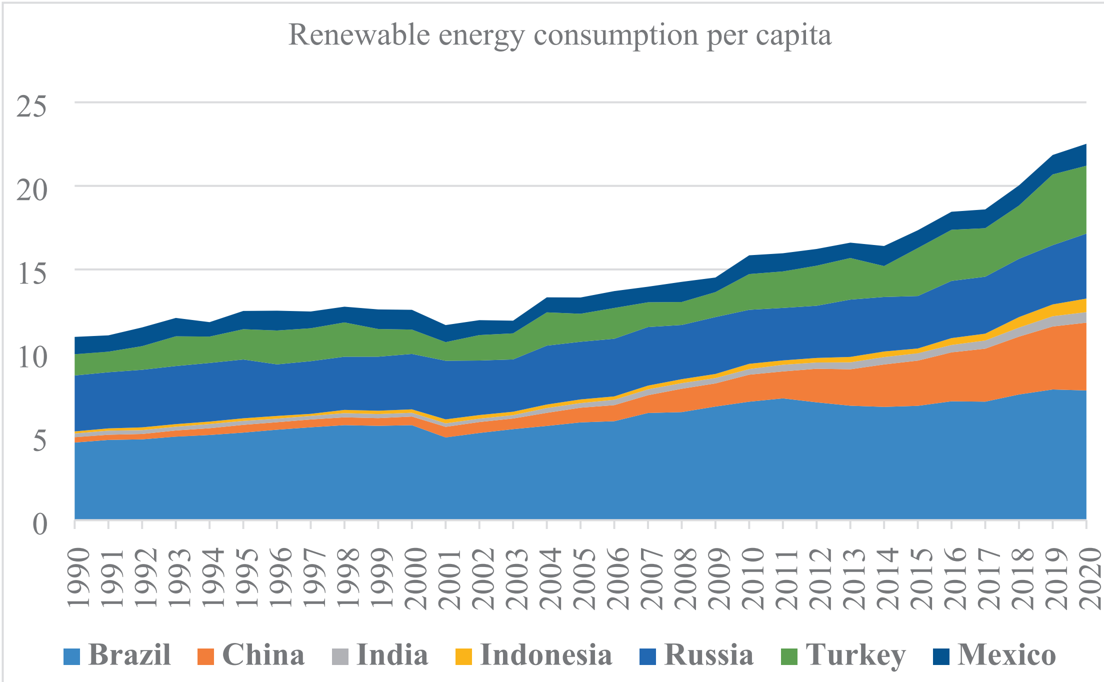

Fig. 4. An overview of renewable energy consumption per capita in the E-7 countries.

Table 2
Variables description.

Variables	Descriptions	Data sources
Carbon emissions (CE)	Metric tons per capita	WDI
Financial development index (FD)	This measure provides a more insightful view of financial development by accounting for efficiency, depth, and access of both financial institutions and market segments.	IMF
Renewable energy consumption (RNEC)	Per capita total renewable energy consumption	IEA
Green technology (GRT)	Several registered patents related to the environment	OECD statistics
Economic growth (EC)	Per capita GDP (constant 2010 US$)	WDI
Trade openness (TO)	Total imports plus exports in percent of GDP	WDI

Table 3
Statistical summary.

Variables	Mean	Std. Dev.	Maximum	Minimum
LnCE	1.055	0.781	2.683	−0.439
LnFD	0.402	0.106	0.637	0.191
LnRNEC	2.748	0.915	4.071	−2.648
LnGRT	5.127	2.481	10.878	−2.302
LnGDP	8.007	1.081	9.678	5.707
LnTO	3.721	0.391	4.705	2.781

role in the fight against environmental deterioration. Energy innovation relies heavily on the financial sector, which can complement its positive contributions and contribute to a more environmentally sustainable economy.

As expected, RNEC coefficients are negative and statistically significant across all models, implying a reduction in CE with a higher renewable energy consumption over time. Additionally, our results suggest that RNEC can play a pivotal role in moving from fossil fuels to zero-carbon energy and achieving sustainable development goals. Unlike fossil fuels, renewable sources of energy such as wind, hydroelectricity, and solar are carbon-free, helping the economy grow without endangering the environment. This finding is in agreement with those of Shafiei and Salim (2014), Chen and Lei (2018), and Shan et al. (2021), who noted that renewable energy reduces CE and improves environment quality. Furthermore, the interaction term is used to study the joint effect of FD and renewable energy consumption. It appears that the coefficient of interaction term is significant and negative, suggesting that FD reduces carbon emissions by producing renewable energy. The results of this research are in line with those of Qamruzzaman and Jianguo (2020), who indicated that renewable energy and FD are positively correlated. From the combined negative impact of FD and RNEC, it can be concluded that FD affects carbon emissions in a conditional manner. It follows that FD can reduce carbon emissions when it promotes renewable energy development.

The outcomes further reveal that green technology has a negative and statistically significant impact on CE. In statistical terms, if green technology increases by 1%, CE will be mitigated by 0.032% to 0.037%. These values support green technologies that have the potential to reduce CE in the long-term. This finding supports the view that technology innovation has been and will continue to be an integral part of the shift away from fossil fuels towards greener solutions. A key enabler of this energy transition will be technology innovation, particularly in the renewable energy sector (Gielen, 2019; Chien et al., 2021). Thus, green technology is essential for improving energy efficiency and lowering greenhouse gas emissions. A similar finding was found by Bai et al. (2020). A further analysis indicates that the estimated coefficient of joint effect between FD and green technology is negative and significant with

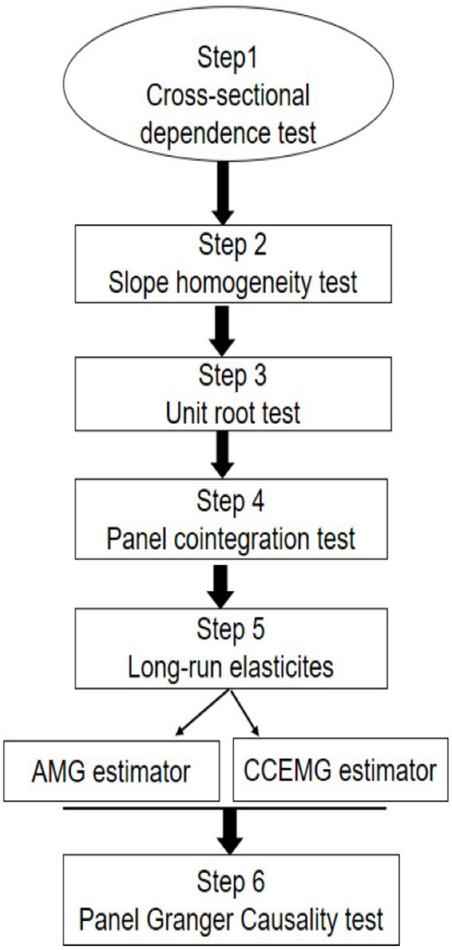

Fig. 5. Step-by-step estimation.

Table 4
Cross-sectional dependence test estimations.

Variables	Pesaran scaled LM		Pesaran CD	
	Statistics	P-values	Statistics	P-values
LnCE	33.735[a]	0.000	9.855[a]	0.000
LnFD	48.255[a]	0.000	18.042[a]	0.000
LnRNEC	81.022[a]	0.000	14.954[a]	0.000
LnGTI	63.399[a]	0.000	20.657[a]	0.000
LnGDP	70.080[a]	0.000	21.909[a]	0.000
LnTO	17.558[a]	0.000	5.231[a]	0.000

Note: a = significant at the 1 percent level.

CE, suggesting that FD reduces CE through green technologies. A study by Tamazian et al. (2009) stated that FD assists listed companies in promoting technology innovation, in order to create more energy-efficient systems and generate carbon–neutral economies.

In terms of control variables, the regression outcomes show that economic growth correlates positively with CE, which indicates that economic growth undermines environmental preservation. Considering these findings, it appears that emerging economies do not conduct economic activities in an environmentally friendly way. In the effort to achieve rapid economic growth, emerging economies compromise on environmental quality. Increasing economic activities leads to increased energy consumption that harms the environment (Sharma et al., 2020). These findings are similar to those reported by Wang et al. (2011) for China, Acheampong et al. (2020) for 83 financial heterogeneous economies, and Zhang et al. 2021 for Pakistan. Our regression results also reveal a positive and significant relationship between trade openness and CE. It is confirmed by estimates of trade openness that there is a scale effect. As this study considers emerging countries, this result makes sense in the notion that their primary objective is to enhance their economies by lowering regulations on environmental protection (Vural 2020). A positive impact of trade openness on carbon emissions accords with findings presented by Dou et al. (2021) and in

Table 5
Homogeneity test estimations.

Test	Statistics	Probability
$\tilde{\Delta}$	12.48[a]	0.000
$\tilde{\Delta}_{adjusted}$	13.62[a]	0.000

Note: a = significant at the 1 percent level.

Table 6
unit root test estimations.

Variables	CADF		CIPS	
	Level	First-difference	Level	First-difference
LnCE	−1.874	−4.308[a]	−2.133	−2.873[b]
LnFD	−2.171	−4.659[a]	2.592	3.962[a]
LnRNEC	−1.925	−4.561[a]	1.744	2.816[a]
LnGTI	−2.272	−4.788[a]	2.670	4.551[a]
LnGDP	−2.318	−4.869[a]	2.357	3.688[a]
LnTO	−2.114	−4.875[a]	2.870	4.463[a]

Note: a = significant at the 1%; b = significant at the 5%.

Table 7
Cointegration (Westerlund bootstrap) test estimations.

Statistics	Values	Z-values	P-values	Robust P-values
G_t	−2.894[b]	−1.717	0.032[b]	0.020
G_a	−8.247[a]	−2.468	0.004[a]	0.000
P_t	−9.226[a]	−4.059	0.000[a]	0.000
P_a	−14.702[a]	−2.490	0.006[a]	0.000

Note: a = significant at the 1%; b = significant at the 5%.

Table 8
AMG long-run estimates.

Dependent variable: CE			
Variables	Model (1)	Model (2)	Model (3)
LnFD	0.488[a]	0.452[a]	0.536[a]
	(0.175)	(0.163)	(0.183)
LnRNEC	−2.338[a]	−2.125[a]	−2.294[a]
	(0.294)	(0.283)	(0.297)
LnGTI	−0.037[b]	−0.041[b]	−0.032[c]
	(0.016)	(0.014)	(0.017)
LnGDP	0.571[a]	0.498[a]	0.563[a]
	(0.169)	(0.146)	(0.174)
LnTO	0.073[a]	0.075[a]	0.074[a]
	(0.019)	(0.018)	(0.017)
Ln(FD*RNEC)	–	−0.091[a]	–
		(0.033)	
Ln(FD* GTI)	–	–	−0.017[a]
			(0.004)
Constant	10.379[b]	12.770[a]	8.379[c]
	(3.460)	(4.042)	(3.460)
Wald test	67.79[a]	60.09[a]	54.71[a]
RMSE	0.072	0.019	0.061

Note: a = significant at the 1%; b = significant at the 5%; c = significant at the 10%.

Table 9
Robustness check: CCEMG long-run estimates.

Dependent variable: CE			
Variables	Model (1)	Model (2)	Model (3)
LnFD	0.714[a] (0.286)	0.739[a] (0.274)	0.682[a] (0.311)
LnRNEC	−1.894[a] (0.372)	−1.953[a] (0.365)	−1.927[a] (0.380)
LnGTI	−0.042[b] (0.017)	−0.053[a] (0.022)	−0.052[a] (0.024)
LnGDP	0.565[a] (0.248)	0.619[a] (0.233)	0.592[a] (0.257)
LnTO	0.064[a] (0.019)	0.066[a] (0.018)	0.048[c] (0.013)
Ln(FD*RNEC)	–	−0.123[a] (0.048)	–
Ln(FD* GTI)	–	–	−0.036b (0.015)
Constant	9.063[b] (3.432)	10.608[a] (3.921)	12.116[a] (4.247)
Wald test	44.59[a]	53.86[a]	58.31[a]
RMSE	0.061	0.052	0.064

Note: a = significant at the 1%; b = significant at the 5%; c = significant at the 10%.

contrast with the findings of Dogan and Turkekul (2016) for the USA and Inglesi-Lotz and Dogan (2018) for Sub-Saharan Africa's top 10 electricity producers. These results difference might be attributed to the notion that the countries with several regulations regarding their openness are more likely to be able to import green technologies that are appropriate to improving the environment.

In order to test the robustness and validity of AMG results, the CCEMG estimator is used. In Table 9, the results of the CCEMG approach are reported. The findings from CCEMG are similar to findings from AMG regarding coefficient direction. Thus, we can ensure that our results are robust regardless of the method used.

Country-wise heterogeneous results are shown in Table 10. Our discussion begins with FD, which is positive and significant in the case of China, India, Russia, and Mexico. In terms of statistics, a 1% increase in FD results in an increase in CE of 0.518%, 0.731%, 0.095%, and 0.215%, respectively. This implies that carbon emissions will increase with progress in FD. However, these findings are similar to those reported by (Saud et al., 2020; Habiba et al., 2021). These findings are likely due to the fact that efficient financial systems minimize the frictions in the market, which makes it easier for businesses to secure financing. Afterwards, the funding is used for expanding business operations, for example, by enhancing the capacity of human resources or adding more staff. Consequently, this will increase emissions. On the other hand, the results for Brazil, Indonesia, and Turkey express that FD in the respective economies does not adversely affect the environment. Moreover, it is estimated that the long-term coefficients of renewable energy consumption are negative and significant for all coun-

Table 10
AMG estimations.

Variables	Brazil	Indonesia	India	China	Russia	Turkey	Mexico
LnFD	−0.017 (0.035)	0.003 (0.004)	0.518[a] (0.263)	0.731[a] (0.428)	0.095[b] (0.038)	−0.008 (0.011)	0.215[b] (0.069)
LnRNEC	−0.663[a] (0.358)	−0.498[a] (0.126)	−0.379[b] (0.085)	−1.207[a] (0.924)	−0.634[a] (0.136)	−0.102[b] (0.042)	−0.384[b] (0.207)
LnGTI	−0.095[a] (0.042)	−0.013 (0.015)	−0.044[b] (0.017)	−0. 087[a] (0.032)	−0.061[a] (0.025)	−0.027[b] (0.009)	−0.035[a] (0.011)
LnGDP	0.486[a] (0.152)	−0.002 (0.006)	0.286[b] (0.053)	0.173[a] (0.049)	0.128[b] (0.036)	0.246[b] (0.059)	0.155[a] (0.034)
LnTO	0.048 (0.063)	0.027[c] (0.135)	0.004 (0.022)	0.082[a] (0.037)	0.015[c] (0.009)	0.124[b] (0.054)	0.138[a] (0.052)
Constant	9.073[a] (3.448)	8.379[b] (4.460)	−2.686[a] (0.725)	6.953[a] (1.463)	−11.235[a] (3.953)	−4.291 (2.334)	8.732[b] (3.016)

Note: a = significant at the 1%; b = significant at the 5%; c = significant at the 10%.

Table 11
Outcomes of the D-H causality test.

	LnCE	LnFD	LnREN	LnGTI	LnGDP	LnTO
LnCE		4.569[a] (3.012) [0.001]	1.228 (-0.963) [0.335]	3.039 (0.632) [0.527]	6.039[a] (5.632) [0.000]	4.609[a] (3.315) [0.008]
LnFD	8.465[a] (5.415) [0.000]		4.746[a] (2.769) [0.005]	4.684[a] (2.702) [0.006]	4.482[b] (2.482) [0.013]	7.852[a] (6.148) [0.000]
LnRNEC	3.230[b] (1.201) [0.022]	4.399[b] (2.392) [0.016]		3.383[c] (1.287) [0.078]	4.265[b] (2.707) [0.035]	3.827[c] (1.770) [0.076]
LnGTI	4.714[a] (2.846) [0.001]	1.895 (-0.331) [0.740]	4.402[b] (2.396) [0.016]		5.712[a] (3.821) [0.000]	1.594 (-0.658) [0.510]
LnGDP	7.371[a] (5.451) [0.000]	8.011[a] (5.626) [0.000]	7.303[a] (5.552) [0.000]	6.701[a] (4.896) [0.000]		5.616[a] (3.453) [0.000]
LnTO	6.225[a] (4.379) [0.000]	4.385[c] (2.289) [0.017]	4.597[a] (2.608) [0.009]	6.720[a] (4.917) [0.000]	8.839[a] (7.222) [0.000]	

Note: a = significant at the 1%; b = significant at the 5%; c = significant at the 10 percent level. () provides the z-bar statistics, and [] provides probability values.

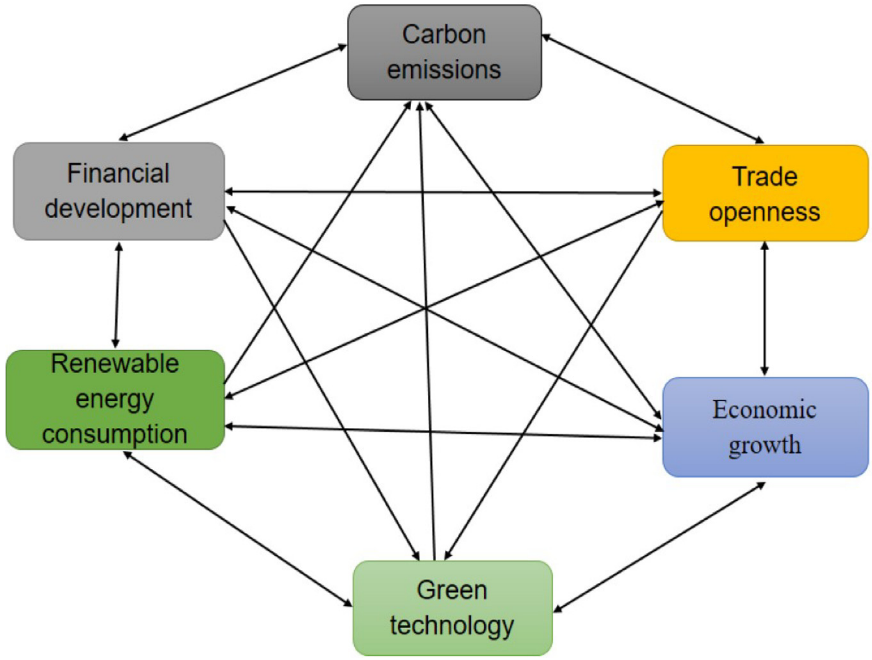

Fig. 6. A graphic representation of the causal relationship between variables.

tries. Increasing renewable energy consumption by 1% leads to a decrease in CE by 0.724% (Brazil), 0.588% (Indonesia), 0.379% (India), 1.016% (China), 0.520 (Russia), 0.098 (Turkey), and 0.363 (Mexico). Taking into consideration these results, it can be concluded that using renewable energy is a viable strategy towards achieving sustainable development goals. Finally, the coefficients of green technology are negative and significant for Brazil, India, China, Russia, Turkey, and Mexico, whereas insignificant for Indonesia. Hence, green technology contributes to environmental quality in a positive way. Particularly, a 1% increase in green technologies leads to a reduction in CE of 0.095% (Brazil), 0.044% (India), 0.087% (China), 0.061% (Russia), 0.027% (Turkey), and 0.035% (Mexico). These results confirm those found in earlier studies (Paramati et al., 2021; Cheng and Yao, 2021). Innovative technologies could play a significant role in converting the economic and industrial structures of countries in the E-7 to more sustainable energy sources.

Table 11 reports the results of Dumitrescu and Hurlin causality tests. It appears that a bidirectional relationship exists between FD and CE at the 1% significance level. In other words, the development of the financial sector leads to higher CE because it tends to drive economic growth through fossil fuels, thereby contributing to ecological degradation. Further, the results show that RNEC is unidirectionally correlated with CE. Similarly, green technology exhibits a unidirectional correlation with carbon emissions, implying that renewable energy and green technology have the potential to solve environmental problems. In addition, it is worth noting that a bidirectional link exists between FD and the consumption of renewable energy at the 1% and 5% significance levels. In this way, a strong and developed financial sector helps boost investments in clean energy and contributes to achieving renewable energy goals. Economic growth influences FD, and in turn, FD influences economic growth. In the same way, trade openness and FD both affect each other at a significance level of 1% and 5%. Bidirectional links are observed between economic growth and CE, trade openness and CE, renewable energy and economic growth, renewable energy and trade openness, economic growth and green technology, and economic growth and trade openness. However, a unidirectional causality runs from trade openness to green technology (see Fig. 6).

5. Conclusion and policy implications

Around the globe, countries are implementing environmental innovations and investing in advanced technology to achieve sustainable development. As part of this effort, the current study explores the effect of FD, renewable energy consumption, and green technology on CE seven emerging countries from 1990 to 2020. Furthermore, the paper examines the combined effects of FD and renewable energy consumption, as well as FD and green technology on carbon emissions. It used advanced econometric techniques to determine CD, heterogeneity, unit roots, and long-run parameters to obtain efficient and consistent results. The empirical findings of the long-run estimator revealed that FD contributes to the problem of global warming. In contrast, renewable energy consumption and green technology improve environmental quality by lowering carbon emissions. Our study also examined the indirect effects of FD on carbon emissions. Interestingly, the interaction between FD and the use of renewable energy minimizes carbon emissions through this channel. Likewise, FD can positively affect environmental quality when combined with green technology. However, the results remain robust when different econometric methods are employed.

From this empirical analysis, some important implications can be drawn that could contribute to the achievement of sustainable development goals. Firstly, the empirical findings recommend that financial development contributes to the degradation of the environment, which suggests that policymakers should improve their financial structures in these countries to prevent environmental degradation. This requires emerging economies to take steps to innovate and improve financial instruments in order to minimize environmental damage. It is also important to prevent the flow of money to polluting industries and to support projects that are environmentally friendly. Moreover, Laws, regulations, and internal demands of financial institutions should be adjusted continuously for the purpose of minimizing environmental problems resulting from economic growth.

Secondly, the findings of the renewable energy consumption variable reveal a significant and positive connection with carbon emissions. Also, the results of the interaction term between FD and renewable energy consumption enhance environmental sustainability, so, these governments should provide subsidies to renewable energy projects vigorously to formulate a strategy of boosting the development of renewable energy that will reduce environmental degradation. Furthermore, the government should adopt energy policies in a timely and efficient manner with the goal of mitigating ecological issues. It is possible to achieve this goal through the adoption of non-carbon sources of energy in the E-7 economies. Policymakers should promote clean energy while improving energy efficiency. Furthermore, renewable energy should be used in areas with high energy consumption in order to lessen the dependence on outdated energy infrastructure while ensuring energy security. With this step, they will be able to take a first step toward the accomplishment of SDGs 7 and 13.

Thirdly, we find that green technologies improve the quality of the environment. Therefore, policymakers must make strenuous efforts to support environmental innovations and technologies to advance green initiatives. Policymakers need to ensure that green innovation and technology can address economic and ecological challenges in the context of sustainable development. To improve the environment, it is also important to establish green guidelines for technologies. Innovative technologies and benefits associated with the environment create a market platform that fosters close collaboration between competing firms. Furthermore, the benefits of green technology innovation will enhance sustainable growth and provide decent employment opportunities. By taking this step, these economies can contribute to the achievement of SDG 8. Another important finding is that economic growth is positively correlated with carbon emissions. Governments and policymakers in these countries should formulate environmental policies and regulations that are more sustainable and efficient. For the purpose of diminishing carbon emissions without adversely affecting economic growth, it is also imperative that outdated technologies be replaced with the most advanced technologies.

This study has some shortcomings. For instance, this study considered the overall financial development index, whereas different segments of financial development along with other variables such as institutional quality could be considered in future studies for a more in-depth analysis. A further limitation of this study is the time span of the dataset, which could be taken into consideration in future research. Finally, aggregated data on renewable energy is used to quantify the role of renewable energy to curb environmental degradation in seven emerging countries. In order to provide additional insight, it may be beneficial to use segregated renewable energy sources in these emerging nations, or in other developed and developing nations.

CRediT authorship contribution statement

Umme Habiba: Conceptualization, Software, Methodology, Formal analysis, Writing – original draft. **Cao Xinbang:** Formal analysis, Writing – review & editing. **Shahid Ali:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix 1

Variance Inflation Factor (VIF) test results for endogeneity.

Variables	VIF	Tolerance
LnCE	1.78	0.5617
LnFD	1.54	0.6493
LnRNEC	1.13	0.8849
LnGTI	1.42	0.7042
LnGDP	1.80	0.5556
LnTO	1. 67	0.5988

References

Abbasi, F., Riaz, K., 2016. CO_2 emissions and financial development in an emerging economy: an augmented VAR approach. Energy Policy 90, 102–114.

Abid, M., 2017. Does economic, financial and institutional developments matter for environmental quality? A comparative analysis of EU and MEA countries. J. Environ. Manage. 188, 183–194.

Acheampong, A.O., 2019. Modelling for insight: does financial development improve environmental quality?. Energy Econ. 83, 156–179.

Acheampong, A.O., Amponsah, M., Boateng, E., 2020. Does financial development mitigate carbon emissions? Evidence from heterogeneous financial economies. Energy Econ. 88, 104768.

Ahmad, M., Ahmed, Z., Yang, X., Hussain, N., Sinha, A., 2021. Financial development and environmental degradation: do human capital and institutional quality make a difference?. Gondwana Res..

Al-Mulali, U., Ozturk, I., Lean, H.H., 2015a. The influence of economic growth, urbanization, trade openness, financial development, and renewable energy on pollution in Europe. Nat. Hazards 79 (1), 621–644.

Al-Mulali, U., Tang, C.F., Ozturk, I., 2015b. Does financial development reduce environmental degradation? Evidence from a panel study of 129 countries. Environ. Sci. Pollut. Res. 22 (19), 14891–14900.

Bai, C., Feng, C., Yan, H., Yi, X., Chen, Z., Wei, W., 2020. Will income inequality influence the abatement effect of renewable energy technological innovation on carbon dioxide emissions?. J. Environ. Manage. 264, 110482.

Bhattacharya, M., Churchill, S.A., Paramati, S.R., 2017. The dynamic impact of renewable energy and institutions on economic output and CO_2 emissions across regions. Renew. Energy 111, 157–167.

Bilgili, F., Ulucak, R., Koçak, E., İlkay, S.Ç., 2020. Does globalization matter for environmental sustainability? Empirical investigation for Turkey by Markov regime switching models. Environ. Sci. Pollut. Res. 27 (1), 1087–1100.

Bölük, G., Mert, M., 2015. The renewable energy, growth and environmental Kuznets curve in Turkey: an ARDL approach. Renew. Sust. Energ. Rev. 52, 587–595.

Boutabba, M.A., 2014. The impact of financial development, income, energy and trade on carbon emissions: evidence from the Indian economy. Econ. Model. 40, 33–41.

Bulut, U., 2017. The impacts of non-renewable and renewable energy on CO_2 emissions in Turkey. Environ. Sci. Pollut. Res. 24 (18), 15416–15426.

Charfeddine, L., Kahia, M., 2019. Impact of renewable energy consumption and financial development on CO_2 emissions and economic growth in the MENA region: a panel vector autoregressive (PVAR) analysis. Renew. Energy 139, 198–213.

Chen, W., Lei, Y., 2018. The impacts of renewable energy and technological innovation on environment-energy-growth nexus: New evidence from a panel quantile regression. Renew. Energy 123, 1–14.

Cheng, Y., Yao, X., 2021. Carbon intensity reduction assessment of renewable energy technology innovation in China: a panel data model with cross-section dependence and slope heterogeneity. Renew. Sust. Energ. Rev. 135, 110157.

Chien, F., Anwar, A., Hsu, C.C., Sharif, A., Razzaq, A., Sinha, A., 2021. The role of information and communication technology in encountering environmental degradation: proposing an SDG framework for the BRICS countries. Technol. Soc. 65, 101587.

Dietz, T., Rosa, E.A., 1997. Effects of population and affluence on CO_2 emissions. Proc. Natl. Acad. Sci. 94 (1), 175–179.

Dogan, E., Turkekul, B., 2016. CO_2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. Environ. Sci. Pollut. Res. 23 (2), 1203–1213.
Dou, Y., Zhao, J., Malik, M.N., Dong, K., 2021. Assessing the impact of trade openness on CO_2 emissions: evidence from China-Japan-ROK FTA countries. J. Environ. Manage. 296, 113241.
Du, K., Li, P., Yan, Z., 2019. Do green technology innovations contribute to carbon dioxide emission reduction? Empirical evidence from patent data. Technol. Forecast. Soc. Change 146, 297–303.
Dumitrescu, E.I., Hurlin, C., 2012. Testing for Granger non-causality in heterogeneous panels. Econ. Model. 29 (4), 1450–1460.
Eberhardt, M., Bond, S., 2009. Cross-section dependence in nonstationary panel models: a novel estimator.
Ehigiamusoe, K.U., Lean, H.H., 2019. Effects of energy consumption, economic growth, and financial development on carbon emissions: evidence from heterogeneous income groups. Environ. Sci. Pollut. Res. 26 (22), 22611–22624.
Farhani, S., Chaibi, A., Rault, C., 2014. CO_2 emissions, output, energy consumption, and trade in Tunisia. Econ. Model. 38, 426–434.
Feng, K., Hubacek, K., Guan, D., 2009. Lifestyles, technology and CO_2 emissions in China: a regional comparative analysis. Ecol. Econ. 69 (1), 145–154.
Ganda, F., 2019. The impact of innovation and technology investments on carbon emissions in selected organisation for economic Co-operation and development countries. J. Clean. Prod. 217, 469–483.
Gielen, D., Boshell, F., Saygin, D., Bazilian, M.D., Wagner, N., Gorini, R., 2019. The role of renewable energy in the global energy transformation. Energy Strategy Rev. 24, 38–50.
Gokmenoglu, K.K., Sadeghieh, M., 2019. Financial development, CO_2 emissions, fossil fuel consumption and economic growth: the case of Turkey. Strateg. Plan. Energy Environ. 38 (4), 7–28.
Habiba, U., Xinbang, C., 2022. The impact of financial development on CO_2 emissions: new evidence from developed and emerging countries. Environ. Sci. Pollut. Res., 1–14.
Habiba, U., Xinbang, C., Ahmad, R.I., 2021. The influence of stock market and financial institution development on carbon emissions with the importance of renewable energy consumption and foreign direct investment in G20 countries. Environ. Sci. Pollut. Res. 28 (47), 67677–67688.
Hao, Y., Zhang, Z.Y., Liao, H., Wei, Y.M., Wang, S., 2016. Is CO_2 emission a side effect of financial development? An empirical analysis for China. Environ. Sci. Pollut. Res. 23 (20), 21041–21057.
Hawksworth, J., Audino, H., Clarry, R., 2017. The long view: how will the global economic order change by 2050 (Retrieved, 15, 2017).
Inglesi-Lotz, R., Dogan, E., 2018. The role of renewable versus non-renewable energy to the level of CO_2 emissions a panel analysis of sub-Saharan Africa's ig 10 electricity generators. Renew. Energy 123, 36–43.
Jalil, A., Feridun, M., 2011. The impact of growth, energy and financial development on the environment in China: a cointegration analysis. Energy Econ. 33 (2), 284–291.
Jamel, L., Maktouf, S., 2017. The nexus between economic growth, financial development, trade openness, and CO_2 emissions in European countries. Cogent Econ. Finance 5 (1), 1341456.
Kapetanios, G., Pesaran, M.H., Yamagata, T., 2011. Panels with non-stationary multifactor error structures. J. Econom. 160 (2), 326–348.
Kakar, Z. K. (2016). Financial development and energy consumption: Evidence from Pakistan and Malaysia. Energy Sources B: Econ. Plan. Policy 11(9), 868-873.
Kayani, G.M., Ashfaq, S., Siddique, A., 2020. Assessment of financial development on environmental effect: implications for sustainable development. J. Clean. Prod. 261, 120984.
Khan, I., Zakari, A., Ahmad, M., Irfan, M., Hou, F., 2022. Linking energy transitions, energy consumption, and environmental sustainability in OECD countries. Gondwana Res. 103, 445–457.
Le, T.H., Le, H.C., Taghizadeh-Hesary, F., 2020. Does financial inclusion impact CO_2 emissions? Evidence from Asia. Finance Res. Lett. 34, 101451.
Lee, K.H., Min, B., 2015. Green R&D for eco-innovation and its impact on carbon emissions and firm performance. J. Clean. Prod. 108, 534–542.
Levine, R., Zervos, S., 1998. Stock markets, banks, and economic growth. Am. Econ. Rev., 537–558.
Lin, S., Sun, J., Marinova, D., Zhao, D., 2018. Evaluation of the green technology innovation efficiency of China's manufacturing industries: DEA window analysis with ideal window width. Technol. Anal. Strateg. Manag. 30 (10), 1166–1181.
Maji, I.K., Habibullah, M.S., Saari, M.Y., 2017. Financial development and sectoral CO_2 emissions in Malaysia. Environ. Sci. Pollut. Res. 24 (8), 7160–7176.
McCollum, D., Gomez Echeverri, L., Riahi, K., Parkinson, S., 2017. Sdg7: Ensure access to affordable, reliable, sustainable and modern energy for all.
Nasreen, S., Anwar, S., 2015. The impact of economic and financial development on environmental degradation: an empirical assessment of EKC hypothesis. Stud. Econ. Finance.
Nasreen, S., Anwar, S., Ozturk, I., 2017. Financial stability, energy consumption and environmental quality: evidence from South Asian economies. Renew. Sust. Energ. Rev. 67, 1105–1122.
Nathaniel, S.P., Iheonu, C.O., 2019. Carbon dioxide abatement in Africa: the role of renewable and non-renewable energy consumption. Sci. Total Environ. 679, 337–345.
Pachauri, R.K., Allen, M.R., Barros, V.R., Broome, J., Cramer, W., Christ, R., van Ypserle, J.P., 2014. Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change, pp. 151. Ipcc.
Paramati, S.R., Mo, D., Huang, R., 2021. The role of financial deepening and green technology on carbon emissions: evidence from major OECD economies. Finance Res. Lett. 41, 101794.
Pata, U.K., 2018. Renewable energy consumption, urbanization, financial development, income and CO_2 emissions in Turkey: testing EKC hypothesis with structural breaks. J. Clean. Prod. 187, 770–779.
Pesaran, M.H., 2006. Estimation and inference in large heterogeneous panels with a multifactor error structure. Econometrica 74 (4), 967–1012.
Pesaran, M.H., 2007. A simple panel unit root test in the presence of cross-section dependence. J. Appl. Econ. 22 (2), 265–312.
Pesaran, M.H., Yamagata, T., 2008. Testing slope homogeneity in large panels. J. Econom. 142 (1), 50–93.
Pesaran, M.H., 2004. General diagnostic tests for cross section dependence in panels (IZA Discussion Paper No. 1240). Institute for the Study of Labor (IZA).
Petrović, P., Lobanov, M.M., 2020. The impact of R&D expenditures on CO_2 emissions: evidence from sixteen OECD countries. J. Clean. Prod. 248, 119187.
https://www.pwc.com/my/en/publications/pwc-annual-report-2017.html
Qamruzzaman, M., Jianguo, W., 2020. The asymmetric relationship between financial development, trade openness, foreign capital flows, and renewable energy consumption: fresh evidence from panel NARDL investigation. Renew. Energy 159, 827–842.
Sadorsky, P., 2010. The impact of financial development on energy consumption in emerging economies. Energy policy 38 (5), 2528–2535.
Sadorsky, P., 2011. Financial development and energy consumption in Central and Eastern European frontier economies. Energy Policy 39 (2), 999–1006.
Samargandi, N., 2017. Sector value addition, technology and CO_2 emissions in Saudi Arabia. Renew. Sust. Energ. Rev. 78, 868–877.
Saud, S., Chen, S., Haseeb, A., 2019. Impact of financial development and economic growth on environmental quality: an empirical analysis from Belt and Road Initiative (BRI) countries. Environ. Sci. Pollut. Res. 26 (3), 2253–2269.
Saud, S., Chen, S., Haseeb, A., 2020. The role of financial development and globalization in the environment: accounting ecological footprint indicators for selected one-belt-one-road initiative countries. J. Clean. Prod. 250, 119518.
Shafiei, S., Salim, R.A., 2014. Non-renewable and renewable energy consumption and CO_2 emissions in OECD countries: a comparative analysis. Energy policy 66, 547–556.
Shahbaz, M., Mallick, H., Mahalik, M.K., Loganathan, N., 2015. Does globalization impede environmental quality in India?. Ecol. Indic. 52, 379–393.
Shahbaz, M., Nasir, M.A., Roubaud, D., 2018. Environmental degradation in France: the effects of FDI, financial development, and energy innovations. Energy Econ. 74, 843–857.
Shan, S., Genç, S.Y., Kamran, H.W., Dinca, G., 2021. Role of green technology innovation and renewable energy in carbon neutrality: a sustainable investigation from Turkey. J. Environ. Manage. 294, 113004.
Sharif, A., Baris-Tuzemen, O., Uzuner, G., Ozturk, I., Sinha, A., 2020. Revisiting the role of renewable and non-renewable energy consumption on Turkey's ecological footprint: evidence from Quantile ARDL approach. Sustain. Cities Soc. 57, 102138.
Sharma, R., Sinha, A., Kautish, P., 2020. Examining the impacts of economic and demographic aspects on the ecological footprint in South and Southeast Asian countries. Environ. Sci. Pollut. Res. 27 (29), 36970–36982.
Sinha, A., Shahbaz, M., 2018. Estimation of environmental Kuznets curve for CO_2 emission: role of renewable energy generation in India. Renew. Energy 119, 703–711.
Sinha, A., Sengupta, T., Alvarado, R., 2020. Interplay between technological innovation and environmental quality: formulating the SDG policies for next 11 economies. J. Clean. Prod. 242, 118549.
Svirydzenka, K., 2016. Introducing a new Broad-based Index of Financial Development. International Monetary Fund.
Tamazian, A., Chousa, J.P., Vadlamannati, K.C., 2009. Does higher economic and financial development lead to environmental degradation: evidence from BRIC countries?. Energy policy 37 (1), 246–253.
Usman, M., Balsalobre-Lorente, D., Jahanger, A., Ahmad, P., 2022. Are Mercosur economies going green or going away? An empirical investigation of the association between technological innovations, energy use, natural resources and GHG emissions. Gondwana Res..
Vural, G., 2020. How do output, trade, renewable energy and non-renewable energy impact carbon emissions in selected Sub-Saharan African Countries?. Resour. Policy 69, 101840.
Waheed, R., Chang, D., Sarwar, S., Chen, W., 2018. Forest, agriculture, renewable energy, and CO_2 emission. J. Clean. Prod. 172, 4231–4238.
Wang, B., Wang, Z., 2018. Imported technology and CO_2 emission in China: collecting evidence through bound testing and VECM approach. Renew. Sust. Energ. Rev. 82, 4204–4214.
Wang, S.S., Zhou, D.Q., Zhou, P., Wang, Q.W., 2011. CO_2 emissions, energy consumption and economic growth in China: a panel data analysis. Energy policy 39 (9), 4870–4875.
Weber, T.A., Neuhoff, K., 2010. Carbon markets and technological innovation. J. Environ. Econ. Manage. 60 (2), 115–132.

Westerlund, J., 2007. Testing for error correction in panel data. Oxf. Bull. Econ. Stat. 69 (6), 709–748.
Xing, T., Jiang, Q., Ma, X., 2017. To facilitate or curb? The role of financial development in China's carbon emissions reduction process: a novel approach. Int. J. Environ. Res. Public Health 14 (10), 1222.
Xu, Y., Umar, M., Kirikkaleli, D., Adebayo, T.S., Altuntaş, M., 2022. Carbon neutrality target in Turkey: measuring the impact of technological innovation and structural change. Gondwana Res..
Yao, X., Tang, X., 2021. Does financial structure affect CO_2 emissions? Evidence from G20 countries. Finance Res. Lett. 41, 101791.
Zafar, M.W., Zaidi, S.A.H., Sinha, A., Gedikli, A., Hou, F., 2019. The role of stock market and banking sector development, and renewable energy consumption in carbon emissions: insights from G-7 and N-11 countries. Resour. Policy 62, 427–436.
Zafar, M.W., Sinha, A., Ahmed, Z., Qin, Q., Zaidi, S.A.H., 2021. Effects of biomass energy consumption on environmental quality: the role of education and technology in Asia-Pacific Economic Cooperation countries. Renew. Sust. Energ. Rev. 142, 110868.
Zhang, L., Godil, D.I., Bibi, M., Khan, M.K., Sarwat, S., Anser, M.K., 2021. Caring for the environment: how human capital, natural resources, and economic growth interact with environmental degradation in Pakistan? A dynamic ARDL approach. Sci. Total Environ. 774, 145553.
Zhang, B., Wang, B., Wang, Z., 2017. Role of renewable energy and non-renewable energy consumption on EKC: evidence from Pakistan. J. Clean. Prod. 156, 855–864.