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Green energy, non-renewable energy, financial development and economic growth with carbon footprint: heterogeneous panel evidence from cross-country

Najia Saqib

Finance Department, College of Business Administration, Prince Sultan University, Riyadh, Kingdom of Saudi Arabia

ABSTRACT

This study examines the relationship between green energy, non-renewable energy, financial development, and economic growth with carbon footprint by using panel data from 63 emerging and developed economies for the time period from 1990 to 2020. The study utilises second-generation panel data econometrics techniques to investigate cross-section independence and adjust for cross-section heterogeneity. The studies also used the CIPS and CADF unit root tests, Wester Lund bootstrap cointegration techniques, and AMG and CCEMG heterogeneous panel causality techniques. The findings show that, over the long run, all variables are cointegrated. Additionally, the data indicate that non-renewable energy consumption leads to carbon footprint, whereas green energy reduces environmental degradation and supports the reduction of environmental hazards. Likewise, financial development has a considerable negative effect on environmental degradation. A statistically significant bidirectional correlation is found between green energy, nonrenewable energy, financial development, economic growth, and carbon footprint according to the Dumitrescu-Hurlin causality test. Finally, according to the findings of the study, the economies that were examined should use more green energy in order to reduce their carbon footprint.

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Carbon footprint; green energy; non-renewable energy; financial development; economic growth; panel D-H causality test; heterogeneous panel analysis

JEL CLASSIFICATIONS
C23; Q20; Q32; Q43; O40

1. Introduction

Economies that rely heavily on energy from fossil fuels are increasingly focusing on green energy sources. 'Green energy' is a colloquial term for 'green' or 'sustainable' energy sources. Sustainable energy sources include solar, wind, rain, and geothermal heat, all of which have low environmental impacts when used. Many societal benefits can be attributed to the use of green energy and energy efficiency, including decreased energy costs, better air quality and public health, and an increase in job

CONTACT Najia Saqib dr.najiasaqib@gmail.com; nsaqib@psu.edu.sa

creation and economic growth. Conserving green energy is widely recognised as a critical component of reducing carbon footprint. There is a carbon imprint on more than two thirds of worldwide energy production and consumption. The use of green energy sources has an immense impact on reducing the carbon footprint of the world.

The eradication of catastrophic climate events that continue to damage the entire planet is one of the most explosive concerns of the last two to three decades. Due to its ability to hold heat, carbon footprint is both a major source of global warming and an immediate danger to the environment. Natural and man-made catastrophes are to blame for climate change (Udemba, 2020) Carbon dioxide (CO_2), sulphur hexafluoride (SF6), nitrous oxide (N_2O), and methane (CH_4) are some of the gases that contribute to global warming because of human activities such as deforestation, industrial smoke, and fossil fuel burning. (Grossman & Krueger, 1991) also analysed three air contaminants in 42 nations to see if they were associated with economic growth. While at low-income levels, he found that sulphur dioxide and carbon dioxide levels rose in correlation with per capita GDP, at higher-income levels, he found that these concentrations declined and an inverted U-shaped association exists between pollution levels and income growth.

The analysis concludes that evidence of the relationship between carbon footprint, green energy, non-renewable energy and economic growth is critical for environmental policy. Green energy development or use seems to have a significant impact on both the economy and the environment. Another way, boosting economic, human, and environmental development through the use of green energy is important because it is more environmentally friendly (Rafindadi & Ozturk, 2017). Various factors, time periods, nations, and econometric methodologies have been researched empirically in the past to see if there is a long-term link between the use of green energy and sustainable economic growth. Green energy, carbon footprint, and economic growth are all intertwined (Apergis & Payne, 2011; Ozturk, 2010; Payne, 2010).

Furthermore, some studies have suggested that green energy does not help to reduce the carbon footprint (Frondel et al., 2010; Marques & Fuinhas, 2012). From this perspective (Apergis et al., 2010), they claim that green energy adoption is frequently coupled with excessive complexity in green energy development. In most cases, the cost of constructing green energy systems is mitigated by the utilisation of non-renewable energy sources such as coal and natural gas. In certain instances, the cost of unskilled labour and the unmet goal of a low-carbon economy often exceed the cost of green intermittent renewables. Due to the extensive deployment procedure, the economy fails to shrink the grey proposed clustering, resulting in adverse outcomes.

The expanse of thermal emissions released into the atmosphere by the world's most carbon-emitting countries varies dramatically. Major emerging economies are in dire need of economic growth, which frequently results in environmental degradation. As a result, developed economies often emit more per capita than emerging economies, although some emerging economies are also growing at the fastest rate in the world (Kong & Khan, 2019). The panel report on (BP, 2019) statistics on global energy shows that this carbon emitting emerging and developed economies significantly increase carbon footprint: China (27.8%), the United States (15.1%), India (7.3%), Russia (4.8%), Japan (3.3%), Germany (2.1%), South Korea (2.0%), Iran (1.8%), Saudi Arabia (1.6%), Canada (1.6%), Indonesia (1.4%). These statistics show that these economies cause the most environmental harm. The emitting countries' energy use amounts to roughly 82 percent of global consumption (Newell et al., 2019). However, in recent years, the entire global population has contributed to environmental destruction, and finding equitable and effective solutions to global pollution, carbon footprint, global warming, and environmental protection, while maintaining economic growth has now become exceedingly challenging.

On the other hand, stable financial system helps reduce environmental destruction and improves business prospects, product and service interchange, savings, investment efficiency, and technology however, if the financial sector is expanded without consideration for the country′s economic circumstances, the repercussions could be disastrous (Charfeddine & Kahia, 2019; Shahbaz et al., 2012) also found that financial development enhances the amount of environmental deficit. The increase in carbon footprint has pushed governments to undertake efforts toward the execution and formulation of energy plans aimed at encouraging the use of green & sustainable energy and thereby eliminating carbon footprint in the economic process (Sharif et al., 2020). As a result, it is necessary to evaluate the influence of green energy and non-renewable energy, as well as financial inclusion, on the carbon footprint in emerging and developed economies in order to construct a suitable policy.

Many studies have demonstrated that there is a link between green energy and non-renewable energy, financial development, economic growth, and carbon footprint (Assi et al., 2021; Usman & Makhdum, 2021). Real-income growth affects energy consumption indirectly and this influence might be favourable or adverse, depending on how well energy management and economic growth are organised. Consequently, expansion in manufacturing tends to enhance production behaviour and activities. This will lead to increased economic growth and energy consumption, while also exacerbating global warming and carbon footprint (Shahbaz et al., 2012; Yang et al., 2021).

Using heterogeneous panel analysis techniques and a cross-sectional dependency test, this study contributes to understand the link between green energy and non-renewable energy, financial development, and economic growth with carbon footprint in 63 emerging and developed economies. This research also investigates the long-run elasticity of all variables so these elasticities reflect the cross-sectional and panel longitudinal dimensional composition and provide more significant results than time series techniques. The remaining portion of the paper is organised as follows: To begin, Section 2 presents an outline of the theoretical underpinning and empirical evidences. Sections 3 and 4 detail the data, model and econometric modelling strategy and estimation results respectively. Toward the end of the research, Section 5 analyses the conclusion, policy implications and future research recommendations.

2. Theoretical underpinning and empirical evidence

Carbon footprint, financial development, green energy, non-renewable energy use and economic growth are examined in a variety of inconclusive literatures, as shown in Table 1. Previous research has shown that economic growth and environmental

Table 1. Summary of the literature review on the nexus between carbon footprint, financial development, green energy, non-renewable energy and economic growth.

Authors	Time period/Countires	Econometric techniques	Findings
(Apergis & Payne, 2009)	1971–2004 6 Central American countries	Panel Vector Error correction model	In long-run, energy consumption has a statistically significant positive impact on pollution, while actual production follows the (EKC) theory. Short-run dynamics show unidirectional causality from energy consumption and GDP to emissions, as well as bidirectional causality. Long-term, it appears that energy consumption and emissions are directly correlated.
(Ozturk & Acaravci, 2010)	1968–2005 Turkey	ARDL Bound	Energy conservation strategies, such as restricting energy usage and limiting carbon dioxide emissions, will have no negative impact on Turkey's real production growth.
(Acaravci & Ozturk, 2010)	1960–2005 19 European countries	ARDL Bound	EKC hypothesis is invalid for the majority of the countries studied when it comes to energy conservation measures such as restricting usage and reducing carbon dioxide emissions.
(Tugcu et al., 2012)	1980–2009 G7 countries	ARDL Bound	REC and NREC greatly contribute to economic growth and A bidirectional causality relationship exists between NREC and GDP.
(Bölük & Mert, 2014)	1990–2008 EU Countries	FE Panel Estimation	The EKC does not hold for carbon emissions in the 16 EU countries. In terms of carbon footprint, renewable energy use contributes about half as much as fossil energy consumption in the EU.
(Al-Mulali et al., 2015)	1980–2011 129 countries	GMM techniques	FD improves the quality of the environment.
(Apergis & Payne, 2015)	1980–2010 11 South American countries	Panel Error correction model	Bidirectional causality between all variables is evident and importance of renewable energy for sustainable economic growth and carbon footprint reduction.
(Ajmi et al., 2015)	1960–2010 G-7 states	Time-varying Granger causality test	In the case of Italy and Japan, the inverted N-shaped curves found do not support the EKC hypothesis and unidirectional causality running from GDP to carbon footprint
(Salahuddin et al., 2015)	1980–2012 6 GCC Countries	DOLS, FMOLS, DFE and VECM causality test	FD significantly improves the environmental quality, while economic growth stimulates pollution.
(Jebli et al., 2016)	1980–2010 25 OECD countries	FMOLS DOLS	Bidirectional causality between all variables is evident, renewable energy and trade reduce carbon footprint and also support the EKC hypothesis
(Saidi & Mbarek, 2016)	1990–2013 9 developed countries	FMOLS, DOLS	deny the EKC hypothesis. Financial development reduces carbon

(*continued*)

Table 1. Continued.

Authors	Time period/Countires	Econometric techniques	Findings
			emissions over time, meaning that it reduces environmental degradation. Urbanisation reduces carbon footprint.
(Dogan & Seker, 2016)	1985–2011 23 countries	FMOLS, DOLS	Carbon footprint are reduced through FD.
(Khan et al., 2017)	2001–2014 34 UMIC countries	PCA, FMOLS, and VECM causality test	In Europe, FD raises carbon footprint, but NREC and REC are more prevalent across the world's continents. Europe is the only continent where FD does not have an impact on carbon footprint.
(Bhattacharya et al., 2017)	1991–2012 85 Developing & Developed countries	GMM techniques	In terms of economic growth, REC has a significant and positive effect, but it has the opposite effect when it comes to carbon footprint.
(Bekhet et al., 2017)	1980–2011 GCC countries	ARDL, unrestricted error correction and VECM test	In Saudi Arabia, the United Arab Emirates, and Qatar, the relationship between carbon footprint and NREC is Unidirectional; in Oman and Kuwait, the relationship is bidirectional. In Oman, the relationship between FD and carbon footprint is Unidirectional.
(Ito, 2017)	2002–2011 42 Developing countries.	GMM techniques	REC reduces the carbon footprint while NREC stimulate it.
(Nasreen et al., 2017)	1980–2012 5 South Asian Countries	ARDL	Carbon footprint are reduced through FD.
(Bhat, 2018)	1992–2016 BRICS countries	GMM techniques	NREC & GDP increase while REC reduces carbon footprint.
(al Mamun et al., 2018)	1980–2015 25 OECD countries	FMOLS and DOLS Cointegration techniques	Financial markets encourage the use of green energy, but the availability of NREC reduces the link between financial markets and green energy use.
(Saqib, 2018)	1996–2017 GCC countries	GMM techniques	bidirectional causal relationship exists between energy consumption and economic growth.
(Cai et al., 2018)	1965–2015 G-7 countries	ARDL	REC reduces the carbon footprint. Cointegration exists only in 2 countries out of seven
(Khan et al., 2019)	1995–2017 34- HIC countries	FMOLS, DOLS, FGLS, AMG and D-H causality test	FD reduces the carbon footprint in Asia and the United States, NREC moves faster, and REC reduces carbon footprint.
(Wang & Dong, 2019)	1990–2014 14 SSA countries	FMOLS, AMG and D- H causality test	REC reduces the carbon footprint by GDP, NREC and URB. The NREC, GDP, and URB all have a bidirectional causal relationship with carbon footprint.
(Charfeddine & Kahia, 2019)	1980–2015 24 MENA countries	PVAR approach	There is certainly room for improvement on the part of the FD and the REC in terms of promoting environmental stability and economic development.
(Zafar et al., 2019)	1990–2015 APEC countries	CUP-FM, CUP-BC, and D- H causality test	GDP, REC, and NREC all have a bidirectional causality

(*continued*)

Table 1. Continued.

Authors	Time period/Countires	Econometric techniques	Findings
			relationship with each other. REC, NREC, and TOP all stimulate economic growth.
(Ganda, 2019)	2000–2014 25 OECD Countries	GMM technique	Carbon footprint can be reduced by the use of green energy and R&D.
(Destek & Sarkodie, 2019)	1977–2013 11 countries	AMG	In BRICS countries, the EKC hypothesis stands true, and FD increases pollution levels, whereas GDP and carbon footprint are connected in a bidirectional way.
(Le Quéré et al., 2020)	1990–2014 46 developing countries	AMG, CCEMG and panel D-H causality test	Bidirectional relationship occurs between NREC and FD and economic growth. While the NREC, GFCF, FD, and TOP all play a significant role in boosting the economic growth.
(Saidi & Omri, 2020)	1990–2014 15 top REC countries	FMOLS and VECM Granger causality test	Bidirectional causality exists between REC, GDP, and carbon footprint. REC is more responsible for increasing GDP growth and decreasing carbon footprint.
(Ulucak & Khan, 2020)	1992–2016 BRICS countries	FMOLS and DOLS	Validity of the EKC hypothesis is demonstrated by the environmental sustainability provided by the green energy, non-renewable energy and urbanisation respectively.
(Salahuddin et al., 2020)	1984–2016 34 SSA countries	AMG, CCEMG, and D-H causality test	Green energy and FD improve environmental quality and whereas green energy increases national savings. GDP continues to drive up carbon footprint.
(Ahmad et al., 2020)	1990–2017 90 countries	DK	FD accelerates carbon footprint
(Saud et al., 2020)	1990–2014 49 countries	PMG	FD accelerates carbon footprint
(Usman et al., 2020)	1995–2017 20 major polluted countries	FMOLS, PMG, AMG and PANEL D-H causality test	Both FD and CF have bidirectional causality, while FD and non-renewable energy consumption exacerbate carbon footprint.
(Saqib, 2021)	1987–2019 14-MENA Countries	VAR & Granger causality test	Neither in Bahrain nor in Malta is there a connection between GDP and CF. unidirectional link in between CF and GDP in Egypt, Iran, Tunisia, Algeria, Kuwait, Morocco, Qatar, Saudi Arabia & Turkey and bidirectional causality discovers between carbon footprint and GDP in Cyprus & Oman.
(Saqib & Benhmad, 2021)	1995–2015 22 European Nations	FMOLS	Validity of the EKC hypothesis is demonstrated by the environmental sustainability.
(Qayyum et al., 2021)	1984–2019 South Asian Nations	ARDL	Validity of the EKC hypothesis is demonstrated by the environmental sustainability.
(Kihombo et al., 2022)	1990–2017 West Asia and Middle East	CUP-FM and CUP-BC	Bidirectional causality and significant relationship discover between GDP and carbon footprint.

Source: Author Compilation.

sustainability are two sides of the same coin that must be balanced (Khan et al., 2019). Recognising these detrimental effects on environmental sustainability, developed countries incorporated pro-environmental policies and prompted firms to integrate green energy sources into their manufacturing and strategic operations through a variety of incentives, including tax exemptions and/or subsidies on green products, which not only stimulate economic development but also contribute to the environmental sustainability (Kouhizadeh et al., 2020; Zhu et al., 2020).

Recent empirical research on the link between carbon footprint, green energy and economic growth can be categorised into numerous strands. Green energy and its determinants have been highlighted in recent studies (Sohag et al., 2021; Taşkın & Demir, 2020; Ulucak, 2020). Many of these studies, such as (Fang, 2011) for China, (Payne, 2011) for the United States, (Adedoyin et al., 2021) and (Salahuddin et al., 2020) for countries in Sub-Saharan Africa (SSA), (Chien & Hu, 2007) for 45 economies, (Inglesi-Lotz, 2016) for countries in the OECD, (Ozturk & Bilgili, 2015) for 51 countries in Sub-Sahara depending on the number of stages of production, green energy can create more jobs, particularly when the technological accessories are manufactured and controlled domestically and can still be cost-effective as well. Both production growth and employment prospects could be facilitated by expanding the use of green energy to a greater level (Dai et al., 2016).

The literature on the relationship between real per capita income and green energy usage in emerging and OECD nations (Apergis et al., 2010) is also helpful in this regard. According to Tugcu et al. (2012), a rise in the share of green energy in the total energy mix for the G7 countries increases GDP. Accordingly, a number of additional studies confirm the link between China′s GDP, carbon footprint and an increase in the share of green energy in the entire energy mix (Fang, 2011) and for Denmark (Mathiesen et al., 2011).

Various research has been done on energy utilisation and carbon footprint in developing and developed countries, as shown in the above literature review. Green energy has no causal association with carbon footprint in the U.S.A. (Menyah & Wolde-Rufael, 2010) and (Apergis et al., 2010) also found no causal link between green energy consumption and carbon footprint in panel analyses of 19 countries. So, a time-frequency causal analysis is still needed to analyse the causal link between green energy consumption and carbon footprint.

3. Data, model and econometric modelling strategy

Panel data from 63 emerging and developed economies were used for this study, which covered the years 1990–2020. As shown in Table 2, the data on carbon footprint (CF), GDP per capita (Y), non-renewable energy use (NREU), and green energy use (GEU) comes from the World Development Indicators database (WDI). The International Monetary Fund (IMF) is the source of financial development (FD) data.

GDP per capita is measured by Y, CO_2 footprint are measured by CF, non-renewable energy use is measured by NRE, financial development is measured by FD, and green energy use is defined by GEU. In this study, which uses panel data from 63

Table 2. Data variables and sources.

Variables	Symbol	Measurement	Data sources
Carbon footprint	CF	CO_2 footprint per person	WDI
GDP	Y	GDP per capita	WDI
Financial development	FD	depth, and efficiency of financial institutions and markets	IMF
Green energy use	GEU	Consumption of solar, hydroelectric, geothermal, biomass, and wind energy in the total energy used.	WDI
Non-renewable energy use	NREU	Energy consumption per capita (kWh) as a proxy for non-renewable energy use	WDI

Source: Author's based on data from World development Indicators (WDI).

economies from 1999 to 2020, green and non-renewable energy are utilised as determinants of the carbon footprint model. According to our model, carbon footprints have the following function:

$$CF_{it} = f\ (Y_{it},\ FD_{it},\ GEU_{it},\ NREU_{it}) \quad (1)$$

Whereas; CF_{it} stands for carbon footprint per capita, $Y_{it,}$ is a RGDP per capita, FD_{it} is a financial development as a % of GDP, $GEU_{it,}$ is a green energy and $NREU_{it,}$ is a non-renewable energy.

To proceed, Table 3 shows how statistically significant each indicator is. (i.e., Mean, Median, Minimum, Maximum, Standard Deviation, Skewness and Kurtosis). The mean values of CF, Y, FD, GEU and NREU are 9.9021, 98.3563, 51.2210, 45.0095 and 90.8212, respectively. The standard deviations for CF, Y, FD, GEU and NREU are impressive as 2.6712, 10.3211, 8.6410, 30.1123 and 15.9043, respectively. The variables′ descriptive statistics enable for further analysis. In addition, it is observed that a positive bivariate correlation of GDP exists with all aforementioned variables except renewable energy utilisation.

As seen in Table 4, CF is highly correlated with NREU (0.9931) had the strongest positive correlation with the dependent variable (CF), followed by financial development (0.4961), economic growth (0.6967). However, it is adversely linked with green energy (−0.3001). In addition, it is observed that a positive bivariate correlation of GDP exists with all aforementioned variables except green energy consumption.

Figure 1 portrays the step-by-step econometric modelling strategy for the sake of clarity and ease of understanding by beginning to run the cross-sectional dependence test (CD) on the data. Cointegration and long-run analysis were also done after CD. Finally, panel causality between variables was tested.

4. Estimation results

4.1. Cross-sectional dependence (CSD) test

Increasing interdependence has made panel data analysis more vulnerable to cross-sectional dependency. The problem of cross-sectional interdependence may lead to biased and unreliable assessments if it cannot be resolved while claiming

Table 3. Descriptive statistics.

Variables	Mean	Median	Minimum	Maximum	Std. Dev.	Skewness	Kurtosis
CF	9.9021	8.3721	9.3721	18.3621	2.6712	0.3961	2.4443
Y	98.3563	90.2312	45.3211	85.8921	10.3211	0.4312	9.7120
FD	51.2210	49.3412	30.8231	68.2318	8.6410	0.2189	4.9021
GEU	45.0095	40.9845	31.9865	60.7853	30.1123	0.1230	3.9862
NREU	90.8212	81.7123	40.6412	83.6274	15.9043	0.2313	7.9231

Source: Author Estimation.

Table 4. Correlation matrix.

Variables	CF	Y	FD	GG	NRE
CF	1.0000				
Y	0.6967*	1.0000			
	[10.5512]	–			
FD	0.4961*	0.3562*	1.0000		
	[4.7233]	[5.8112]	–		
GEU	−0.3001*	−0.2102**	−0.1432**	1.0000	
	[−6.7221]	[−3.8921]	[−3.8712]	–	
NREU	0.9931*	0.3312*	0.5997*	−0.4012*	1.0000
	[45.5621]	[22.4123]	[13.2310]	[−12.0013]	–

Note: * and ** denote the significance level at 1%, 5% and 10% respectively, and the t-stats are in parenthesis.
Source: Author Estimation.

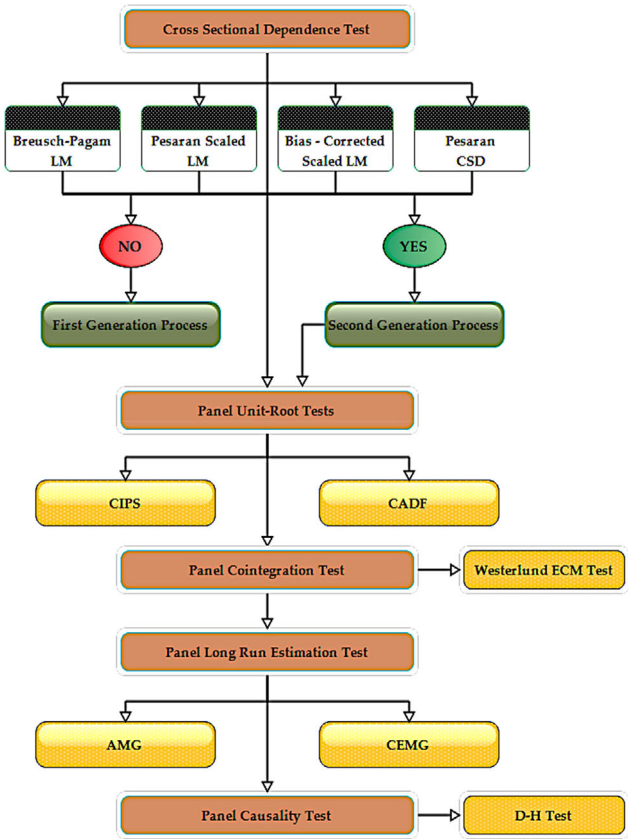

Figure 1. Steps of econometric modelling strategy.
Source: The Author.

independence between cross-sections (Adebayo et al., 2020). It is determined whether there is cross-sectional dependency in this study by calculating the (Pesaran, 2007) test as follows:

$$CSD_{TM} = \left[\frac{TN(N-1)}{2}\right]^{1/2} \overline{\rho}_N \tag{2}$$

where $\overline{\rho}_N$ represents a correlation among the errors. The cross-sectional dependence test's null and alternative hypotheses are as follows:

$$\text{H}_0\text{: } \rho_{ij} = \text{Cov}(\mu_{it}, \mu_{jt}) = 0, \ \ \textit{no} \ \text{cross} - \textit{sectional dependence}$$

$$\text{H}_1\text{: } \rho_{ij} = \text{Cov}(\mu_{it}, \mu_{jt}) \neq 0, \ \ \text{cross} - \textit{sectional dependence}$$

Firstly, CSD across variables and economies in panel data sets must be evaluated. This study used CSD tests to see if CSD exist or not. Table 5 shows all four CSD tests. The CSD test results for cross-sectional variables exhibit statistically significant P-values, indicating that the CSD exists at a 1 percent significance level. According to this, one country′s shock produces a repercussion that can be seen across the entire panel. Therefore, the second-generation tests must be carried out among the variables in the study.

4.2. Panel unit root tests

It was suggested by Rauf et al. (2018) that both parametric and non-parametric approaches be used to verify the right level of cointegration order in panel data (because of the CSD). In the first generation of panel unit root tests CSD effects, heterogeneity, and over-rejection of the null hypothesis (H0) are not taken into account (Choi, 2001). A second-generation panel unit root test, the Cross-sectional Augmented Dickey-Fuller (CADF) and Cross Sectional Augmented CIPS, are used in the study to overcome this issue (Pesaran, 2021). The CADF test is carried out using the following equation:

$$\Delta Y_{it} = \beta_i + a_i y_{i,t-1} + b_i \overline{y}_{t-1} + d_i \Delta \overline{y}_t + \mu_{it} \tag{3}$$

the single lag in the preceding Equation (3), the succeeding Equation (4) is as follows:

$$\Delta Y_{it} = \beta_i + a_i y_{i,t-1} + b_i \overline{y}_{t-1} + \sum_{j=0}^{p} d_{ij} \Delta \overline{y}_{t-j} + \sum_{j=1}^{p} \delta_{ij} \Delta y_{i,t-j} + \mu_{it} \tag{4}$$

where $\overline{y}_{t-j}$ and $\Delta y_{i,t-j}$ show the lagged level mean and each cross-first section′s difference from each unit. The CIPS test statistics are computed after the CADF statistics. The CIPS test statistics are presented below in Equation (5):

Table 5. Cross-sectional dependence test results.

	Breusch-Pagan LM		Pesaran scaled LM		Bias-corrected scaled LM		Pesaran CSD	
Series	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.	Stat.	Prob.
CF	234.9832*	0.000	31.9342*	0.000	30.3427*	0.000	15.7763*	0.000
Y	276.6712*	0.000	36.8645*	0.000	34.0072*	0.000	18.5499*	0.000
FD	270.8123*	0.000	33.6213*	0.000	32.0001*	0.000	16.3312*	0.000
GE	261.9996*	0.000	35.8165*	0.000	38.5423*	0.000	12.4209*	0.000
NREU	298.5610*	0.000	39.6156*	0.000	36.2221*	0.000	14.1396*	0.000

Note: * indicates the significance level at 1%.
Source: Author Estimation.

$$CIPS = N^{-1}\sum_{i=1}^{N} t_i(N, T) \tag{5}$$

It is preferable to use Second-generation panel unit root tests that provide robust coefficients when variables and panels demonstrate heterogeneity and CSD. Second-generation panel unit root (CIPS and CADF) tests that address the CSD problem are depicted in Table 6 and indicated by the rejection of the null hypothesis of CSD for all variables at the 1% level of significance. The CIPS unit root test results reveal the null hypothesis is rejected for all variables and accept alternative. Generally, assessing the presence of unit root among variables in empirical analysis might lead to inaccurate results. Thus, stationarity of variables is established before empirical estimation.

4.3. Panel cointegration test

After data stationarity, this study will utilise a second-generation panel cointegration test (Westerlund, 2007) to check for long-term cointegration between the variables. This method provides more consistent and trustworthy estimates of cointegration than first-generation panel-cointegration approaches. So, according to (Belaïd & Zrelli, 2019). The functional version of the Westerlund cointegration test is expressed as follows:

$$\Delta Y_{it} = \delta' d_t + \eta_i\left(Y_{i,t-1} - \beta_i' x_{i,t-1}\right) + \sum_{j=1}^{p_i}\eta_{ij}\Delta y_{i,t-j} + \sum_{j=0}^{p_i}\gamma_{ij}\Delta x_{i,t-j} + \mu_{it} \tag{6}$$

After confirming the variables' stationarity, the second-generation cointegration test (Westerlund, 2007) bootstrap panel cointegration is used to assess the variables' cointegration for analysing the long-run relationship between variables over the entire sample of 63 emerging and developed economies. Because of these benefits, bootstrapping panel cointegration is increasingly being used by researchers to investigate long-term relationships (Lee & Brahmasrene, 2013; Westerlund, 2007) has developed a novel panel cointegration test that focuses on structural rather than residual dynamics. The results show that these tests have restricted normal distributions and are more consistent. According to Westerlund (2007) and Persyn and Westerlund (2008) the cointegration hypothesis is tested using two separate tests: group mean and panel mean. Westerlund (2007) developed four test statistics based on the Error Correction Model: Ga, Gt, Pa, and Pt. The Gt and Pt are calculated using the error correction model's

Table 6. Panel unit root test results.

	CIPS		CADF	
Variable	I(0)	I(1)	I(0)	I(1)
CF	−2.186	−5.165**	−1.951	−4.253*
Y	−1.510	−3.260*	−1.352*	−3.001*
FD	−2.195	−3.995*	−2.081*	−3.082*
GEU	−2.147	−5.033**	−2.223	−4.102*
NREU	−2.032	−4.658*	−2.645*	−3.919**

Note: *, ** & *** indicates the significance level at 1%, 5% and 10% respectively.
Source: Author Estimation.

Table 7. Panel cointegration test results.

Statistics	G_t	Ga	P_t	Pa
Values	−3.892*	−10.443**	−9.310***	−10.903**
Z-values	−3.855	1.931	−1.654	−0.152
P-values	0.070	0.006	0.073	0.101
Robust P-values	0.005	0.000	0.000	0.000

Note: *, **, *** indicate the significance level at 1%, 5% and 10% respectively.
Source: Author Estimation.

standard error parameters. Ga and Pa are based on Newey and West (1994) standard errors corrected for autocorrelations and heteroskedasticity. The findings are offered in two formats, the outcome rejects the null hypothesis and accepts the alternative. The second-generation test confirms the long-term cointegration of the variables. As shown in Table 7, all variables strongly and significantly support the long-run cointegration process at the 1% level in both tests (intercept and intercept & trend).

4.4. Long-run estimation test

When an econometric model is subjected to both cross-sectional dependency and economy-specific heterogeneity, panel estimators may yield inconsistent and biased results, leading to inaccurate interpretations (Wang & Dong, 2019). Eberhardt and Bond (2009) presented an augmented mean group (AMG) technique to address these difficulties. AMG regression enables policymakers in achieving more precise policy objectives since it provides results that are particular to the economy. The two-phase AMG process is represented by the following two Equations (7) and (8):

$$AMG\ regression\ (first-phase):\ \Delta \mathrm{Y}_{\mathrm{it}} = \alpha_{\mathrm{i}} + \beta_{\mathrm{i}}\Delta \mathrm{x}_{\mathrm{it}} + \gamma_{\mathrm{i}} g_{\mathrm{t}} + \sum_{\mathrm{t}=2}^{\mathrm{T}} \eta_{\mathrm{i}}\Delta \mathrm{R}_{\mathrm{t}} + \mu_{\mathrm{it}} \tag{7}$$

$$\text{AMG regression (second} - \text{phase):}\ \ \hat{\beta}_{AMG} = N^{-1}\sum_{i=1}^{N}\hat{\beta}_i \tag{8}$$

Correlation and heterogeneity among individual cross sections were also addressed using the CCEMG approach in this study. Non-stationarity, heterogeneous slopes, and CSD are all well-suited for this test, which also deals with unobservable elements (Pesaran, 2006; Usman, Makhdum, et al., 2021). This test's functional appearance is shown in the following Equation (9):

Table 8. Panel long-run estimation test results.

	AMG		CCEMG	
Variables	Coeff.	Prob.	Coeff.	Prob.
Y	0.7825*	0.000	0.6991*	0.000
FD	−0.5200**	0.031	−0.5210*	0.006
GEU	−0.4213**	0.0317	0.3218***	0.062
NREU	0.5688*	0.001	0.5912*	0.000
Constant	−9.6201*	0.000	−4.7888	0.320
RMSE	0.0191		0.0210	

Note: *, **, *** indicate the significance level at 1%, 5% and 10% respectively and RMSE indicates Root Mean Squared Error.
Source: Author Estimation.

$$\text{CCEMG regression}: \tilde{\Pi}_{MG} = 2\tilde{\Pi}_{MG} - \frac{1}{2}\left(\hat{\Pi}^{a}_{MG} + \hat{\Pi}^{b}_{MG}\right) \tag{9}$$

where $\hat{\Pi}^{a}_{MG}$ represents the first half (t = 1, 2, …, (T/2)) of CCEMG in time dimension and $\hat{\Pi}^{b}_{MG}$ represents the second half (t = (T/2) +1, (T/2) +2, (T/2) +3, …, T) of CCEMG, respectively.

According to these findings, economic development and the use of nonrenewable energy sources have a major impact on our planet′s ecological imprint as shown in Table 8. On the other hand, financial development and the extensive use of green energy are key factors in raising the global ecological footprint over the long term in both emerging and advanced economies. According to AMG findings, a 1% influence in financial development will create a 0.5200 percent decrease in the carbon footprint. Statistically, the developed financial industry contributes greatly to these countries′ environmental sustainability. To prevent and regulate carbon footprint, these economies′ financial infrastructures and industrial units use current and eco-friendly technologies (Tamazian et al., 2009).

4.5. Panel causality test

The Dumitrescu-Hurlin test (DH) was created for heterogeneous panel data models. Prior panel causality tests did not take into consideration cross-section dependency; the DH test does; and it works well in panels with imbalances (Dumitrescu & Hurlin, 2012). Dumitrescu and Hurlin came up with the linear model as shown in Equation (10).

$$Y_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_i^{(k)} Y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} X_{i,t-k} + \varepsilon_{i,t} \tag{10}$$

where $\beta_i = \left(\beta_i^{(1)}, \beta_i^{(2)}, \ldots, \beta_i^{(K)}\right), \alpha_i =$ individual fixed effects, $\gamma_i^{(k)} =$ Lag parameters, K = lag length and $\beta_i^{(k)} =$ slope parameters. $\gamma_i^{(k)}$ and $\beta_i^{(k)}$ show the units′ differences.

$$H_0: \beta_i = 0 \text{ for } \forall i, \forall i = 1, \ldots\ldots, N$$

$$H_1: \left\{ \begin{array}{l} \beta_i = 0 \text{ for all } i = 1, 2, 3\ldots\ldots\ldots\ldots, N_1 \\ \beta_i \neq 0 \text{ for all } i = N_1 + 1, \; N_1 + 2., N \end{array} \right\}$$

Table 9. Panel causality test results.

Null Hypothesis (Ho)	W-Stats.	Zbar-Stats.	*p*-value	Remarks
CF $\nLeftrightarrow$ Y	4.8771*	4.1002	0.0010	Y $\leftrightarrow\leftrightarrow$ EF
Y $\nLeftrightarrow$ CF	6.8951*	5.9788	0.0000	
FD $\nLeftrightarrow$ CF	7.8831*	6.5538	0.0000	FD $\leftrightarrow$ CF
CF $\nLeftrightarrow$ FD	5.6001*	4.2921	0.0000	
NRE $\nLeftrightarrow$ CF	5.0052*	3.9971	0.0100	NRE $\rightarrow$ CF
CF$\nLeftrightarrow$ NRE	3.0301*	1.0052	0.0001	
GE $\nLeftrightarrow$ CF	4.8769*	3.9520	0.0024	GE $\leftrightarrow$ CF
CF $\nLeftrightarrow$ GE	4.3210*	2.0451	0.0005	

Note: * specify the significant at 1%. $\rightarrow$ symbolised a one-way causality ssociation, and $\leftrightarrow$ denotes to two-way causality association, and $\nLeftrightarrow$ symbolised as 'does not homogeneously cause'.
Source: Author Estimation.

Using Wald statistics to evaluate the null and alternative hypotheses for a specific individual is a reliable method. The following Equation (11) represents the results of the panel test:

$$W_{N.T}^{HNC} = N^{-1} \sum_{i=1}^{N} W_{i,T} \tag{11}$$

where Dumitrescu and Hurlin (2012) advocated using the z-test statistic as stated in Equation (12) for greater time dimensions as contrasted to cross-sections (T > N).

$$\mathrm{Z}_{\mathrm{N,T}}^{\mathrm{HNC}} = \sqrt{\frac{\mathrm{N}}{2\mathrm{K}}}\left(\mathrm{W}_{\mathrm{N,T}}^{\mathrm{HNC}}\right) - K \tag{12}$$

To conclude, we utilised the D-H non-causality test to see if there was a link between the variables we were investigating. Table 9 and Figure 2 indicated that increasing the use of non-renewable energy leads to carbon footprint, suggesting a bidirectional causality between economic growth, financial development, and green energy. On the other hand, there appears to be a unidirectional causality between non-renewable energy use and carbon footprint. Prior research supports this notion, and it is important to note that most emerging or high carbon emitting economies rely on conventional energy sources like oil, gas and coal. However, the biocapacity of the environment is being enhanced by the use of green energy sources.

5. Conclusion and policy recommendation

This study examines the influence of green energy and non-renewable energy consumption on environmental degradation from 1990 to 2020 utilising a multivariate framework and panel data sets for 63 developing economies. This study's findings represent a ground-breaking attempt to examine the relationship between economic growth, carbon footprint, and green energy and non-renewable energy consumption across a large panel of countries. The findings of this study reinforce the widely held belief in the literature that non-renewable energy consumption has a positive and significant effect on overall carbon footprint, whereas green energy consumption has a negative and significant impact on the global ecosystem. In short, non-renewable

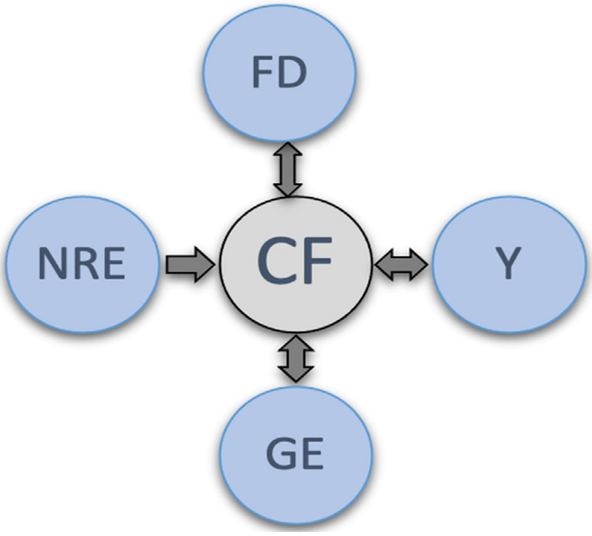

Figure 2. Flow of causality relationship (Carbon Footprint Function).
Source: The Author.

energy is likely contributing to worldwide carbon footprint, whereas green energy contributes to mitigating and regulating worldwide carbon footprint, as this study also illustrates. Conversely, financial development has a significant unfavourable effect on carbon footprint. Renewable energy sources should be promoted in this study, which found that green and renewable electrical infrastructures, as well as eco-friendly projects, should be given more attention. This will help the economies studied, as well as their energy security and pollution (Usman, Khalid, et al., 2021; Usman, Yaseen, et al., 2021). Cleaner energy and energy-efficient equipment are long-term projects that require financial support. In this case, well-developed markets and institutions can help these projects move forward. This will help the environment because it will cut down on the amount of energy that is used (Nasreen et al., 2017; Usman et al., 2020).

On the basis of these findings, it is proposed that governments of emerging and developed carbon emitting economies increase international and national strategies to address carbon footprint while also reducing non-renewable energy usage. Additionally, they must promote green energy usage across all sectors. Additionally, the government invests more in advanced technology to create a more effective and efficient energy producing system, which contributes to the reduction of carbon footprint. Furthermore, these countries must have an adequate and suitable alternative to expand their dependence on non-renewable energy sources that are generally not polluting to the environment. Similarly, government must take significant action, such as reducing non-renewable energy consumption and increasing the ratio of green energy use. Additionally, the government may initiate a micro-finance proposal for hydrological and biomass generation. As a result of this, the government will benefit and sustained growth will be possible. As a result, energy policies in these countries should prioritise environmental growth, economic growth, and the use of green energy.

Researchers, on the other hand, are given particular attention so that they can analyse the results of these inventions in depth. Extending the data chronology and added more variables allows researchers to perform a more comprehensive empirical investigation on the same variables. The dynamic nexus of the environmental Kuznets curve (EKC) and the pollution heaven, halo hypothesis can also be investigated in future research. In addition, future studies may include variables that represent cultural activities, such as social, institutional, and political indicators, which may influence the financial and energy-led growth hypothesis and their impact on environmental quality. These variables have different preferences in specific countries. In addition, the findings of this study should inspire further research on the same indicators (and other indicators) for emerging and developed economies individually.

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ORCID

Najia Saqib http://orcid.org/0000-0003-2795-2012

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