Economic Research-Ekonomska Istraživanja

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rero20

Dynamic effect of green financing and green technology innovation on carbon neutrality in G10 countries: fresh insights from CS-ARDL approach

Xiao Jian & Sahar Afshan

To cite this article: Xiao Jian & Sahar Afshan (2023) Dynamic effect of green financing and green technology innovation on carbon neutrality in G10 countries: fresh insights from CS-ARDL approach, Economic Research-Ekonomska Istraživanja, 36:2, 2130389, DOI: 10.1080/1331677X.2022.2130389

To link to this article: https://doi.org/10.1080/1331677X.2022.2130389

Published online: 18 Nov 2022.

ECONOMIC RESEARCH-EKONOMSKA ISTRAŽIVANJA
2023, VOL. 36, NO. 2, 2130389
https://doi.org/10.1080/1331677X.2022.2130389

OPEN ACCESS Check for updates

Dynamic effect of green financing and green technology innovation on carbon neutrality in G10 countries: fresh insights from CS-ARDL approach

Xiao Jian[a]* and Sahar Afshan[b]

[a]Dong Fureng Economic & Social Development School, Wuhan University, Wuhan, Hubei, China; [b]Department of Economics and Finance, Sunway University Business School, Sunway University, Subang Jaya, Malaysia

ABSTRACT

There is a notion that finance plays a crucial role in anthropogenic; however, the emerging trends have been observed to incorporate environmental concerns into sustainable financing. Moreover, technological innovations tend to help in achieving carbon neutrality. This research examines the role of green financing (GFIN) and green technologies in dealing with carbon neutrality in G10 economies from 2000 through 2018. Advanced panel estimations; Cross-Sectional ARDL, cross-sectional dependence, unit root test with and without structural breaks, slope homogeneity, and panel cointegration has applied. The long- and short-run estimates confirm that GFIN and technologies promote carbon neutrality. Moreover, the long-run results endorse the validity of the Environmental Kuznets Curve. Similar findings are observed in the short run except for EKC; however, their marginal contribution toward carbon neutrality is relatively higher in the long run. Moreover, the negative sign of the error correction term endorses convergence towards steady-state equilibrium. These results are endorsed by alternative estimators and offer valuable recommendations.

ARTICLE HISTORY
Received 8 June 2022
Accepted 15 September 2022

KEYWORDS
Green financing; green innovations; environmental sustainability; CS-ARDL

JEL CLASSIFICATIONS
O3; O13; O16; G32

1. Introduction

The latest findings by UNFCCC (2021) report that finance and technology are among the critical factors in reducing greenhouse gas emissions by up to 40% by the end of 2030. This phenomenon focuses on green financing (GFIN) in dealing with those challenges linked with the environment and nature with the help of collecting and pooling various investment-related support from public and private partnerships (Al Mamun et al., 2022). One of the significant examples of GFIN is green bonds, which

CONTACT Xiao Jian hhbbj1108@163.com
*China Electric Power International Forwarding Co. Ltd. CEIFA Beijing, China.

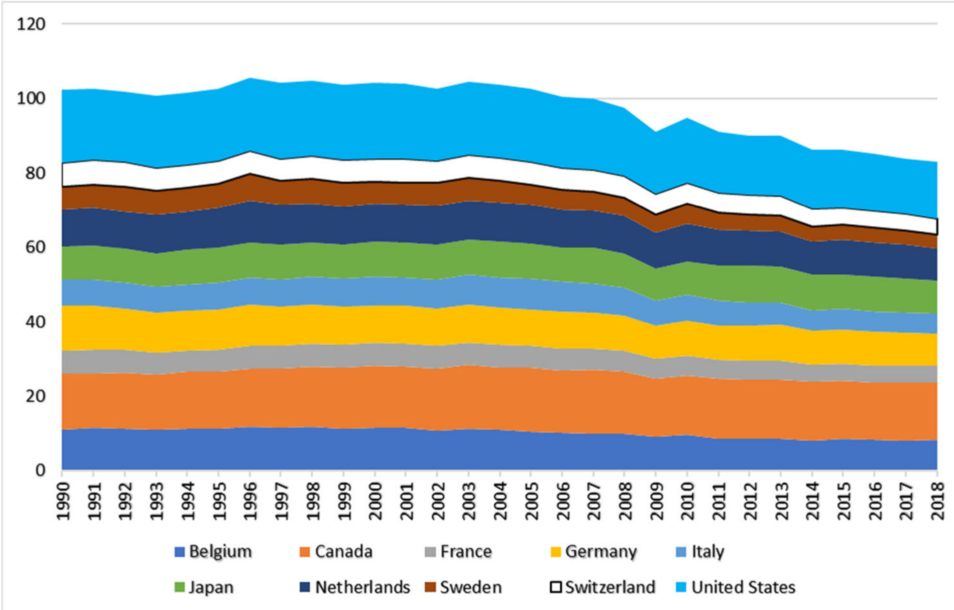

Figure 1. CO_2 emissions (metric tons per capita). Source: Data from WDI (2022).

are assumed to be a more viable option to combat climate change than any other financing arrangement in the contemporary financial markets. More specifically, since 2007, GFIN in green bonds has shown remarkable growth while reaching an investment point of 360 billion USD by 2021 (Al Mamun et al., 2022). Since the beginning of the Industrial Revolution, financial markets and their products have significantly mobilised different investment patterns and financial products. One of the fundamental notions reflects a crucial role of finance in anthropogenic covering the human role in the natural environment (Irfan et al., 2022; Scholtens 2017). However, very little has been investigated to examine the nexus between finance and environmental concerns.

Meanwhile, over the past couple of years, financial sectors around the globe, specifically in the developed economies, have been examined while paying attention to GFIN and related investment projects. This attention has created new pathways toward green and sustainable growth, indicating that green financial instruments help promote a green environment (Razzaq et al., 2022; Sachs, 2015). More specifically, the promotion of GFIN is an ongoing phenomenon through green bonds, green stocks, green loans, green home mortgages, green equity programs, auto loans and climate credit cards, respectively (Meo & Karim, 2022). The aforementioned discussion has clarified that green finance interacts with the financial system and environment. However, the literature support for the nexus between ecological finance and environmental concerns has been observed in very few studies. For example, Li and Jia (2017) claim that ecological finance is one of the most effective ways to mitigate environmental pollution and related issues, where green investment helps promote new technologies and innovation in renewable energy sources (Böhringer et al., 2015). Therefore, current research is motivated enough to examine the role of GFIN on carbon neutrality among G10 economies. Figure 1 reflects the carbon emission (metric tons per capita) for G10 economies during the last three decades.

In addition, green technology innovations (GTIs) play a substantial part in environmental protection and green economic development. Technological advancement helps focus on sustainable development goals like ecological protection while working for carbon neutrality (Shan et al., 2021). More specifically, carbon neutrality refers to achieving net-zero carbon emission, which is of significant interest among policymakers, environmentalists, and other stakeholders (Sun et al., 2021, 2022). Although GTI has been under considerable attention in recent years, however, the earlier concept is entitled 'environmentally sound technologies (ESTs)' (Verhoosel, 1998). At the same time, the traditional idea of technologies is entirely transformed into sustainable solutions while considering their social, environmental and economic impact.

A range of activities and financial support have been observed among G10 economies to support GTI. However, significant attention is still required in promoting the GTI to combat environmental concerns like carbon emissions. This article contributes to extant literature manifolds. First, it investigates the role of GFIN towards carbon neutrality among the G10. Second, we unveil the influence of green innovations on carbon neutrality using advanced panel estimations such as Cross-Sectional Augmented Autoregressive Distributed Lag (CS-ARDL). Third, the validity of EKC among G10 economies is also tested by empirically supporting the relationship between economic growth, carbon neutrality and other vital indicators. The empirical findings indicate that GFIN helps achieve carbon neutrality by 0.319% in the long run. Likewise, economic growth reflects a direct source of enhancing carbon dioxide emissions over the study period. However, an increasing trend in economic growth after a certain level comes with sustainable outcomes while reducing carbon emissions in the targeted economies. Moreover, GTI helps achieve carbon neutrality by 0.189% in the long run.

The structure of the article is organised in the following manner: the current section is entitled Section 1, which covers the introduction and background of the study variables. Section 2 covers the literature review while exploring the relationship between the variables. Section 3 describes the research methods and econometric model. Section 4 provides the empirical findings and related discussion, whereas Section 5 covers the conclusion, policy implications and limitations.

2. Literature review

2.1. GFIN and CO_2 emissions

GFIN increments financial flows from private, public and not-for-profit sectors towards sustainable development. The financial flows could come from micro-credit, banking, investments and insurance sources. One core aspect of GFIN is managing social and environmental challenges and implementing strategies that bring decent profits and ecological benefits (UNEP, 2022). GFIN plays an essential role in developing the economy through increased funding for sustainable development and enhancing interest in green growth at international levels (WEF, 2020).

Wu et al. (2021) estimate the long-term factors for developing a clean and green environment in G7 economies. This work aims to determine the change in CO_2 emission levels for a sustainable environment based on the panel data between 2010 and 2018 for G7 countries. The study implements the Augmented Dickey-Fuller (ADF) and fully modified least square (FMLS) approaches to estimate and provide the long-term relationship between GFIN and CO_2 emissions. Empirical results of the study reveal that GFIN techniques help mitigate environmental hazards such as carbon emissions. It also enhances the confidence in policymakers to invest more in GFIN towards green economic development. Moreover, the results of the study state that a 1% increase in GFIN improves the environmental quality by 0.375% in G7 economies by reducing CO_2 emissions. Environmental pollution must be diminished, and energy generation must move to alternate, modern and sustainable sources (Ozturk et al., 2022). Meo and Abd Karim (2022) examine the cointegration between GFIN and CO_2 emissions in the top 10 economies with improved green investment and sustainable development, including Denmark, Canada, Japan, United States, Switzerland, Sweden and United Kingdom. The study employs a Quantile-on-Quantile Regression (QQR) approach to determine the dependence structure of given variables within different quantiles. Findings of the study show that GFIN negatively impacts the CO_2 emissions; however, this correlation can vary based on different quantiles. Variations between the relationship also occur due to GFIN market situation and country-specific regulations for GFIN and environmental regulations.

C. Sun (2021) provides empirical evidence on the development of GFIN and its quantitative impact on CO_2 emissions. It offers empirical research for developing a carbon trading system based on environmental regulations to attain carbon neutrality. Carbon trading plays a vital role in GFIN and evaluating businesses involved in carbon emissions. The study develops an analysis model based on machine learning and big data analytics to determine the relationship between GFIN and CO_2 emissions. The study also conducts simulation tests for the verification of the given model. It also compares the research outcomes with the actual situation based on the simulation to build a correlation between shared variables. Findings of the work show that the proposed model provides a good correlation analysis between GFIN and CO_2 emissions. Environmental sustainability can be achieved through enhanced GFIN in the long run. L. Guo, Zhao et al. (2022) aim to determine the impact of GFIN on the agriculture sector and CO_2 emissions. The study analyses panel data from 2000 to 2019 from Chinese provinces while focusing on unit root tests, cross-sectional dependence and cointegration. The study provides a long-run correlation between GFIN and agriculture-based carbon emissions. The Granger causality test affirms the bidirectional association between agricultural emissions and increased GFIN. However, GFIN will significantly lower fertiliser consumption and agricultural carbon emissions within a decade. The research outcomes establish an essential empirical basis for Chinese regions to create CO_2 emission reduction programs. China first launched a policy framework and competitive landscape to encourage the growth of GFIN, and the 'dual carbon neutrality' goal was formally proposed in 2020. Moreover, many countries include carbon neutrality goals in their strategic aims for a sustainable environment (Ozturk & Ullah, 2022).

Reduction in CO_2 emissions is critical in realising the carbon neutrality goal in G10 economies with higher investment in green development and green energy production. C.-Q. Guo, Wang et al. (2022) provide a causal model that reveals the direct and indirect interrelationship between GFIN and CO_2 emissions in China while analysing the data between 2006 and 2019. The datasets employed in the study are taken from local and national statistical departments. The regression analysis reveals the moderating role of technological development in the correlation between GFIN and CO_2 emissions. The study also employs the Spatial Durbin Model (SDM) to investigate the relationship between the given variables. The empirical research findings show that GFIN contains a significant direct impact on curbing carbon emission rates. It further recommends improving the GFIN development alliance with other economies with innovative reforms. Green growth is an exceptional strategy for achieving a sustainable environment. Hussain et al. (2021) provide a model for reducing CO_2 emissions through increased investment in green innovation and technology. It determines the impact of GFIN on carbon emission levels based on the data between 2000 and 2020 for high GDP economies. The study implements an advanced econometric model such as the cross-sectional ARDL approach for long- and short-run correlations between the given variables. Findings of the study reveal that enhanced GFIN substantially increases green development and decreases carbon emission levels in higher GDP economies, including the G10 countries. Based on the results, policymakers could devise effective regulations towards increased investment in GFIN that ultimately eliminate the CO_2 emission in a long-run and provide a sustainable environment. The literature on GFIN can influence policymakers to include this aspect in country's carbon neutrality goals

2.2. GTI and CO_2 emissions

GTI aims to attain long-term sustainable development and social, economic and environmental advantages. It also ensures energy and resource safety while eliminating or reducing environmental degradation (Wang et al., 2021). Moreover, it can attain greenhouse gas reduction targets, energy efficiency and environmental protection. Increased GTI can improve the energy sector, which substantially provides economic growth. Du et al. (2019) investigated the effect of GTI on carbon neutrality based on the data between 1996 and 2012 for developing world economies. It also estimates the levels of income that affect the GTI in reducing CO_2 emissions. A single threshold impact is also estimated regarding the income levels that affect the GTI. Moreover, GTI does not significantly reduce carbon emissions for economies with lower income levels. However, the regime change occurs at a very high-income level.

Furthermore, the study discovers a reversed U-shape relationship between per capita carbon emissions and GTI. The study recommends that mechanism innovations be used to lower the cost of GTI diffusion in developing nations. Sustainable development goals can be attained through efficient carbon emission measures and climate regulations. Literature studies provide the impact of GTI in emissions mitigation based on structural changes and a linear framework. Razzaq et al. (2021) examine the relationship between GTI and CO_2 emissions in BRICS economies by employing panel data between 1990 and 2017. Empirical findings of the study highlight the cointegration between the given variables in given quantiles. It uses a set of nonlinear modeling, including Quantile Regression, Unit Root Test, Quantile Causality and Regression analysis to reveal the association between the given variables. Findings show that carbon emission mitigating impacts of GTI are only practical for higher emission quantiles in China, Brazil, Russia and India. In contrast, GTI is weakly related to CO_2 emissions in the case of lower emission quantiles. The study's overall outcomes reveal that GTI reduces CO_2 emissions with higher levels.

GTI is also essential for developing economic growth that promotes CO_2 emissions, which is one of the biggest environmental challenges. Du and Li (2019) provide the precise effect of GTI on CO_2 emissions. The study shows that GTI is only effective in the case of higher-income countries. Moreover, there is no significant evidence that GTI positively impacts CO_2 emissions in lower-income countries. The study's findings are robust as determined through alternative model characteristics. It proposes adopting and developing GTI in less developed countries to raise living standards and economic growth. The study also suggests upgrading green technologies with enhanced investment in this sector through innovative methodologies. The study also highlights the policies required to encourage the worldwide adoption of GTI, such as GT transfer. Khurshid et al. (2022) reveal the role of GTI in reducing carbon emission levels. The study also determines the position of trademarks and patents in alleviating CO_2 emissions by employing the data between 2000 and 2018. The study implements the OLS techniques and nonlinear ARDL method to establish a correlation between the given variables. The Granger causality approach is also employed to test the causality relationship between GTI and CO_2 emissions. The given variables show both unidirectional and bidirectional causal linkages; however, the consequences are mainly based on country and its economic situation.

The Paris Agreement provides a unified adaptation for a global reaction toward environmental degradation. The long-term goals of this agreement include holding the global temperature rise below 2 °C. China aims to attain carbon neutrality by 2060 through several regulations, and one of these measures is the improved implementation of GTI. Zeng et al. (2022) analyse the GTI levels in different provinces of China based on the panel data between 2001 and 2019. The study implements the panel threshold and econometric models and the Global Malmquist Luenberger (GML) index to analyse the nonlinear impacts of GTI on CO_2 emissions in China. Findings of the study reveal that GTI has been on the rise, but innovation effectiveness is low in Chinese Western provinces. The spatial impacts of GTI play a vital role in diminishing CO_2 emissions. A more significant effect is estimated in underdeveloped areas of China with higher reductions in carbon emissions. Sustainable development is linked with GTI, which leads to a sustainable environment.

Cai et al. (2021) examine the relationship between GTI and CO_2 emissions based on the data between 2006 and 2019 in the context of Chinese provinces and subregions. The study employs a Space-panel econometric technique based on the STIRPAT model. The study also analyses the geographic data to determine the spatial pattern and correlation between the variables. Results show that GTI has a negative cointegration with CO_2 levels. In addition, based on the regional data, GTI is effectively reducing CO_2 emission levels in Central and Eastern regions of China. In contrast, an increase in GTI can promote CO_2 emission levels in the Western region. In addition, the results reveal that CO_2 emissions are derived through factors including industrial infrastructure, economic growth, energy utilisation patterns and gross domestic product, which positively impact CO_2 emission levels in China.

2.3. Gross domestic product and CO_2 emissions

Gross Domestic Product (GDP) plays an essential role as it provides data about the size or value of an economy and how an economy performs in the current situation. The growth rate of GDP is taken as an indication of an economy's health, whereas a rise in real GDP indicates that a country's economy is doing well (IMF, 2020). Some components of GDP include a country's consumption rate, investment, imports and exports. Algarini (2020) investigates a causal correlation between GDP and CO_2 emissions from oil and gas generation in Saudi Arabia based on the data between 1990 and 2017. The study employs the Granger causality and Vector Autoregressive model tests to establish a bidirectional relationship between economic growth (GDP) per capita and CO_2 emission levels. Otim et al. (2022) determine the impact of GDP per capita on CO_2 emission level, which leads to environmental degradation and global warming. The study provides the effect of GDP per capita and energy utilisation on CO_2 emission rates in Uganda based on the data between 1986 and 2018. It employs the Vector error correction method to establish a long-run correlation between the given variables. The study provides the elasticity of CO_2 emissions per capita with respect to GDP per capita, which is found to be 1.856. The Granger causality approach provides a unidirectional relationship between the given variables, supporting the EKC hypothesis. The study's findings show that an increase in GDP per capita has a positive impact on CO_2 emission levels in Uganda.

Rahman et al. (2018) evaluate the cointegration between GDP and CO_2 emissions in emerging economies such as Bangladesh. The study employs traditional quadratic and log models with standard attributes to determine the cointegration between the given variables. The study confirms a direct and positive relationship between GDP and environmental implications. Implementing stringent environmental policies can balance economic growth and environmental sustainability. The study also suggests developing environmental protection awareness, effectively utilising natural resources, and implementing green technologies for a sustainable environment. Developing nations aim to achieve sustainable economic growth and effective energy utilisation. Tong et al. (2020) investigate the correlation between GDP per capita and CO_2 emissions levels in E7 economies. The E7 economies, including India, Mexico, Brazil, Indonesia, Russia, China and Turkey, are highly concerned with developing strategies for CO_2 emissions reduction. The research findings reveal that a spatial correlation is found between GDP and CO_2 emissions based on the data obtained for Brazil, where carbon emission rates directly depend on economic growth. Granger causality test shows the presence of short-run Granger causality between GDP per capita and carbon emission per capita for India, Brazil, China and Mexico. Findings of the study

Table 1. Details of the variables.

Name	Nature	Measurement and Source
Carbon neutrality	Dependent	CO_2 emissions (metric tons per capita), WDI
Green financing	Independent	(Million USD from IRENA include investment in green energy supply)
Green technology innovations	Independent	Eco-patents/technologies % of total patents/technologies from OECD.stat
Economic growth via gross domestic product	Control	Current USD, WDI

Source: Author's estimations.

show that higher energy consumption leads to increased economic development, which eventually enhances carbon emission levels in the context of E7 economies.

Karimi et al. (2021) examine the correlation between economic well-being and carbon emission levels in the case of Iran. The study employs the panel integration data for 1975–2017 to implement the bound testing methodology. The study's findings show a long-run correlation between the given variables. It reveals that a rise in GDP per capita in Iran positively impacts CO_2 emissions and increases the emission level. In contrast, the increasing utilisation of green technologies and emission reduction regulations can effectively improve the GDP per capita in the case of Iran. The results could be due to Iran's energy portfolio having less renewable energy. Moreover, human capital and labor factors are statically necessary, explaining the findings' economic consequences and providing specific policy suggestions. The United Nation's sustainable development goals include preserving the environment and improving environmental quality. Andrée et al. (2019) investigate the relationship between economic growth in per capita GDP and carbon emissions based on the data between 1990 and 2018. The study documents a U-shaped correlation between the per capita GDP and environmental degradation factors. It employs machine learning techniques to establish a relationship between the given variables across economic factors. Findings of the empirical study reveal that increasing GDP in developing and developed economies of the world significantly reduce CO_2 emissions in a long-term relationship.

3. Methodology and variables' description

The variable's description and data sources are presented in Table 1. Economic and financial shock variations develop a problem based on cross-sectional dependence (CSD). A weak CSD can be stated through economic availability. In contrast, a strong CSD occurs based on shocks affecting all other sectors. The observed shocks may include the demand, macroeconomic and differences in economic regulations for each country. The given research provides biased outcomes because of the CSD, as the hidden or unobserved variables are correlated with independent variables in the regression equation. In identifying variability among CSD and slope, the most-suited estimator discovered for the given research approach is 'CS-ARDL'. Moreover, Çoban and Topcu (2013) provide the CS-ARDL approach, managing the issues mentioned earlier with a liable corresponding impacts parameter.

For the current research work, CO_2 emissions are the dependent variable that is critically analysed through the impacts of independent variables, including GFIN, GTI and gross domestic product (GDP) in the context of G-10 economies of the world.

$$CO_{2,i,t} = f\ (GFIN_{i,t},\ GTI_{i,t},\ GDP_{i,t}) \tag{1}$$

From Equation (1), the term (i) denotes the cross-sectional dependence, whereas the term (t) shows the period taken for the study. Regression analysis from Equation (1) provides:

$$CO_{2it} = \beta_{1it} + \beta_{2it}GFIN_{it} + \beta_{3it}GTI_{it} + \beta_{4it}GDP_{it} + \alpha_i + \delta_{it} \tag{2}$$

The autoregressive distributed lag (ARDL) approach can be implemented through the following equation [Equation (3)]:

$$W_{i,t} = \sum_{i=0}^{pw} \varphi_{i,t} W_{i,t-1} + \sum_{i=0}^{pz} \gamma_{i,t} Z_{i,t-1} + \varepsilon_{i,t} \tag{3}$$

Furthermore, Equation (3) is utilised for each given variable for the average cross-section, which provides the following equation (4). An average cross-section can minimise the impacts of CSD for the given work (Török & Konka, 2018).

$$W_{it} = \sum_{i=0}^{pw} \varphi_{i,t} W_{i,t-1} + \sum_{i=0}^{pz} \gamma_{i,t} Z_{i,t-1} + \sum_{i=0}^{px} \alpha_i \overline{X}_{t-1} + \varepsilon_{i,t} \tag{4}$$

Here;

$$\overline{X}_{t-1} = (\overline{W}_{i,t-1}, \overline{Z}_{i,t-1}) \tag{5}$$

From Equation (5), W_{it} shows the value for the dependent variable, which is the CO_2 emissions in the given study, while all other independent variables are provided through the term $Z_{i,t-1}$ including GFIN, GTI, and GDP for the G-10 economies. In addition, the average values for both independent and dependent variables can be provided by $\overline{X}_{t-1}$, which eliminates the issues regarding cross-sectional dependence based on spillover impacts. Lag values for given variables can also be determined through P_x, P_w and P_z. The CS-ARDL methodology provides a long-run value for given variables obtained from the coefficients of short-term correlation. The mean group estimator (MGE) and long-term coefficients are provided as follows:

$$\hat{\pi}_{CD-ARDL,i} = \frac{\sum_{I=0}^{pz} \hat{\gamma}_{Ii}}{1 = \Sigma_{I=0}}\ \hat{\varphi}_{I,t} \tag{6}$$

$$\hat{\hat{\pi}}_{MG} = \frac{1}{N} \sum_{i=1}^{N} \hat{\pi}_i \tag{7}$$

Table 2. Results of cross-sectional dependence analysis.

Variable	Test statistics (*p* values)
CO_2	35.152*** (0.000)
GFIN	19.128*** (0.000)
GTI	21.076*** (0.000)
GDP	45.149*** (0.000)

Note: ***, **, * explain the level of significance at 1%, 5% and 10% respectively, whereas the values are in parentheses contains *p* values.
Source: Author's estimations.

The approximated short-term coefficients are provided as:

$$\Delta W_{it} = \vartheta_i[W_{i,t-1} - \pi_i Z_{i,t-1}] - \sum_{i=0}^{pw-1} \varphi_{i,t} \Delta_i W_{i,t-1} + \sum_{i=0}^{pz} \gamma_{i,t} \Delta_i Z_{i,t-1} + \sum_{i=0}^{px} \alpha_i \overline{X}_t + \varepsilon_{i,t} \tag{8}$$

In Equation (8):

$$\Delta_i = t - (t-1) \tag{9}$$

$$\hat{\pi}_i = \frac{\sum_{i=0}^{pz} \hat{\gamma}_{i,t}}{\hat{\tau}_i} \tag{10}$$

$$\hat{\hat{\pi}}_{\mathrm{MG}} = \frac{1}{N} \sum_{i=1}^{N} \hat{\pi}_{\mathrm{i}} \tag{11}$$

4. Results and discussion

In the initial step, cross-sectional dependence was examined for the study variables: carbon emission, GFIN, GTIs and economic growth via GDP. The null hypothesis for the CSD test assumes that CSD does not exist in the study data, whereas H1 rejects it (Pesaran, 2015). The results in Table 2 show that the score of test statistics has shown highly significant values with a significance level of 1% for the selected independent and dependent variables. This means that there is a presence of CSD in the study data; therefore, H1 is accepted at a 1% significance level.

This research mainly focuses on the key tests suggested by Pesaran (2007) and Bai and Carrion-I-Silvestre (2009) to examine the stationarity properties. These tests have a significant presence in the existing literature over the rest of the traditional unit root tests due to their range of benefits and consideration of cross-sectional dependence. Moreover, these tests also observed the heterogeneity in the slope coefficients and structural breaks in the data. Therefore, Table 3 shows that both tests show the absence of stationarity at the level. However, per Pesaran's (2007) tests, the data is stationarity. These results provided a pathway for taking the first-order difference, which Bai and Carrion-I-Silvestre (2009) applied accordingly. The findings provide evidence for rejecting H0 while accepting H1 to claim that there is stationarity in the data or no unit root where the data contains the cross-sectional dependence, slope

Table 3. Results of unit root test with & without structural break Pesaran (2007).

	Level I(0)				First difference I(1)	
Variables	CIPS	M-CIPS			CIPS	M-CIPS
CO2	−5.056***	−3.147**			–	–
GFIN	−3.171***	−5.010**			–	–
GTI	−4.119***	−4.103**			–	–
GDP	−3.124***	−6.004**			–	–
Bai and Carrion-i-Silvestre (2009)						
	Z	P_m	P	Z	P_m	P
CO2	0.402	0.280	18.110	−3.150***	4.199***	53.151***
GFIN	0.241	0.147	22.085	−5.021***	6.005***	76.104***
GTI	0.310	0.210	17.134	−4.111***	3.174***	61.116***
GDP	0.199	0.166	24.007	−6.006***	4.161***	55.123***

Note: The significance level is determined by 1%, 5% and 10% indicated through ***, **, and *.
Source: Author's estimations.

Table 4. Results of slope heterogeneity analysis.

Statistics	Test value (p value)
Delta tilde	64.144*** (0.000)
Delta tilde adjusted	79.086*** (0.000)

Note: ***, ** and * explain the level of significance at 1%, 5% and 10% respectively, whereas the values are in parentheses contains p values.
Source: Author's estimations.

heterogeneity and structural breaks. These findings are reported in Table 3 with respective significance levels.

In panel data estimations, testing for slope heterogeneity is another essential concern by researchers. The findings in Table 4 are presented through the modified Swamy (1970) test to examine the homogeneity in the slope coefficients. Moreover, Pesaran and Yamagata (2008) have examined the stated test and further discussed it. One of the vital points observed in the existing literature is that checking for slope heterogeneity is very important, as neglecting it may lead to unreliable findings in the upcoming stages of panel data estimations. More specifically, H0 assumes a presence of slope homogeneity, whereas H1 rejects it and claims it. Table 4 confirms that the test output under delta tilde and delta tilde adjusted are 64.144 and 79.086, significant at 1%. Therefore, H1 is accepted, whereas H0 is rejected, which mainly supports the presence of homogeneity in the slope coefficients.

This research applies the panel cointegration test of Westerlund and Edgerton (2008). For applying the stated test, the null hypothesis assumes that there is no cointegration where the CSD exists in the data. However, H1 indicates that with the presence of CSD, cointegration also exists. The findings in Table 5 confirm cointegration for three cases; no breaks, mean shift and regime shift. The results are highly significant at 1%; therefore, H0 is rejected. In addition, the second part of Table 5 shows the cointegration test based on the Banerjee and Carrion-i-Silvestre (2017) test. The stated findings also confirm the existence of cointegration among the model variables.

In the preceding steps, this research applies a range of tests like CSD, slope heterogeneity, unit root and panel cointegration. Afterward, we provide the empirical findings through CS-ARDL for the long- and short run. The findings in Table 6 report the long-run estimation first. It shows that economic growth is positively and

Table 5. Results of Westerlund and Edgerton (2008) panel cointegration analysis.

Test	No break	Mean shift	Regime shift
Z_φ (N)	−8.061***	−7.055***	−8.159***
p_{value}	0.000	0.000	0.000
Z_τ (N)	−6.823***	−5.718***	−6.410***
p_{value}	0.000	0.000	0.000
Results of Banerjee and Carrion-i-Silvestre's (2017) cointegration analysis			
Countries	No deterministic specification	With constant	With trend
Dependent Variable: CO_2 emission			
Full Sample	−3.143***	−4.081***	−3.101***
Belgium	−5.022***	−3.115***	−5.041***
Canada	−4.104***	−5.010***	−4.105***
France	−5.004***	−4.024***	−5.025***
Germany	−3.155***	−4.107***	−3.062***
Italy	−4.126***	−3.063***	−4.110***
Japan	−3.152***	−5.014***	−5.030***
Netherlands	−4.110***	−4.024***	−5.025***
Sweden	−3.046***	−4.107***	−3.062***
Switzerland	−5.008***	−3.063***	−4.110***
United States	−4.014***	−5.014***	−5.030***
United Kingdom	−4.125***	−3.055***	−3.044***

Note: Critical value (CV) at 5%** and 10% *with constant is −2.32, −2.18 and with trend is −2.92 and −2.82.
Source: Author's estimations.

Table 6. Results of CS-ARDL analysis (Long run).

Variables	Coefficients	*t*-statistics
Long-Run Estimates		
GDP	0.258***	5.175
GDP_2	−0.134**	−2.201
GFIN	−0.319**	−2.154
GTI	−0.189**	−2.820
Short-Run		
ΔGDP	0.248**	2.252
ΔGDP_2	−0.055*	−1.701
ΔGFIN	−0.099**	−2.042
ΔGTI	−0.134*	−1.814
ΔECT	−0.168**	−2.328

Note: ***, ** and * explain the level of significance at 1%, 5% and 10% respectively.
Source: Author's estimations.

significantly linked with CO_2, providing evidence that more economic growth is not sustainable as it creates more carbon emissions, hence hampering environmental health. The coefficient of GDP reflects a change of 0.258% in carbon emission over the long run estimations with the T-statistics of 5.175. A direct nexus between economic growth and carbon emission is based on the notion that producing goods and services in the selected economies require more energy consumption is associated with higher emissions. In this regard, Acheampong (2018) states a causal association between economic growth and carbon emission. Mikayilov et al. (2018) focus on Azerbaijan under the shadow of EKC. Five different cointegration methods were applied, and it found that economic growth significantly and positively impacts carbon emissions over the long run. Malik et al. (2020) examine both the symmetric and asymmetric impact of economic growth and foreign investment on CO_2 emissions in Pakistan. The findings state that economic growth is significantly and positively linked with carbon emissions, confirming ECK's existence in Pakistan. However, contrary to the aforementioned discussion, Nawaz et al. (2021) focuses on both BRICS and OECD economies while exploring the impact of economic growth on carbon emission. A negative nexus exists between carbon emission and economic growth among these economies.

Moreover, the long-run relationship between GDP2 and carbon emissions is negatively significant, where the coefficient reflects a change of −0.134% in carbon emission due to a 5% increase in economic growth beyond a certain threshold. It shows that above a certain level, economic growth towards environmental sustainability is productive; hence the presence of EKC is confirmed. It implies that in the early stages of economic growth, pollution emissions increase with a decline in environmental quality. However, beyond some level of per capita income, the trend reverses (Stern, 2001). The nexus between the square of GDP and CO_2 is widely discussed and justified in different studies. Van Song et al. (2022) focus on the US economy and claim that GDP square helps reduce carbon emissions. Chien et al. (2021) observe the trends in environmental degradation for ASEAN economies. Considering CS-ARDL for both long-run and short-run results, they confirm that the square of GDP helps lower the environmental degradation in carbon emission and ecological footprints. Besides, Kais and Sami (2016), Acaravci and Ozturk (2010), and Sadiq et al. (2022) have also explored the empirical nexus between GDP2 and CO_2 in different economies.

As stated earlier, understudy the background and literature discussion, GFIN helps improve environmental quality by promoting sustainable projects. Consequently, as shown in Table 6 (long run), the empirical results prove that GFIN significantly improves environmental degradation while reducing CO_2. More specifically, it confirms an improvement of 0.319% in declining carbon emissions among G10 economies. It confirms that a significant flow of funds in financial markets of G10 economies in the form of GFIN has been observed, which in return helps reduce environmental pollution. The theoretical and empirical support for the association between GFIN and CO2 exists where Ren et al. (2020) provide an innovative index based on four green indicators. Their results confirm that using new energy and green finance helps reduce the carbon intensity in China. Through neural network modeling, Sun et al. (2021) examines the correlation between green finance and carbon emission. It is inferred that technical progress is vital in promoting the nexus between GFIN and carbon emission. Meo and Karim (2022) focus on the top ten economies that support GFIN to reduce carbon emissions. The study findings confirm that GFIN helps reduce CO_2 emissions in the selected counties.

In the final step, long-run estimation examines the nexus between GTIs and CO_2 emissions. The results indicate a significantly negative coefficient, provided that ecological technologies are a good source of environmental protection. More specifically, an overall reduction of 0.189% in CO_2 emission has been experienced because of GTI. Shan et al. (2021) claim that green technologies can reasonably help regional governments achieve carbon neutrality targets. Their estimations through BARDL confirm that GTI and carbon neutrality through CO_2 emission are cointegrated over longer.

In addition, a decline in CO_2 emissions has been experienced through GTI in Turkey. Yue et al. (2021) investigate Thailand's region for the role of green technologies in dealing with carbon emissions. It is inferred that Thailand's technologies and

Table 7. Robustness regressions.

	AMG			CCEMG		
Dependent variables	Coefficients	*t* statistics	*p* values	Coefficients	*t*-statistics	*p* values
GDP	0.301**	2.174	0.000	0.186***	3.696	0.000
GDP_2	−0.118*	−1.678	0.092	−0.097**	−2.320	0.000
GFIN	−0.335**	−2.415	0.000	−0.254**	−2.216	0.000
GTI	−0.165***	−3.805	0.000	−0.121**	−2.046	0.000
Wald test	–	18.010	0.000	–	24.358	0.000

Note: ***, ** and * explain the level of significance at 1%, 5% and 10% respectively.
Source: Author's estimations.

sustainable tourism practices reduce carbon emissions. Razzaq et al. (2021) observe the asymmetric and inter-association between green innovations and carbon emission for the BRICS economies. They confirm that GTI helps mitigate carbon emission only at higher emission quantiles. However, the direction and magnitude of the relationship between ecological technologies and carbon emission varied across different BRICS economies. Therefore, it is inferred that promoting green technologies is a remedy for environmental pollution.

Moreover, the short-run results are also covered in Table 6, where a change in GDP is a direct determinant of carbon emission, whereas the square of GDP is insignificant and thus fails to endorse EKC in the short-run. In addition, GFIN and green technologies also reduce carbon emissions in G10 in the short run. Although the direction of the coefficients in the short run is similar to the long run, the coefficients' size is significantly smaller than in the long run. Finally, ECT suggests convergence towards steady-state equilibrium with a convergence rate of 16.8%.

Table 7 presents the findings of AMG and CCEMG for robustness. The results confirm a significant and positive nexus between GDP and CO_2 emissions, where the coefficients are 0.301 and 0.186 under the stated methods. Moreover, the square of GDP was negatively correlated with CO_2 emissions in both AMG and CCEMG estimators. It is inferred that the existence of EKC in G10 economies is evident where the economic growth up to a certain level is prone to environmental health. Green financial market-related activities and ecological innovations are the critical determinants for securing environmental deprivation.

5. Conclusion and policy suggestions

This research examines the nexus between GFIN, GTIs and carbon neutrality in G10 economies. We employ CS-ARDL estimator to examine long-run and short-run relationships among model variables considering the data's cross-sectional dependency, slope heterogeneity, unit root and cointegration properties. The estimations confirm the presence of cross-sectional dependence, heterogeneity in the slope coefficients, stationarity properties and cointegration between the variables of interest. In addition, both long-run and short-run results confirm that GFIN and environmental technologies help in improving the natural environment in G10 economies. However, economic growth tends to increase carbon emission at an early stage, however, after a specific threshold increase in income reduces the ecological burden and validates the EKC hypothesis. These findings suggest that the government should focus on promoting and creating a green culture in their relative financial markets. Moreover, issuing green credit facilities, bonds and financial products may help sustain the natural environment by reducing the economic dependency on traditional energy sources like fuel and coal. Meanwhile, promoting renewable energy sources at the household and industry level by providing green credit facilities may generate significant effects. Besides, governments in G10 economies should also focus on their relative fiscal policies, green investment and social capital under GFIN development. This would help to improve the green financial system while prioritising green activities and processes.

This research only provides advanced panel estimations for exploring the role of GFIN and GTIs in dealing with carbon neutrality. In contrast, the other indicators, like environmental policy stringency, carbon taxes and green growth, are missing in reflecting their role in ecological sustainability. In addition, cross-sectional comparisons among different economies are also missing in this research using alternative proxies of carbon neutrality.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Acaravci, A., & Ozturk, I. (2010). On the relationship between energy consumption, CO_2 emissions and economic growth in Europe. *Energy*, *35*(12), 5412–5420. https://doi.org/10.1016/j.energy.2010.07.009]

Acheampong, A. O. (2018). Economic growth, CO_2 emissions and energy consumption: What causes what and where? *Energy Economics*, *74*, 677–692. https://doi.org/10.1016/j.eneco.2018.07.022

Al Mamun, M., Boubaker, S., & Nguyen, D. K. (2022). Green finance and decarbonization: Evidence from around the world. *Finance Research Letters*, *46*, 102807. https://doi.org/10.1016/j.frl.2022.102807

Algarini, A. (2020). The relationship among GDP, carbon dioxide emissions, energy consumption, and energy production from oil and gas in Saudi Arabia. *International Journal of Energy Economics and Policy*, *10*(1), 280–285. https://doi.org/10.32479/ijeep.8345

Andrée, B. P. J., Chamorro, A., Spencer, P., Koomen, E., & Dogo, H. (2019). Revisiting the relation between economic growth and the environment; a global assessment of deforestation, pollution and carbon emission. *Renewable and Sustainable Energy Reviews*, *114*, 109221. https://doi.org/10.1016/j.rser.2019.06.028

Banerjee, A., & Carrion-i-Silvestre, J. L. (2017). Testing for panel cointegration using common correlated effects estimators. *Journal of Time Series Analysis*, *38*(4), 610–636. https://doi.org/10.1111/jtsa.12234

Bai, J., & Carrion-I-Silvestre, J. L. (2009). Structural changes, common stochastic trends, and unit roots in panel data. *The Review of Economic Studies*, *76*(2), 471–501.

Böhringer, C., Rutherford, T. F., & Springmann, M. (2015). Clean-development investments: An incentive-compatible CGE modelling framework. *Environmental and Resource Economics*, *60*(4), 633–651. https://doi.org/10.1007/s10640-014-9762-3

Cai, A., Zheng, S., Cai, L., Yang, H., & Comite, U. (2021). How does green technology innovation affect carbon emissions? A spatial econometric analysis of China's provincial panel data. *Frontiers in Environmental Science*, *9*, 1–12. https://doi.org/10.3389/fenvs.2021.813811

Chien, F., Hsu, C.-C., Sibghatullah, A., Hieu, V. M., Phan, T. T. H., & Hoang Tien, N. (2021). The role of technological innovation and cleaner energy towards the environment in

ASEAN countries: proposing a policy for sustainable development goals. *Economic Research-Ekonomska Istraživanja*, 1–16. https://doi.org/10.1080/1331677X.2021.2016463

Çoban, S., & Topcu, M. (2013). The nexus between financial development and energy consumption in the EU: A dynamic panel data analysis. *Energy Economics*, *39*, 81–88. https://doi.org/10.1016/j.eneco.2013.04.001

Du, K., & Li, J. (2019). Towards a green world: How do green technology innovations affect total-factor carbon productivity. *Energy Policy*, *131*, 240–250. https://doi.org/10.1016/j.enpol.2019.04.033

Du, K., Li, P., & Yan, Z. (2019). Do green technology innovations contribute to carbon dioxide emission reduction? Empirical evidence from patent data. *Technological Forecasting and Social Change*, *146*, 297–303. https://doi.org/10.1016/j.techfore.2019.06.010

Guo, C.-Q., Wang, X., Cao, D.-D., & Hou, Y.-G. (2022). The impact of green finance on carbon emission–analysis based on mediation effect and spatial effect. *Frontiers in Environmental Science*, *10*, 1–17. https://doi.org/10.3389/fenvs.2022.844988

Guo, L., Zhao, S., Song, Y., Tang, M., & Li, H. (2022). Green finance, chemical fertilizer use and carbon emissions from agricultural production. *Agriculture*, *12*(3), 313. https://doi.org/10.3390/agriculture12030313

Hussain, Z., Mehmood, B., Khan, M. K., & Tsimisaraka, R. S. M. (2021). Green growth, green technology, and environmental health: evidence from high-GDP countries. *Frontiers in Public Health*, *9*, 1–13.

IMF. (2020). *Gross domestic product: An economy's all.* https://www.imf.org/external/pubs/ft/fandd/basics/gdp.htm#:~:text=GDP%20is%20important%20because%20it,the%20economy%20is%20doing%20well.

Irfan, M., Razzaq, A., Sharif, A., & Yang, X. (2022). Influence mechanism between green finance and green innovation: Exploring regional policy intervention effects in China. *Technological Forecasting and Social Change*, *182*, 121882. https://doi.org/10.1016/j.techfore.2022.121882

Kais, S., & Sami, H. (2016). An econometric study of the impact of economic growth and energy use on carbon emissions: panel data evidence from fifty eight countries. *Renewable and Sustainable Energy Reviews*, *59*, 1101–1110. https://doi.org/10.1016/j.rser.2016.01.054

Karimi, M., Ahmad, S., Karamelikli, H., Dinç, D., Khan, Y., Sabzehei, M., & Abbas, S. (2021). Correction: Dynamic linkages between renewable energy, carbon emissions and economic growth through nonlinear ARDL approach: Evidence from Iran. *PLoS One*, *16*(10), e0258612. https://doi.org/10.1371/journal.pone.0258612

Khurshid, A., Rauf, A., Calin, A. C., Qayyum, S., Mian, A. H., Qayyum, S., & Fatima, T. (2022). Technological innovations for environmental protection: Role of intellectual property rights in the carbon mitigation efforts. Evidence from western and southern Europe. *International Journal of Environmental Science and Technology*, *19*(5), 3919–3934. https://doi.org/10.1007/s13762-021-03491-z

Li, W., & Jia, Z. (2017). Carbon tax, emission trading, or the mixed policy: Which is the most effective strategy for climate change mitigation in China? *Mitigation and Adaptation Strategies for Global Change*, *22*(6), 973–992. https://doi.org/10.1007/s11027-016-9710-3

Malik, M. Y., Latif, K., Khan, Z., Butt, H. D., Hussain, M., & Nadeem, M. A. (2020). Symmetric and asymmetric impact of oil price, FDI and economic growth on carbon emission in Pakistan: Evidence from ARDL and nonlinear ARDL approach. *Science of the Total Environment*, *726*, 138421. https://doi.org/10.1016/j.scitotenv.2020.138421

Meo, M. S., & Abd Karim, M. Z. (2022). The role of green finance in reducing CO_2 emissions: An empirical analysis. *Borsa Istanbul Review*, *22*(1), 169–178.

Mikayilov, J. I., Galeotti, M., & Hasanov, F. J. (2018). The impact of economic growth on CO_2 emissions in Azerbaijan. *Journal of Cleaner Production*, *197*, 1558–1572. https://doi.org/10.1016/j.jclepro.2018.06.269

Nawaz, M. A., Hussain, M. S., Kamran, H. W., Ehsanullah, S., Maheen, R., & Shair, F. (2021). Trilemma association of energy consumption, carbon emission, and economic growth of BRICS and OECD regions: quantile regression estimation. *Environmental Science and*

Pollution Research International, *28*(13), 16014–16028. https://doi.org/10.1007/s11356-020-11823-8

Otim, J., Mutumba, G., Watundu, S., Mubiinzi, G., & Kaddu, M. (2022). The effects of gross domestic product and energy consumption on carbon dioxide emission in Uganda (1986–2018). *International Journal of Energy Economics and Policy*, *12*(1), 427–435. https://doi.org/10.32479/ijeep.12552

Ozturk, I., Aslan, A., & Altinoz, B. (2022). Investigating the nexus between CO2 emissions, economic growth, energy consumption and pilgrimage tourism in Saudi Arabia. *Economic Research-Ekonomska Istraživanja*, *35*(1), 3083–3098. https://doi.org/10.1080/1331677X.2021.1985577

Ozturk, I., & Ullah, S. (2022). Does digital financial inclusion matter for economic growth and environmental sustainability in OBRI economies? An empirical analysis. *Resources, Conservation and Recycling*, *185*, 106489. https://doi.org/10.1016/j.resconrec.2022.106489

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, *22*(2), 265–312. https://doi.org/10.1002/jae.951

Pesaran, M. H., & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of Econometrics*, *142*(1), 50–93.

Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. *Econometric Reviews*, *34*(6–10), 1089–1117. https://doi.org/10.1080/07474938.2014.956623

Rahman, M. M., Bindu, K. J., & Islam, M. K. (2018). Linking per capita GDP to energy consumption, ecological footprint, and carbon dioxide emission in a developing economy in the world: The case of Bangladesh. *Journal of Banking and Financial Dynamics*, *2*(1), 9–15. https://doi.org/10.20448/journal.525.2018.21.9.15

Razzaq, A., Sharif, A., An, H., & Aloui, C. (2022). Testing the directional predictability between carbon trading and sectoral stocks in China: New insights using cross-quantilogram and rolling window causality approaches. *Technological Forecasting and Social Change*, *182*, 121846. https://doi.org/10.1016/j.techfore.2022.121846

Razzaq, A., Wang, Y., Chupradit, S., Suksatan, W., & Shahzad, F. (2021). Asymmetric inter-linkages between green technology innovation and consumption-based carbon emissions in BRICS countries using quantile-on-quantile framework. *Technology in Society*, *66*, 101656. https://doi.org/10.1016/j.techsoc.2021.101656

Ren, J., Gao, B., Zhang, J., & Chen, C. (2020). Measuring the energy and carbon emission efficiency of regional transportation systems in China: Chance-constrained DEA models. *Mathematical Problems in Engineering, 2020*, 9740704. https://doi.org/10.1155/2020/9740704

Sachs, J. D. (2015). Goal-based development and the SDGs: Implications for development finance. *Oxford Review of Economic Policy*, *31*(3–4), 268–278. https://doi.org/10.1093/oxrep/grv031

Sadiq, M., Kannaiah, D., Yahya Khan, G., Shabbir, M. S., Bilal, K., & Zamir, A. (2022). Does sustainable environmental agenda matter? The role of globalization toward energy consumption, economic growth, and carbon dioxide emissions in South Asian countries. *Environment, Development Sustainability*, 1–20. https://doi.org/10.1007/s10668-021-02043-2

Scholtens, B. (2017). Why finance should care about ecology. *Trends in Ecology & Evolution*, *32*(7), 500–505. https://doi.org/10.1016/j.tree.2017.03.013

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. *Journal of Environmental Management*, *294*, 113004. https://doi.org/10.1016/j.jenvman.2021.113004

Stern, D. I. (2001). The environmental Kuznets curve: a review. *The Economics of Nature the Nature of Economics*, *193*, 1–18.

Sun, C. (2021). The correlation between green finance and carbon emissions based on improved neural network. *Neural Computing and Applications*, *34*, 1–15.

Sun, Y., Duru, O. A., Razzaq, A., & Dinca, M. S. (2021). The asymmetric effect eco-innovation and tourism towards carbon neutrality target in Turkey. *Journal of Environmental Management*, *299*, 113653. https://doi.org/10.1016/j.jenvman.2021.113653

Sun, Y., Razzaq, A., Sun, H., & Irfan, M. (2022). The asymmetric influence of renewable energy and green innovation on carbon neutrality in China: Analysis from non-linear ARDL model. *Renewable Energy*. *193*, 334–343. https://doi.org/10.1016/j.renene.2022.04.159

Swamy, P. A. (1970). Efficient inference in a random coefficient regression model. *Econometrica: Journal of the Econometric Society*, 311–323. https://doi.org/10.2307/1913012

Tong, T., Ortiz, J., Xu, C., & Li, F. (2020). Economic growth, energy consumption, and carbon dioxide emissions in the E7 countries: a bootstrap ARDL bound test. *Energy, Sustainability and Society*, *10*(1), 1–17. https://doi.org/10.1186/s13705-020-00253-6

Török, Á., & Konka, B. (2018). Episode or hysteresis? Some theoretical and policy lessons from the crisis of 2008. *Acta Oeconomica*, *68*(s2), 45–70. https://doi.org/10.1556/032.2018.68.s2.3

UNEP. (2022). *Green financing*. https://www.unep.org/regions/asia-and-pacific/regional-initiatives/supporting-resource-efficiency/green-financing#:∼:text=Green%20financing%20is%20to%20increase,sectors%20to%20sustainable%20development%20priorities.

UNFCCC. (2021). Annual report 2021. Retrieved from https://unfccc.int/annualreport#:⍰:text=The%20UN%20Climate%20Change%20secretariat's,COP%2026%20in%20Glasgow%2C%20where

Van Song, N., Tiep, N. C., van Tien, D., Van Ha, T., Phuong, N. T. M., & Mai, T. T. H. (2022). The role of public-private partnership investment and eco-innovation in environmental abatement in USA: evidence from quantile ARDL approach. *Environmental Science and Pollution Research International*, *29*(8), 12164–12175. https://doi.org/10.1007/s11356-021-16520-8

Verhoosel, G. (1998). Beyond the unsustainable rhetoric of sustainable development: Transferring environmentally sound technologies. *Georgetown International Environmental Law Review*, *11*, 49.

Wang, M., Li, Y., & Liao, G. (2021). Research on the Impact of Green Technology Innovation on Energy Total Factor Productivity, Based on Provincial Data of China. *Frontiers in Environmental Science*, *9*, 1–11. https://doi.org/10.3389/fenvs.2021.710931

WDI. (2022). CO2 emissions (metric tons per capita). Retrieved from https://data.worldbank.org/indicator/EN.ATM.CO2E.PC

WEF. (2020). *What is green finance and why is it important?* https://www.weforum.org/agenda/2020/11/what-is-green-finance/

Westerlund, J., & Edgerton, D. (2008). A simple test for cointegration in dependent panels with structural breaks. *Oxford Bulletin of Economics and Statistics*, *70*(5), 665–704. https://doi.org/10.1111/j.1468-0084.2008.00513.x

Wu, X., Sadiq, M., Chien, F., Ngo, Q.-T., Nguyen, A.-T., & Trinh, T.-T. (2021). Testing role of green financing on climate change mitigation: Evidences from G7 and E7 countries. *Environmental Science and Pollution Research International*, *28*(47), 66736–66750.

Yue, X.-G., Liao, Y., Zheng, S., Shao, X., & Gao, J. (2021). The role of green innovation and tourism towards carbon neutrality in Thailand: Evidence from bootstrap ADRL approach. *Journal of Environmental Management*, *292*, 112778. doi:https://doi.org/10.1016/j.jenvman.2021.112778

Zeng, S., Li, G., Wu, S., & Dong, Z. (2022). The impact of green technology innovation on carbon emissions in the context of carbon neutrality in China: Evidence from spatial spillover and nonlinear effect analysis. *International Journal of Environmental Research and Public Health*, *19*(2), 730. https://doi.org/10.3390/ijerph19020730