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Non-Linear Effects of Green Finance on CO_2 Emissions: Fresh Evidence from Developing Countries in BRI Region

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Abstract **Original Research Article**

Economic growth and environmental sustainability are the main challenges in reducing CO_2 emissions globally. Thus, empirical steps are needed to achieve the realization of environmental sustainability due to the rapid dynamics of the economy on the environment. Economic activity realized through the effect of green finance becomes a non-linear investigation of CO_2 emissions. The target research area is developing countries in the Belt and Road Initiative (BRI) region selected during the period 1990-2023. Based on the STIRPAT framework, we apply the regression method with two-way fixed effects and PFMOLS models, applying DK because the panel data is also complemented by cross-sectional (CD). Based on the empirical analysis that has been conducted, there is a significant relationship from green finance variables to CO_2 emissions and a long-term equilibrium relationship between all explanatory variables and CO_2 emissions. All findings are evidence of an inverted U-shaped relationship. The findings have implications for policy implementation in economic development to support the use of renewable energy by introducing the adoption and innovation of environmentally friendly technologies. Income group countries face major challenges in transitioning to renewable energy sources.

Keywords: Green finance; CO_2 emissions; global climate; green economics; environmental preservation.

INTRODUCTION

Climate change, which contributes to a gradual increase in temperature, is caused by global warming from industrial growth activities. It is a global challenge that climate change is on the rise, although its impacts are felt most severely in developing countries. Carbon pollution is a component of the atmosphere that depletes most of the ozone layer. The important role of the ozone layer is to naturally prevent the negative effects of greenhouse gases. However, ongoing depletion conditions allow sunlight to penetrate and damage existing ecosystems (Nezahat and Mehmet, 2019; Jean *et al*., 2021).

Developing countries in general are facing a serious problem of increasing greenhouse gas emissions that can be addressed through climate-friendly projects with green investments or better known as green finance. It is important to realize the goal of carbon neutrality by 2060 (El Khoury *et al*., 2024). In support of this great endeavour, green finance needs to contribute in an important role to low-carbon development. Green finance is within the scope of economic activities that aim to support environmental sustainability, climate change reduction solutions, and the promotion of effective and efficient resource management (Azer *et al*., 2024; Gul & Hussain, 2024). Of course, in this case it needs to involve the provision of financial services to run activities such as project investment to the governance of risk management.

Green finance is a financial medium that strongly supports and provides climate protection from environmental changes due to pollution. Investment projects with the adoption and innovation of environmentally friendly technologies have been in demand and increasing since the last decade and are predicted to reach $750 billion by 2030, but their application in developing countries has a high gap (Chen and Zhao, 2021). Efforts to reduce greenhouse gas emissions require creative and innovative methods, especially in countries that still use fossil fuels. Countries globally are starting to transform towards an economy that is sustainable and has a climate-proof effect. So that financial institutions that can provide it by implementing green finance because of this transition require a large cost allocation to reduce global climate change and can help for developing countries in achieving it, especially in the Belt and Road Initiative (BRI) group (Clapp and Pillay, 2017).

The application of green finance in addressing climate change in developing countries generally does not meet the minimum size requirements by underwriters in the green finance market (Sartzetakis, 2021; Banga, 2019). On the other hand, developing countries account for 63% of the world's total CO_2 emissions. The empirical fact of green finance is the link between economy and environmental sustainability, therefore developing countries can optimize the role of green finance to minimize gas emissions caused by environmental pollution. So, it is important to conduct further research for developing countries in using green finance to reduce CO_2 emissions and whether green finance can also help them.

This study focuses only on BRICS countries for the following reasons: (i) In contrast to many developing countries, the BRICS have experienced a rapid transition from ecological surplus to ecological deficit, largely due to the region's tremendous growth over the past decade. The BRICS countries contribute twenty-one percent to global GDP and account for forty-one percent of the world's population with foreign exchange reserves of four trillion US$ (Ibrahim *et al*., 2023; Udeagha & Muchapondwa, 2023). They control a large part of the world economy. Economic growth also causes the region to consume more than forty percent of global energy, making it a major contributor to global CO_2 emissions (Danish and Wang, 2018).

This study therefore contributes related to environmental sustainability. This is because to the best of our knowledge, this study is the first to investigate the non-linear effects of green finance on CO_2 emissions in developing countries (low and middle income) for the period 1990-2023. In addition, we examine the EKC hypothesis using varying income levels of country groups, which may provide findings and policy implications for the environment. Some of the considerations that have been presented motivate us to examine the dynamic impact of green finance in reducing CO_2 emissions in developing countries located in the BRI Region.

The implications of this research study are for policy makers and the government. In realizing environmental sustainability by implementing policies that can encourage the application of green finance. This is a step in reducing the gap in investment activities in environmentally friendly projects (Bhutta *et al*., 2022). After the explanation for the introduction, the next section is a literature review that will review previous research on the topic under study, then the research methodology is explained in detail, the results and discussion will be interpreted based on previous research and critical analysis. Finally, the conclusion will summarize the whole, and directions for future research.

METHODOLOGY

Theoretical framework

To investigate the impact of green finance on CO_2 emissions, we used STIRPAT (Stokastic Impact through Regression on Population, Prosperity, and Technology) developed by Dietz and Rosa (1997). The basic model of STIRPAT can be expressed in an exponential form as follows:

$$\mathrm{I_{it}} = \alpha \mathrm{P_{it}^{\beta} A_{it}^{\gamma} T_{it}^{\lambda}} \mu \text{ ……………………………… (1)}$$

Where I indicate the environmental impact, P represents the population of a country, and A indicates prosperity, T indicates technology and μ is the term error of the STIRPAT model that implies the stochastic process of the stochastic process. For empirical analysis, the model can be transformed into a log-linear transformation as follows:

$$\mathrm{lnI_{it}} = \alpha_0 + \alpha_1 \mathrm{lnP_{it}} + \alpha_2 \mathrm{lnA_{it}} + \alpha_3 \mathrm{lnT_{it}} + \mu_{\mathrm{it}} \text{ ….. (2)}$$

The STIRPAT model has also been further refined by Donglan *et al*., (2010). In addition, some researchers have developed this model by adding additional factors (Ma *et al*., 2017; Niu & Lekse, 2018).

Model Specification

Since our basic model covers the impact of green finance on CO_2 emissions, we have modified and expanded the STIRPAT model in the following form Our expanded and modified STRIPAT model includes green finance variables as well as additional factors such as financial development, natural resources, and trade openness, which have been neglected by previous researchers.

$$\mathrm{lnEPCO}_{2_{it}} = \propto_0 + \propto_1 \mathrm{lnEI_{it}} + \propto_2 \mathrm{lnGF_{it}} + \propto_3 \mathrm{lnEG_{it}} + \propto_4 \mathrm{lnNRR} + \propto_5 \mathrm{lnFD_{it}} + \propto_6 \mathrm{lnTO_{it}} + \mu_{\mathrm{it}} \text{ ……….. (3)}$$

Here CO_2 emissions measure environmental impact, EI shows energy intensity which is a proxy for technology (T), Economic Growth per capita represents prosperity (A). For Economic Growth (EG), Green Finance (GF), Natural Resource Rent (NRR), Trade Openness (TO), and Financial Development (FD) are additional control variables. Lower energy intensity (EI) signifies greater use of green technologies, greater reliance on cleaner energy, and less consumption of primary energy sources (fossil fuel consumption). Therefore, previous studies have used EI as a proxy for the effect of technology on the environment (Nezahat and Mehmet, 2019; Jean *et al*., 2021; Daniel *et al*., 2022).

Previous studies by Oluyomi *et al*., (2020) and Malika and Samir (2023), have also successfully applied a non-linear version of the non-linear STIRPAT model to test the EKC hypothesis. Therefore, we include a squared EG term in Equation 4 to test the bell-shaped relationship between economic growth and environmental degradation.

$$\ln EPCO_{2_{it}} = \propto_0 + \propto_1 \ln EI_{it} + \propto_2 \ln EG_{it} + \propto_3 \ln EG_{it}^2 + \propto_4 \ln GF_{it} + \propto_5 \ln NRR_{it} + \propto_6 \ln FD_{it} + \propto_7 \ln TO_{it} + \mu_{it} \quad \ldots\ldots (4)$$

Equation 4 tests the EKC hypothesis by including the squared term of EG. We expect an inverted U-shaped relationship between EG and CO_2 emissions if the coefficient of EG is positive (>0) and the coefficient of its squared term is negative-lower than zero (<0). Coupled with the EKC hypothesis, the non-linear relationship between energy intensity and CO_2 has been examined in equation 5 to test whether there has been a structural shift in the energy structure.

$$\ln EPCO_{2_{it}} = \propto_0 + \propto_1 \ln EI_{it} + \propto_2 \ln EG_{it} + \propto_3 \ln GF_{it} + \propto_4 \ln GF_{it}^2 + \propto_5 \ln NRR_{it} + \propto_6 \ln FD_{it} + \propto_7 \ln TO_{it} + \mu_{it} \quad \ldots\ldots (5)$$

We have added the squared term of green finance (GF2) to equation 6 to prove the green finance theory, which states that green finance is considered as the main driver of environmental protection and sustainable development. One of the main roles in creating environmental sustainability is through the implementation of the green economy, which also includes budgets used specifically as environmental carrying capacity (Lee, 2020; Muhammad *et al.*, 2021; Zhijuan *et al.*, 2022; Julie, 2023). The expected result is a negative coefficient of GF so that the green finance theory can be accepted ($\alpha 6 < 0$).

Data sources and its definitions

We have collected annual data for the period 1990-2023 from the World Development Indicators (WDI) database of the World Bank. Carbon emission (metric tons per capita) is the dependent variable of our study. The independent variables include Green Finance (GF), Energy Intensity (EI), Economic Growth (EG), Natural Resources Rents (NRR), Trade Openness (TO), Financial Development (FD). Based on the availability of consistent data for all variables, this research study uses panel data from 23 developing countries in the BRI region.

Table 1: Description of Variables

Variables	**Abbreviation**	**Measurement scale**	**Unit**	**Source**
Environmental Pollution-Carbon Dioxide Emissions ($EPCO_2$)	$EPCO_2$	CO_2 emissions that from people's economic activities such as fossil fuel combustion fossil fuels, cement production, and gas flaring.	Metric tons per capita	WDI
Green Finance (GF)	GF	Indikator of the performance of environmental management nationally related to environmental protection and management.	Percent	IRENA
Economic Growth/ GDP growth (EG)	EG	Avalue added of goods and services produced by various production units in the territory of a country in a certain period of time	% of annual	WDI
Total natural resources rents (NRR)	NRR	The economic rent of a natural resource equals the value of capital services rendered by the natural resources	% of GDP	WDI
Energy Intensity	EI	Energy use kg of oil equivalent per capita scaled by GDP per capita	% of GDP	WDI
Trade Openness (TO)	TO	The outward or inward orientation of a given country's economy.	% of GDP	WDI
Financial Development (FD)	FD	Measures the level of development of a country's financial sector including the development of financial markets and institutions	Percent	WDI

This study aims to examine the effect of green finance on CO_2 emissions for BRI member countries. The data collection period starts from 1990 and ends in 2023 due to the availability of consistent data on all variables. In Table 1. the operational definition of each variable has been given. In addition, all data is sourced from WDI represents World Development Indicator (https://data.worldbank.org/) while IRENA denotes International Renewable Energy Agency (https://www.irena.org/). Before applying panel unit root test and estimation procedure Before applying panel unit root test and estimation procedure, all variables have been transformed into logarithm form to reduce the possibility of econometric problems such as autocorrelation, heteroscedasticity, dimensionality of variables and improve the reliability of estimation (Hossain, 2011; Shahbaz *et al.*, 2012; Wang *et al.*, 2017).

Econometric techniques

Slope heterogeneity and cross-section dependence of the panel.

Cross-sectional presence can make empirical results biased, false, and misleading. Previous research generally used Breusch and Pagan (1980) to test cross-sectional dependencies, but this method has some econometric problems. Therefore, Pesaran (2004) introduced stronger tests such as Cross-sectional Dependency (CD) and Langrage Multiplier (LM) to address the shortcomings of previous methods. The following equation presents the CD and LM tests.

$$\mathrm{CD} = \sqrt{\left(\frac{2\mathrm{T}}{\mathrm{N(N-1)}}\right)}\left(\sum_{\mathrm{i=1}}^{\mathrm{N-1}}\sum_{\mathrm{j=i+1}}^{\mathrm{N}}\hat{\rho}_{\mathrm{ij}}\right): \mathrm{N}(0,1) \ \ldots\ldots\ldots (6)$$

$$\mathrm{CD} = \sqrt{\left(\frac{2\mathrm{T}}{\mathrm{N(N-1)}}\right)}\left(\sum_{\mathrm{i=1}}^{\mathrm{N-1}}\sum_{\mathrm{j=i+1}}^{\mathrm{N}}\hat{\rho}_{\mathrm{ij}}\right)\frac{(T-k)\hat{\rho}_{ij}^2-E(t-k)\hat{\rho}_{ij}^2}{Var(T-k)\hat{\rho}_{ij}^2} \ \ldots\ldots (7)$$

The results of the cross-sectional dependency test are given in the table. Almost all show very significant values at a significance rate of 1 percent, which clearly indicates that our data has a cross-sectional dependence problem in terms of green finance and CO_2 emissions.

Panel Unit Root Tests

Because our data has cross-sectional dependency problems, the unit root panel of the first generation of tests is inappropriate. Therefore, we have implemented the second generation of test root units proposed by Pesaran (2007) that consider cross-sectional dependence. The basic equation of each variable can be expressed as follows:

$$\mathrm{y_{it}} = (1-\phi)\mu_{\mathrm{i}} + \phi_{\mathrm{i}}\mathrm{y_{i,t-1}} + \mu_{\mathrm{it}}, \mathrm{i} = 1,\ldots\ldots,\mathrm{N}; \mathrm{t} = 1,\ldots\ldots,\mathrm{T} \ \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where error term μit can be stated as the function of an unobserved common factor ft.

$$\mu_{\mathrm{it}} = \gamma_i f_t + \varepsilon_{it} \ \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where εit indicates an idiosyncratic country-specific factor, so equation (9) can be transformed into the following equation:

$$\Delta \mathrm{y_{it}} = \alpha_i + \beta_i y_{i,t-1} + \gamma_i f_t + \varepsilon_{it} \ \ldots\ldots\ldots\ldots (10)$$

Hence the Cross-sectional Augmented Dickey-Fuller (CADF) panel unit root test can be expressed as follows:

$$\Delta \mathrm{y_{it}} = \alpha_i + b_i y_{i,t-1} + d_i \Delta\hat{y}_t + \varepsilon_{it} \ \ldots\ldots\ldots\ldots (11)$$

In equation (12), the null hypothesis of non-stationary is based on the OLS estimator to determine the order of integration relating to each series. Moreover, the t-statistic of CADF can be mathematically stated in equation.

$$t_t(\mathrm{N,T}) = \frac{\Delta y_i^i \bar{M}_w y_{i,-1}}{\hat{\sigma}_i\left(y_i^i \bar{M}_w y_{i,-1}\right)^{1/2}} \ \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

The more specific case of the above-mentioned generalized form is stated in the following equation but requires simulation for the determination of critical values of Cross-sectional Im Pesaran Statistic (CIPS).

$$\mathrm{CIPS(N,T)} = \bar{\mathrm{t}} = \mathrm{N}^{-1}\sum_{\mathrm{i=1}}^{\mathrm{N}}\mathrm{t_i}\ (\mathrm{N,T}) \ \ldots\ldots\ldots\ldots (13)$$

Panel Cointegration Tests

After examining the problem of cross-sectional dependency and unit root, the next step is to determine the co-integration relationship between series by applying the latest techniques from Westerlund (2007), which is a cointegration test based on error correction that allows cross-sectional dependence problems. One of the outstanding features of this method is that it is based on structural dynamics, not residual, and therefore not affected by unobserved factors (Tufail *et al.*, 2021). The econometric model can be expressed as follows:

$$\Delta y_{it} = \delta_i' d_t + \alpha_i y_{it-1} + \lambda' X_{it-1} + \sum_{j=1}^{pi}\alpha_{ij}\Delta v_{it-j} + \sum_{j=0}^{pi}\lambda_{ij}\Delta x_{it-j} + e_{it} \ \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

In this equation, αi determines the speed of adjustment at which short-run fluctuations in the model are restored to long-run equilibrium. Westerlund (2007) has developed four tests to determine co-integration. The first two tests are called group mean statistics and can be stated as follows:

$$\mathrm{G}_t = \frac{1}{N}\sum_{i=1}^{N}\frac{\hat{\alpha}_i}{SE(\hat{\alpha}_i)} \ \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

$$\mathrm{G}_a = \frac{1}{N}\sum_{i=1}^{N}\frac{T\hat{\alpha}_i}{\hat{\alpha}_i(1)} \ \ldots\ldots\ldots\ldots\ldots\ldots (16)$$

If these two tests are statistically significant, we can reject the null hypothesis that there is a cointegrating relation among variables in the whole panel. The remaining two-panel statistics examine the existence of cointegrating relation in at least one country.

Estimating Long-Run Elasticities

Panel co-integration testing only builds co-integration relationships between variables. However, the aim of this research is not only to determine the long-term impact of green finance on environmental degradation, but also to investigate its non-linear impact, which cannot be done by co-integration methods. For this purpose, we have implemented an advanced test of Dynamic Seemingly Unrelated Regression (DSUR) proposed by Nasreen *et al.*, (2018). This technique is very flexible and not only addresses the endogeneity problem but also considers the heterogeneity of samples and cross-sectional dependencies that are not possible with the traditional method of ordinary smallest square (Haseeb *et al.*, 2019). Following studies from Danish *et al.*, (2019), we also apply the method of dynamic smallest quadrant (DOLS), and the smallest modified square regression square, as additional strength tests, which consider cross-sectional dependency and produce a strong standard error (Baloch *et al.*, 2019).

Country-Specific Analysis using Augmented Mean Group (AMG)

Following the Danish *et al.*, (2019) study, we also applied an AMG developed by Eberhardt and Teal (2010) to analyse the effects of the green finance path on environmental degradation for each country. AMG is An Autoregressive Distributive Lag (ARDL) panel model that is better than the first-generation ARDL panel technique because it allows cross-sectional dependency and sampling heterogeneity at the same time. This method combines a Common Dynamic Effect (CDE) into its two-stage process estimate for addressing problem problems of intersection dependencies. Furthermore, this method has no precondition for non-stationarity and co-integration between variables (Danish *et al*., 2019). Based on the main features of this AMG, the method is best suited to investigating the impact of green finance at the state level on environmental degradation.

RESULTS AND DISCUSSION

This section is divided into several parts for systematic discussion. First, we discuss the results of the panel cointegration test to establish the long-run relationship between CO2 emissions, green finance and other control variables. Second, this study examines the non-linear effects of Green Finance, Energy Intensity, Economic Growth, Natural Resource Rent, Trade Openness, and Financial Development on carbon emissions. Finally, we provide empirical results from panel causality tests to identify unidirectional or bidirectional relationships between the variables considered.

Result of Slope homogeneity test and cross-section dependence of the panel

The study checks the stationary condition of the concerned variables after determining. The presence of CSD and slope heterogeneity.

Table 2: CSD and Slope homogeneity test

Variables	**CSD Test**	
	F- Value	**P-Value**
EI	25.231***	0.000
GF	27.517***	0.000
EG	24.698***	0.000
NRR	22.615***	0.000
FD	32.715***	0.000
TO	31.734***	0.000
Slope homogeneity test		
Test	Value	P-Value
Δ	8.212***	0.000
Δ Adjusted	10.427***	0.000

Note: ***, ** and * shows 1%, 5% and 10% level of significance

Source: Authors' computation

The slope coefficient homogeneity and cross-sectional dependence test results from Pesaran (2007) are presented in Table 2. Based on our empirical results, we reject the null hypothesis of slope coefficient homogeneity and accept the alternative hypothesis indicating the existence of diversity and differences between cross-sectional units, in practical assessment terms, the findings for EI, GF, EG, NRR, FD and TO indicate the existence of slope coefficient diversity at various significance levels.

Results of unit root tests

Panel unit-root results have been reported in Table 3. All variables contain unit root at level and become stationary at first difference as stated by values of CADF and CIPS.

Table 3: Panel Unit Root Tests

Variabel	**CADF**		**CIPS**	
	C	**C+T**	**C**	**C+T**
lnEI	1.913**	2.444**	2.245	2.274
lnGF	1.457	2.678	1.823**	2.339*
lnEG	2.170	2.113	1.140	2.211*
lnNRR	2.001	1.781	1.201	1.882
lnFD	-1.662***	-2.338***	-1.291***	-2.229***
lnTO	-1.127***	-2.618**	-2.512**	-2.761***
$\ln EPCO_2$	-2.741	-2.351	-2.281	-2.948***
ΔlnEI	-5.324***	-4.352***	-4.532**	-3.735***
ΔlnGF	-5.321**	-3.567**	-4.531***	-4.735***
ΔlnEG	-5.329**	-4.735**	-4.522***	-4.775***
ΔlnNRR	-5.356***	-4.745***	-3.532***	-3.835***
ΔlnFD	-4.379**	-5.735**	-5.532***	-3.875***
ΔlnTO	-3.396***	-4.723***	-3.832***	-4.235***
$\Delta \ln EPCO_2$	-3.662***	-3.485***	-3.681***	-5.615***
Critical Values at:				
1% level of significance	-2.29	-2.62	-2.79	-2.31
5% level of significance	-2.17	-2.73	-2.89	-2.98
10% level of significance	-2.62	-2.11	-2.56	-2.71

Note: C and C+T indicates constant and constant and trend respectively.

Source: Authors' computation

As shown in Table 3 as well, all variables have increasing trend and seem to exhibit the same order of integration, which is also confirmed by the panel unit results of LLC and IPS. If the variables are cointegrated at first difference, then panel cointegration tests such as Pedroni, Kao and Fisher can be applied to establish long-term association between variables.

Panel Cointegration Tests

Before examining the long-run non-linear effects of green finance on carbon emissions, this study determines the long-run equilibrium of the relationship between the variables under consideration. The results of Kao's panel cointegration test are reported in reported in Table 4. for income groups. The ADF test values are significant at the 1 percent significance level for selected countries, indicating a long run cointegration relationship between CO_2 emissions, economic growth, green finance, energy intensity, trade openness, financial development and natural resources. The ADF test is also significant at the 1 percent critical value for the low income and lower middle-income groups. These results indicate the existence of long-run cointegration among the variables considered for the sub-samples.

Table 4: Kao Panel Cointegration Test

Lower- & Lower-Middle Income Group		
	t-Statistic	**Prob.**
ADF	-5.6681***	(0.0000)
Residual variance	0.0178	
HAC variance	0.0112	

Note: *** represents 1% level of significance.

Source: Author’s computation

Testing the EKC Hypothesis

The next step is to analyse the non-linear impact of the Economic Growth (EG) variable along with its quadratic on CO_2 emissions. In addition, it also tests the explanatory variables including energy intensity (EI), Green Finance (GF), Natural Resources Rent (NRR), Financial Development (FD), Trade Openness (TO) on CO_2 emissions. This EKC hypothesis testing uses three panel regression models, namely two-way fixed effects, FMOLS and DK regression. Table 5 reports the results of the EG and its explanatory variables.

Based on Table 5, the EG variable has a positive and significant impact on CO_2 emissions. This can be interpreted that a 1 percent increase in EG can have an impact of 0.17-0.38 percent increase in carbon emissions. In line with the research of Oluyomi *et al*., (2020) which Economic growth has a significant positive impact on CO_2 emissions, as determined by the regression analysis of the study. This finding suggests a cause-and-effect relationship between economic growth and CO_2 emissions, highlighting the need for sustainable practices to reduce environmental effects. In contrast, the squared term of EG was found to have a negative and significant effect on CO_2 emissions at the 1 percent significance level. It can be interpreted that for the squared variable EG, an increase of 1 percent can lead to about 0.07-0.08 percent decrease in carbon emissions. The results found an inverted U-shape of the effect of the EG variable on CO_2 emissions, which further confirmed the EKC hypothesis. The results of the study are in line with Malika and Samir, (2023), Economic growth has an impact on CO_2 emissions in Algeria, with energy consumption increasing emissions. The relationship is heterogeneous, showing an inverted U-shaped curve, indicating that the effect varies significantly between developed and developing countries, with developed countries experiencing a greater increase in emissions.

Table 5: Testing EKC Hypothesis for Selected Countries

Variables	**2W-FE-1**	**2W-FE-2**	**PFMOLS-1**	**PFMOLS-2**	**DK-1**	**DK-2**
EI	0.6814***	0.6822***	0.7627***	0.7926***	0.6876***	0.6885***
	(0.0160)	(0.0187)	(0.0230)	(0.0120)	(0.0162)	(0.0121)
EG	0.3820***	0.3684***	0.1750***	0.1978***	0.2474**	0.2408**
	(0.0636)	(0.0631)	(0.0254)	(0.0212)	(0.1313)	(0.0265)
EG^2	-0.0753***	-0.0731***	-0.0875***	-0.0850***	-0.0831***	-0.0801***
	(0.0057)	(0.0058)	(0.0026)	(0.0022)	(0.0120)	(0.0061)
GF	-1.2550***	1.2122***	1.4437***	-2.4116***	2.3478***	2.4045***
	(0.1132)	(0.0102)	(0.0521)	(0.0782)	(0.2513)	(0.3068)
NRR	1.0151***	2.0145 ***	1.5575***	1.9805***	2.0054 ***	2.0056***
	(0.0085)	(0.0101)	(0.0113)	(0.0082)	(0.0181)	(0.0218)
FD	0.0163***	0.0154***	0.1085***	0.8100***	0.0181*	0.0073*
	(0.0043)	(0.0047)	(0.0018)	(0.0015)	(0.0035)	(0.0036)

Variables	2W-FE-1	2W-FE-2	PFMOLS-1	PFMOLS-2	DK-1	DK-2
TO	0.0253***	0.0133***	0.1075***	0.3221***	0.0172*	0.0062*
	(0.0022)	(0.0035)	(0.0012)	(0.0116)	(0.0029)	(0.0018)
B0	-12.0530***	-13.2764***	n/a	n/a	-12.6423***	-13.6225***
	(0.3206)	(0.3327)	---	---	(0.7852)	(0.7446)
Country Effect	Yes	Yes	---	---	Yes	Yes
Year Effect	Yes	Yes	---	---	---	---
Adj. R-square	0.8254	0.8044	0.8824	0.9953	0.7832	0.7192
F-stat	125.10***	114.34***	---	---	2163.82***	1812.34***
P-value (F-stat)	(0.0000)	(0.0000)	---	---	(0.0000)	(0.0000)
Hausman value	62.04***	56.440***	---	---	---	---

Note: ***, **, * indicate 1%, 5% and 10% significance levels, respectively; 2W-FE, two-way fixed effect; PFMOLS, panel fully modified OLS; DK, Driscoll Kraay regression; standard errors are reported in parentheses ().

Source: Author's computation

Based on these results, it can be interpreted that the variable EG at the beginning causes an increase in CO_2 emissions which results in a decrease in environmental quality. However, in the quadratic period of EG has an inelastic effect on environmental degradation, but after a certain threshold, it can reduce environmental degradation from increasing EG. This indicates that many actions can be taken to change environmental policies in the target country. These findings are in line with the research of Hong-Min *et al*., (2022). Which explains Economic growth in Europe has contributed to increased CO_2 emissions due to factors such as resource utilization, industrialization, and urbanization. However, greater economic access can lead to a reduction in greenhouse gas emissions, suggesting a complex relationship between economic development and emissions. Then from the analysis results for all control variables show positive and significant results for EI, GF, NRR, FD, and TO.

The analysis results from the explanatory variable for EI indicate that a 1 percent increase in EI results in an approximately 0.76-0.79 percent increase in CO_2 emissions. Similar findings were reported by Jiabin and Shaobo (2020). In China, the Energy Intensity Ratio (EIR) significantly impacts CO_2 emissions, with net energy effects causing emissions to grow at a compound annual rate of 6.15% from 2007 to 2018, primarily driven by coal usage. Meanwhile, Muhammad *et al*., (2015) for Sub-Saharan African countries found that energy intensity has a statistically significant positive impact on CO_2 emissions, indicating that higher energy intensity contributes to increased emissions. This relationship underscores the importance of addressing energy intensity in policies aimed at reducing CO_2 emissions.

The Green Finance (GF) variable can reduce environmental quality in targeted countries through the implementation of CO_2 emissions. The coefficient of green finance (GF) is almost all positive in the six positive models, which can be interpreted as each 1% increase in GF resulting in an effect of approximately 0.05-0.07 percent in environmental degradation. The results of this study are in line with Julie (2023), who found that green finance significantly reduces CO_2 emissions by promoting sustainable investments and corporate initiatives. This includes various components such as green credits and funds, which collectively enhance sustainability and drive innovation towards a low-carbon future.

The natural resource variable (NRR) can degrade environmental quality in target countries through unsustainable natural resource management aimed at boosting economic growth. The results of this study are in line with Baolian *et al*., (2023), and Kwami and Samuel (2022). The rent of natural resources, including forest, mineral, and oil rents, is positively correlated with CO_2 emissions in BRICS countries. The economic benefits of these resources can lead to increased emissions through activities such as deforestation and land-use changes, exacerbating the challenges of climate change.

Additionally, financial development and trade openness positively affect CO_2 emissions for the overall panel in all six models; a 1 percent increase can cause approximately 0.01-0.10, and a 0.10-0.32 percent increase in environmental degradation. These findings are in sync with Fuxia (2023), who reported that financial development has a significant positive effect on per capita CO_2 emissions in China, showing an inverted U-shaped relationship. Emission reductions occur when financial development reaches a level of 4.21, with technological innovation and industrial structure acting as negative mediators. In addition, Yue *et al*., (2023) Explaining that it shows that trade openness significantly impacts carbon productivity, revealing a U-shaped relationship where carbon productivity initially decreases before increasing after reaching a certain threshold of trade openness, rather than just focusing on CO_2 emissions.

Testing Non-linear Effect of green finance

In the subsequent tests to obtain an inverted U-shaped relationship between the green finance (GF) variable and its quadratic in all models, namely the two-way fixed effects, PFMOLS, and DK models. Additionally, tests were also conducted on all explanatory variables such as energy intensity (EI), Economic Growth (EG), Natural resource rent (NRR), Financial development (FD), and Trade openness (TO). In Table 7, the results of the investigation into the bell-shaped relationship between green finance and other explanatory variables can be reported.

Based on the test results between GF and CO_2 emissions across all models, it was found that a 1 percent variation in green finance causes an increase in CO_2 emissions by approximately 0.75-0.81 percent. Meanwhile, the results of the quadratic GF test caused a 0.11 percent decrease in environmental degradation. From these results, it can be confirmed that there is an inverted U-shaped relationship between green finance and the increase in CO2 emissions for several countries in the research sample. This is consistent with the findings of Zhijuan *et al.*, (2022). Green financing promotes decarbonization by guiding capital allocation and screening projects, initially increasing CO_2 emissions before curbing them after reaching a certain inflection point. This N-shaped relationship indicates that effective green financing can ultimately reduce CO_2 emissions related to construction.

Table 7: Testing Non-linear Effect of Green Finance on CO_2 Emissions

Variables	**2W-FE-1**	**2W-FE-2**	**PFMOLS-1**	**PFMOLS-2**	**DK-1**	**DK-2**
EI	0.7401***	0.6473***	0.6518***	0.7702***	0.6503***	0.6583***
	(0.0180)	(0.0216)	(0.0152)	(0.0245)	(0.0167)	(0.0166)
EG	0.0177*	0.0166*	0.0250	0.1820**	0.0266	0.0623
	(0.0188)	(0.0145)	(0.0129)	(0.0077)	(0.0181)	(0.0206)
GF	0.8124***	0.8056***	0.7764***	0.7642***	0.7575***	0.7546***
	(0.0225)	(0.0328)	(0.0173)	(0.0158)	(0.0251)	(0.0266)
GF^2	---	-0.0811***	---	-0.0631***	---	-0.1128*
	---	(0.0167)	---	(0.0128)	---	(0.0381)
NRR	2.5510***	2.2821***	3.7535***	3.5682***	3.4116***	3.1526***
	(0.3535)	(0.2557)	(0.1420)	(0.1170)	(0.3812)	(0.5103)
FD	0.0105***	0.0103***	0.0204***	0.0115***	0.0121**	0.0433*
	(0.0077)	(0.0067)	(0.0043)	(0.0088)	(0.0051)	(0.0044)
TO	0.0704***	0.0647***	0.0381***	0.0512***	0.0586***	0.0733***
	(0.0218)	(0.0122)	(0.0076)	(0.0066)	(0.0082)	(0.0129)
B0	-12.7111***	-12.1553***	---	---	-14.2101***	-13.4507***
	(0.7208)	(0.7318)	---	---	(0.8358)	(1.0406)
Country Effect	Yes	Yes	---	---	Yes	Yes
Year Effect	Yes	Yes	---	---	---	---
Adj. R-square	0.8910	0.8237	0.9502	0.9678	0.6248	0.6488
F-stat	118.13***	82.71***	---	---	1812.31***	1562.28***
P-value (F-stat)	(0.0000)	(0.0000)	---	---	(0.0000)	(0.0000)
Hausman value	34.77***	40.80***	---	---	---	---

Note: ***, **, * indicate 1%, 5% and 10% significance levels, respectively; 2W-FE, two-way fixed effect; PFMOLS, panel fully modified OLS; DK, Driscoll Kraay regression; standard errors are reported in parentheses ().
Source: Author's computation

Additionally, this research also investigates all explanatory variables. From Table 7, it is known that all explanatory variables currently also show positive and significant impacts from EI, EG, NRR, FD, and TO. In general, the results of these explanatory variables are similar to those presented in the previous table. The regression results from all models indicate that each 1 percent increase in all explanatory variables causes an increase of 0.74-0.77%, 0.01-0.18%, 0.05-0.07%, 2.28-3.56%, 0.01-0.04%, and 0.03-0.07 percent in CO2 emissions. From the regression results, it can be interpreted that all explanatory variables have an impact on the decline in environmental quality.

Non-linear Effects of Green Finance across Developing Countries in BRI Group.

The entire panel has been tested to analyze the non-linear impact of green finance on Developing Countries in the BRI Group. In Table 8, the results of the analysis for Developing Countries in the BRI Group can be seen. On the energy intensity (EI) variable using the FMOLS panel, it was found to have a positive effect on CO_2 emissions, which means that every 1 percent increase in EI will cause a 0.62-0.64 percent increase in CO_2 emissions. However, in the quadratic form, EI has a negative effect, where each 1 percent increase in EI results in a decrease in CO2 emissions by 0.02-0.03 percent. This result shows an inverted U-shaped effect of the EI variable on environmental degradation.

At the beginning of economic development, energy intensity can cause environmental degradation due to the high consumption of fossil fuels. However, the condition of energy intensity will gradually decrease after reaching a certain maximum consumption level. This phenomenon occurs due to a shift towards the use of energy-efficient and renewable technologies. This is in line with the findings of Shahbaz *et al*., (2015), which found a statistically significant positive impact of energy intensity on CO_2 emissions, indicating that higher energy intensity contributes to increased emissions, posing a challenge for sustainable development and requiring comprehensive economic, energy, and environmental policies. Additionally, supported by recent research according to Gilang (2024), it states that energy consumption intensity significantly affects CO_2 emissions in Indonesia, highlighting the importance of energy consumption in achieving the Sustainable Development Goals (SDG). Conversely, factors such as Foreign Direct Investment and GDP do not significantly affect CO_2 emissions.

Study The next research is to test the EKC hypothesis for economic growth (EG). In Table 8, the results of the FMOLS regression show that each 1 percent increase in the EG variable causes an increase in CO_2 emissions of 1.68-1.80. In contrast, the quadratic term of EG, where every 1 percent increase in EG results in a decrease of 0.04-0.07 in environmental degradation. This confirms that there is a bell-shaped or inverted U relationship between EG and CO2 emissions. This is supported by previous research by Natalia *et al*., (2021) and Shemelis (2021). However, our research findings contradict the study by George *et al*., (2021). This study found that the Environmental Kuznets Curve (EKC) hypothesis does not apply to lower-middle and low-income countries, indicating that there is no confirmed U-shaped inverse relationship between economic growth and CO2 emissions at these income levels.

Table 8: Non-Linear Effects of green finance- Developing Countries in BRI Group

Variables	**EI^2**			**EKC**			**GF^2**		
EI	0.6244***	0.5064***	0.6454***	0.4635***	0.5114***	0.5112***	0.4280***	0.4352***	0.1466***
	(0.0337)	(0.0263)	(0.0253)	(0.0234)	(0.0233)	(0.0182)	(0.0218)	(0.0187)	(0.0158)
EI^2	-0.0312**	-0.0236**	-0.0245**	---	---	---	---	---	---
	(0.0062)	(0.0237)	(0.0215)	---	---	---	---	---	---
EG	0.7412***	0.7381***	0.7704***	1.6852***	1.8085***	1.7466***	0.4756***	0.5671***	---
	(0.0287)	(0.0224)	(0.0231)	(0.1210)	(0.1219)	(0.1832)	(0.0272)	(0.0492)	---
EG^2	---	---	---	-0.0364***	-0.0752***	-0.0622***	---	---	---
	---	---	---	(0.0246)	(0.0234)	(0.0146)	---	---	---
GF	0.1662***	0.1614***	0.1562***	0.1775***	0.1682***	0.1637***	0.0783***	0.1162***	0.1522***
	(0.0116)	(0.0113)	(0.0128)	(0.0120)	(0.0112)	(0.0139)	(0.0118)	(0.0176)	(0.0125)
GF^2	---	---	---	---	---	---	-0.0130***	-0.1135***	-0.0388***
	---	---	---	---	---	---	(0.0572)	(0.0503)	(0.0638)
NRR	0.4601***	0.4727***	0.5168***	0.4251***	0.4415***	0.4686***	0.1157***	0.1121***	0.1733***
	(0.0547)	(0.0445)	(0.0441)	(0.0587)	(0.0505)	(0.0481)	(0.0215)	(0.0108)	(0.0122)
FD	0.1139***	0.0855***	0.1228***	0.0511***	0.0584***	0.0621***	0.1076***	0.1670***	0.1645***
	(0.0107)	(0.0162)	(0.0133)	(0.0211)	(0.0119)	(0.0182)	(0.0123)	(0.0117)	(0.0127)
TO	-0.0051	-0.0023	-0.0009	0.0043	0.0122**	0.0138**	0.8621	0.8600	0.8546
	(0.0059)	(0.0051)	(0.0049)	0.0062	(0.0055)	(0.0052)	(0.0528)	(0.0438)	(0.0541)
Adj.R^2	0.9233	0.9487	0.9388	0.9192	0.9245	0.9038	0.9255	0.9472	0.9221

Note: ***, **, * represent 1%, 5% and 10% levels of significance, respectively; PFMOLS is Panel Fully modified OLS; Adj. R^2 is adjusted R-square

Source: Author's Computation

The current study also analyzes the non-linear impact of green finance (GF) on CO_2 emissions for the target countries. Based on the results of the PFMOLS regression, it can be observed that for every 1 percent increase in GF, CO_2 emissions can increase by 0.07-1.12%, while its square has a negative impact on environmental quality and reduces CO_2 emissions by 0.01-0.11% in Developing Countries in the BRI Group. From the analysis results, it can be interpreted that the initial implementation of green finance at a significant level of 1 percent can reduce environmental quality, but after reaching a certain maximum level, it can significantly reduce environmental degradation. Thus, the study to investigate the non-linear relationship can verify the green finance theory which states that high implementation of green finance can support the improvement of environmental quality. Our findings Our findings align with those of Miaonan *et al.*, (2023) and Julie (2023), who also found a bell-shaped relationship between green finance and carbon emissions. However, our study is the first to examine the non-linear role between green finance and CO_2 emissions in a cross-country context, which also supports the EKC hypothesis.

In Table 8, the results of the analysis of three other control variables are also reported, including the natural resource variable (NRR), financial development (FD), and trade openness (TO). Based on these results, all of them have a significant impact on the increase in CO_2 emissions. The results of the PFMOLS regression indicate that NRR can degrade environmental quality in low-income countries, due to exploitation that generally does not consider the sustainability of environmental preservation. These results are consistent with the research by Chinazaekpere and Samuel (2021) and Xiaotong *et al*., (2023) because higher resource rents can lead to increased emissions due to intensive resource extraction and consumption patterns.

CONCLUSION

The phenomenon of implementing green finance has become part of the challenge of global issues. Over the course of several decades, it has impacted environmental dynamics. Therefore, in this research study, a comprehensive investigation was conducted on the impact of green finance on CO_2 emissions through the STIRPAT model using data from sixty-six countries that represent all variables and are consistent over the period 1990-2023. This study investigates the non-linear impact of energy intensity (EI), Economic Growth (EG), Green Finance (GF), Natural resource rent (NRR), Financial development (FD), and Trade openness (TO) along with their quadratic terms using models such as the two-way fixed effects and the PFMOLS Model.

In this study, because the panel data is also equipped with cross-sectional (CD), it also applies DK which functions to check the validity of previous research results. Can provide strong estimates for econometric cases such as serial correlation, heteroscedasticity, and CD. Based on the empirical analysis that has been conducted, there is a long-term equilibrium relationship between all explanatory variables and CO_2 emissions. Additionally, there is also a significant relationship between the green finance variable and CO_2 emissions in all cases. All the existing findings serve as evidence of the hypothesis.

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