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RESEARCH ARTICLE

The Relationship between Green Innovation, CO_2 Emissions, Gross Domestic Product, and Renewable Energy Supply: A Panel Data Analysis for BRICS Countries and Turkey

Bekir Sami Oğuztürk[1], Ferhat Özbay[2]

Abstract

This study aims to determine the impact of carbon dioxide (CO_2) emissions, Gross Domestic Product (GDP), and green innovation on the renewable energy (RE) supply (RES) by taking panel heterogeneity and cross-section dependence into account. The dataset of this study covers a panel of BRICS countries (fragile five) and Turkey from 2000 to 2017. Based on the heterogeneity and cross-section dependency, the tests we have applied are the CIPS unit root test, Gengenbach, Urbain and Westerlund's (2016) panel cointegration, Mean Group estimator (MG) and fully modified ordinary least squares (FMOLS), and Panel Dumitrescu and Hurlin's (2012) causality techniques. We have found in this study that the variables are cointegrated in the long term. The results show that the CO_2 emission for the whole sample has a negative impact on RES. On a country basis, it shows that green innovation has a positive and robust relationship with RES in Brazil and Turkey. The impact of green innovation on RES does not have a statistically significant relationship in Russia, China, India, or South Africa. CO_2 emission indicates a negative impact on RES in whole countries. While economic growth reduces RES in India, Turkey and South Africa, this effect is the opposite in Brazil and China. This study provides practical policy implications for policymakers and researchers studying in this field.

Keywords

Green Innovation, Renewable Energy, CO_2 emissions, Environment, Panel Cointegration

Introduction

For a sustainable world, one of the fundamental values targeted globally is a sustainable environment, since all communities are increasingly concerned about the loss of natural resources and environmental pollution (Asadi et al., 2020; Song et al., 2019). The raise in energy demands and CO_2 emissions constitute an obstacle to a sustainable environment. According to Global Footprint Network data, world energy capacity is insufficient to meet this demand.

1 **Corresponding Author:** Ferhat Özbay (Asst. Prof. Dr.), Isparta University of Applied Sciences, Yalvaç Vocational School, Isparta, Turkiye. E-mail: ferhatozbayy@hotmail.com ORCID: 0000-0002-7756-3835

2 Bekir Sami Oğuztürk (Prof. Dr.), Süleyman Demirel University, Faculty of Economics and Administrative Sciences, Department of Economics, Isparta, Turkiye. E-mail: bekiroguzturk@sdu.edu.tr ORCID: 0000-0003-3076-9470

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Considering that the energy distribution throughout the world is not optimal and non-RE is the leading cause of CO_2 emissions (Dogan & Seker, 2016; Inglesi-Lotz & Dogan, 2018; Nathaniel & Iheonu, 2019; Shafiei & Salim, 2014), the importance of RES is increasing. Given the role of RE in the debate for a future with reliable and sustainable energy, it is essential to understand its main determinants and draw policy implications for energy policy (Omri & Nguyen, 2014).

Bilan et al. (2019), Apergis & Payne (2014), and Sadorsky (2009) examined the determinants of RE in their studies. They emphasized that economic growth, cost and CO_2 emissions have significant impacts on RE. The essential emerging emphasis is that RES should be increased not only for future energy needs but also to reduce CO_2 emissions and provide a sustainable environment. Considering that scarce resources cannot meet this energy need, the importance of environmental technologies (called green innovation in this study) is increasing. Also, it is known that green innovations play a critical role in accelerating the global energy transition (IRENA, 2021). Besides, Dağlı & Kösekahyaoğlu (2021) state that technology will profoundly impact the environment.

It is understood that the increase in energy demand and environmental pollution makes green innovation even more critical since RE technologies provide clean and abundant energy harvested from self-renewing sources such as the sun, wind, soil and plants (Bull, 2001). RE technologies are considered clean energy sources, and optimum use of these resources minimizes environmental impacts. Also, these technologies generate minimal secondary waste and are more sustainable according to current and future economic and social needs (Panwar et al., 2011). Overall, RE technologies offer an excellent opportunity to reduce greenhouse gas (GHG) emissions and global warming by replacing traditional energy sources (Panwar et al., 2011).

Although there is a significant trend in the literature to recognize the value of green innovation towards achieving sustainable development (Afshar Jahanshahi et al., 2020; Afshar Jahanshahi & Brem, 2020; Asadi et al., 2020), it has not received sufficient attention (Bai et al., 2020a). In this context, this study investigated the impact of CO_2 emissions, GDP, and green innovation on RES by considering panel heterogeneity and cross-section dependence. The first purpose of examining this relationship is to put forward important policies to increase RES. The second objective is to determine whether RES move together with economic growth. We believe that a change to RES is significant in terms of energy demand when economic growth occurs. The OECD (2020) emphasizes implementing national and international low-carbon strategies and further decoupling GHG emissions from economic growth. We also examine whether there is a causal relationship between economic growth, CO_2 and RES, as it is vital to separate economic growth from CO_2 in environmental policies.

Furthermore, the ever-increasing energy demand and CO_2 emissions of rapidly growing developing countries pose a significant environmental risk today. Therefore, it can be accepted that these countries should prioritize formulating policies to combat global warming and use RE resources (Çınar & Yılmazer, 2015). The dataset of this study covers Brazil, Russia, India, China, South Africa, and Turkey (BRICS-T) from 2000 to 2017; also, BRICS-T is the sole cause of almost 43% of CO_2 emissions on Earth (IEA, 2019).

In the first part of this study, we include a literature review which consists of two parts. We first reviewed the topic in the BRICS country's context and then added a literature review that explores the relationship between green innovation, RES and CO_2 emissions. In the second part of this study, we decided which panel data method to use and the correlation matrix of the model. One of the most neglected assumptions in the models used in the literature is whether the model is heterogeneous or not. A critical shortcoming is whether the method chosen when examining long-term coefficients is resistant to cross-sectional dependence and suitable for heterogeneity. For this purpose, we analyzed the matrix of correlations, cross-section dependence, and homogeneity assumptions. We then implemented the unit root test. For stationary variables at level I (1), Gengenbach, Urbain and Westerlund's (2016) panel cointegration test was administered, which is error-correction based and allows for unbalanced panels, heterogeneous structure and correlation between units. And then, we analyzed the residues of variables in a cross-section dependence test. With this test, a decision was made between first and second-generation tests to interpret long-term coefficients. The long-term coefficients were estimated with FMOLS and MG coefficients. Finally, we used Dumitrescu and Hurlin's (2012) panel causality techniques. In the last part of the study, we discussed the results of the analysis. Finally, we provided some policy implications in the conclusion section.

Literature Review

In this section, the studies on the BRICS and BRICS-T context are discussed. In Table 1 below, studies include:

Table 1

RE studies on the BRICS and BRICS-T

Authors	Scope	Methodology	Result
(Anser et al., 2021)	BRICS	Panel AMG	The authors found that RE consumption inhibited CO_2 emissions, whereas GDP, population, and non-RE consumption increased CO_2 emissions.
(Bağrıyanık, 2021)	BRICS	Panel AMG	Export diversity and economic growth affect CO_2 emissions positively.
(Kongbuamai et al., 2021)	BRICS	DSUR method and panel causality tests	Economic growth, RE, non-RE consumption, and industry positively correlate with the ecological footprint (EF). In contrast, the strictness of environmental policy has a negative relationship with the EF.

Authors	Scope	Methodology	Result
(Muhammad et al., 2021)	BRICS and developed and developing countries	GMM and System GMM	Foreign direct investment (FDI) is the cause of environmental degradation in BRICS and developing countries. However, in developed countries, FDI reduces environmental degradation. As a result, the fuel resources of BRICS and RE consumption help reduce environmental degradation in all samples. Besides, ore and metal resources improve environmental degradation in developed countries.
(Nathaniel et al., 2021)	BRICS	CCEMG, AMG, PMG, FMOLS	This study found that economic growth and natural resources increase EF, and human capital is not yet desired to reduce environmental degradation. Therefore, it is stated that RE reduces EF.
(Younis et al., 2021)	BRICS	GMM	The stock index price has a negative relationship with other countries except for Brazil. The study also reveals that FDI, trade openness and urbanization have a significant positive relationship with environmental degradation.
(Zhao et al., 2021)	BRICS	NARDL	The study showed that an increase in geopolitical risk significantly impacted CO_2 emissions in Russia and South Africa. While the reduction of geopolitical risk negatively affects CO_2 emissions in India, China and South Africa, it has a positive coefficient in Russia in the long run.
(Adedoyin et al., 2020)	BRICS	PMG ARDL	The study's findings conclude that an increase in coal rents will not increase CO_2 emissions. They demonstrated that energy diversification in BRICS economies can reduce the global declining energy market, and environmental sustainability will be achieved by separating CO_2 from GDP in BRICS economies.
(Akram et al., 2020)	BRICS	Hidden panel cointegration. Nonlinear panel ARDL	The study's findings say that the effect of the selected variables on CO_2 emissions is asymmetrical and that both energy efficiency and RE help reduce CO_2 emissions in BRICS countries.
(Aziz et al., 2020)	BRICS	MMQR	CO_2 emissions can be reduced by choosing renewable sources.
(Banday & Aneja, 2020)	BRICS	Bootstrap Dumitrescu and Hurlin panel causality test	This research showed that there is unidirectional causality from GDP to CO_2 for all countries except Russia. The causality results from RE consumption to GDP show evidence of the feedback hypothesis for China and Brazil, the growth hypothesis for Russia, the conservation hypothesis for South Africa, and the neutrality hypothesis for India.
(Hassan et al., 2020)	BRICS	Panel CUP-FM and CUP-BC	This study supports the idea that nuclear energy reduces CO_2 emissions. Also, RE corrects environmental pollution in BRICS countries.
(Şengönül, 2018)	BRICS	Panel VECM and causality	There is a causal relationship between electricity consumption to GDP in the short run and from GDP to electricity consumption in the long run.
(İzgi, 2017)	BRICS and MINT	Panel cointegration and causality	Economic activities are positively affected by renewable and non-RE consumption, and non-RE consumption is more effective on economic growth than RE consumption.
(Özşahin et al., 2016)	BRICS -T	Panel cointegration and ARDL	A positive relationship was found between RE consumption and economic development in the long run.
(Dincer, 2000)	BRICS and MINT[1]	Engle-Granger co-integration and Toda Yamamoto causality	This study determined that RE is vital for sustainable development for Brazil and China. However, no association has been detected in other countries.

1 MIST "Mexico, Indonesia, South Korea and Turkey."

Table 1 includes different studies on BRICS and BRICS-T: RE and economic development, RE and sustainable development, energy and growth, economic growth, export diversification and CO_2 emissions.

Three critical highlights in the literature review for BRICS countries in Table 1 above are:

1. RE reduces CO_2 emissions.

2. Economic Growth increases CO_2 emissions.

3. RE reduces environmental pollution and is vital for sustainable development.

Table 2 below presents the literature examining the relationship between green innovation-based RE and CO_2.

Table 2

International RE Studies on the Context of Green Innovation

Authors	Scope	Methodology	Result
(Lin & Zhu, 2019a)	China's provinces	Panel threshold model	The effect of technological innovations on reducing CO_2 is low, but the effect on RE is increasing at a growing rate.
(Danish & Ulucak, 2020)	BRICS	Panel CUP-FM and CUP-BC	Environmental technologies contribute positively to green growth. Besides, it has been observed that RE supports green growth, but non-RE harms green growth.
(Yang et al., 2019)	China's provinces	GMM	The effect of energy price on fossil fueltechnological innovation is more remarkable than RE. Price support is needed to develop RE technology.
(Lin & Zhu, 2019b)	China's provinces	Panel cointegration, causality and System GMM	The innovation process actively responds to climate change. The energy price has a negligible effect on innovation in RE technologies and is caused by the unreasonable energy price mechanism.
(Santra, 2017)	BRICS	Panel Pooled regression modeling	Environmentally innovative technology has a substantial impact on the sustainable performance of BRICS countries. Green technological innovations reduce energy absorption and CO_2 emissions for companies and countries as a whole.
(Zhu et al., 2020)	China's provinces	Panel Spatial analysis	Although not significantly associated with sulfur dioxide, technological innovations in RE help reduce nitrogen oxides and respirable suspended particles
(Bai et al., 2020b)	China's provinces	Panel FE regression model and panel threshold model	Technological innovations in RE help reduce CO_2 emissions per capita. Still, with the increase in income inequality, the possible benefit of technological innovations in RE on CO_2 emissions per capita is reduced and hindered.
(Cheng & Yao, 2021)	China's provinces	Panel MG, CCEMG and AMG, PMG, DFE estimator	RE technology innovation is not affected by carbon intensity in the short run, but its effects are adverse and significant in the long run.
(Hao et al., 2021)	G7	CS-ARDL model	Linear or nonlinear green growth reduces CO_2 emissions.
(Saudi et al., 2019)	Malaysia	ARDL	RE consumption and innovation have a significant and negative impact on carbon dioxide emissions, and economic growth has a significant and positive impact on carbon dioxide emissions.

Authors	Scope	Methodology	Result
(Kılınç & Şahbaz, 2021)	24 selected countries	Panel ARDL and Emirmahmutoğlu and Köse casuality test	R&D expenditures and innovation have an impact on RE.
(Khattak et al., 2020)	BRICS	Panel CCEMG	Apart from Brazil, innovation activities do not impair CO_2 in other BRICS countries.
(Ali et al., 2020)	10 carbon emitter countries	Panel cointegration and CS-ARDL	RE consumption and environmental innovations have a negative impact on consumption-based carbon emissions and region-based carbon emissions.

The general emphasis in Table 2 above is that environmental innovations positively impact RE and negatively impact CO_2 emissions.

Data, Methodology, and Findings

Data and Model

There is not enough discussion on the determinants of RE in the literature. However, it is not the first time that RE is the dependent variable in the literature. Some studies have investigated the effects of variables such as CO_2, per capita GDP and oil prices on RE (Apergis & Payne, 2014; Sadorsky, 2009). This study examines the impact of CO_2 emissions, GDP, and green innovation on the RES with data from 2000 to 2017 in BRICS-T countries.

The model created following the purpose of the study is as in equation 1 below:

$$RES_{it} = \beta_0 + \beta_1\, CO_{2,\mathrm{it}} + \beta_2\, lnGDP_{\mathrm{it}} + \beta_3\, lngreenpatent_{\mathrm{it}} + \varepsilon_{\mathrm{it}} \qquad (1)$$

i=1,2,3,…..6.

t= 1,2,3,4….18.

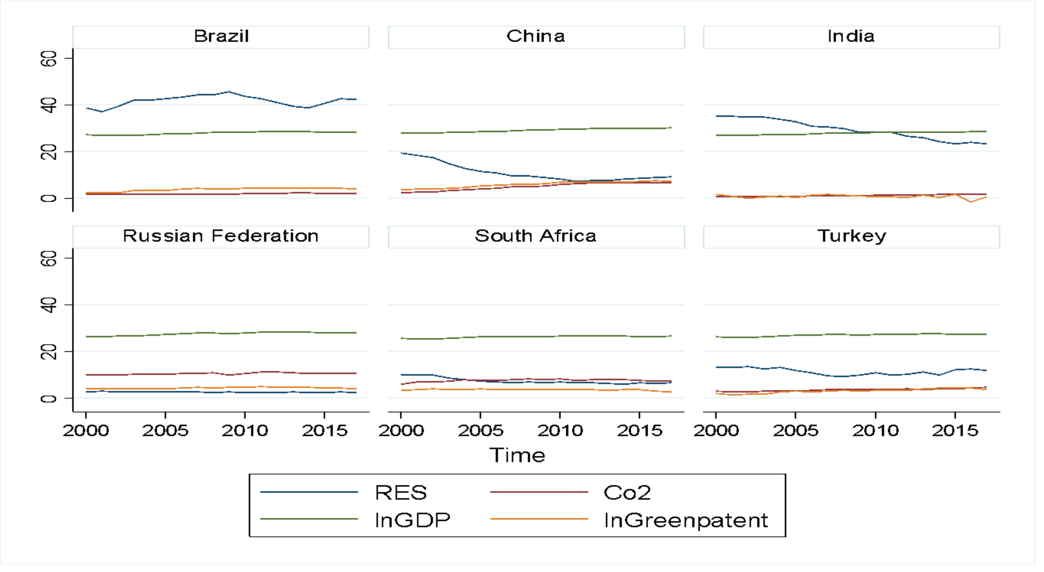
In this study, the variables used definitions, and sources given in Table 3 below.

Table 3

Description of Variables

Variable	Definition	Source
RES	RE supply (percentage of total primary energy supply).	OECD
CO_2	Carbon Dioxide: determined by dividing the total CO_2 emissions by the population.	World bank
lnGDP	Gross domestic product: It represents growth.	World bank
lnGreenpatent	Green Innovation: It Includes patents on environmental technologies.	OECD

Furthermore, the change of the variables over the years is given in Graph 1. According to Graph 1, Brazil seems to have the highest share of RES in total energy. The shares of India's RES in total energy have decreased. The country with the lowest percentage of RES in total energy is Russia. Again, Russia is the leading country in CO_2 emissions per capita. The rise in China's RES in 2007 and after is remarkable. This rise can be said to have stopped the increase in China's CO_2 emissions as of 2013. However, it is the country with the highest CO_2 emissions per capita after Russia.



Graph 1. Variables Views by Countries

Before deciding which method to select, we must examine whether there are multicollinearity or singularity problems among the variables. Accordingly, the VIF statistics and correlation matrix of the variables are given in Table 4 below.

Table 4

VIF and Matrix of Correlations

Variables	**(1)**	**(2)**	**(3)**	**(4)**
(1) RES	1.000			
(2) CO_2	-0.777	1.000		
(3) lnGDP	0.196	-0.118	1.000	
(4) lnGreenpatent	-0.307	0.495	0.466	1.000
VIF		**1/VIF**		
2.100		0.476		
1.670		0.600		
1.610 Mean: 1.790		0.622		

VIF measures the severity of multicollinearity in regression analysis. In this context, it is expected to be between 1 and 5. In the correlation matrix, the variables should not be higher than 0.8. According to findings, the variables in the model do not contain multicollinearity or singularity.

Methodology and Findings

We used the panel data method in this study because the data includes both unit and time dimensions. Panel data models offer many advantages for multi-section analysis to bring together cross-sectional observations over time. In this respect, the most crucial benefit of panel data analysis is that it allows the researcher great flexibility in modeling behavioral differences between individuals (Özbay & Oğuztürk, 2020). Like a time series, spurious regression problems may arise when working with nonstationary data in panel data management (Tatoğlu, 2018). Unit root tests in panel data are divided into first-generation and second-generation tests. In the case of correlation between units in the model, second-generation tests are preferred. In this context, before the unit root test is to be carried out, we should test whether the model is correlated between units.

In the model, the time dimension is higher than the unit dimension. As an inter-unit correlation test, Breusch and Pagan's LM test does not give consistent results when the time dimension is higher than the unit dimension. Pesaran's (2004) Test of Cross Section Dependence was chosen in this study, considering that the unit dimension is larger than the time dimension. Table 5 below shows the correlation between units.

Table 5

Pesaran CD Test

Variable	CD	P-value
RES	0.57	0.569
CO_2	11.11	0.000
lnGDP	15.43	0.000
lnGreenpatent	3.71	0.000

Table 5 above shows that all variables except RES contain inter-unit correlation. In this context, Maddala & Wu's (1999) first-generation unit root test (MW) and Pesaran's (2007) second-generation unit root test (CIPS) are used for unit root tests.

Table 6

Unit Root Test

MW Tests					
Without Trend			**Without Trend**		
Variable	Chi_sq	P-Value	ΔVariable	chi_sq	p-value
RES	9.825	0.631	ΔRES	83.871	0.000
CO_2	17.200	0.142	ΔCO_2	63.214	0.000
lnGDP	8.070	0.780	ΔlnGDP	32.541	0.001
lnGreenpatent	19.239	0.083	ΔlnGreenpatent	110.181	0.000
With Trend			**With Trend**		
Variable	Chi_sq	P-value	ΔVariable	chi_sq	p-value
RES	12.789	0.385	ΔRES	76.602	0.000
CO_2	7.550	0.819	ΔCO_2	56.986	0.000
lnGDP	0.357	1.000	ΔlnGDP	44.005	0.000
lnGreenpatent	19.368	0.080	ΔlnGreenpatent	120.518	0.000

CIPS					
Without Trend			**Without Trend**		
Variable	Zt-bar	p-value	ΔVariable	Zt-bar	p-value
RES	2.402	0.992	ΔRES	-3.021	0.001
CO_2	0.758	0.776	ΔCO_2	-2.399	0.008
lnGDP	-1.541	0.062	ΔlnGDP	-3.247	0.001
lnGreenpatent	-1.399	0.081	ΔlnGreenpatent	-8.127	0.000
With Trend			**With Trend**		
Variable	Zt-bar	p-value	ΔVariable	Zt-bar	p-value
RES	1.828	0.966	ΔRES	-3.391	0.000
CO_2	2.014	0.978	ΔCO_2	-1.105	0.135
lnGDP	-1.130	0.129	ΔlnGDP	-0.970	0.166
lnGreenpatent	-0.528	0.299	ΔlnGreenpatent	-6.474	0.000

According to the unit root test results in table 6 above, the series is I (1) determined to be stationary.

If the series that are not stationary at the level are I (1) cointegrated, they contain long-term relationships, and spurious regression is not encountered (Tatoğlu, 2018).

However, when investigating these relationships in the literature, whether the model is homogeneous or not is not determined. Ignoring this assumption causes wrong model selection; therefore, biased results are obtained. In this context, the homogeneity of the variables was tested with Swamy's (1971) test and Pesaran and Yamagata's (2008) slope heterogeneity test.

Table 7

Testing for Slope Heterogeneity

Pesaran and Yamagata S Testi		
	Delta	p-value
	7.583	0.000
adj.	8.972	0.000
Swamy S Testi		
chi2(20) =	13463.46	Prob > chi2: 0.0000

Test results are tested according to H_0.

H_0: Slope coefficients are homogeneous.

In this context, hypothesis H_0 was rejected: the model was determined to be heterogeneous.

Gengenbach, Urbain, and Westerlund's (2016) cointegration test was used because the model is unbalanced and thus allows for group-specific lag selection and heterogeneity. This test is also one of the most up-to-date tests that would enable inter-unit correlation based on the error correction model.

Table 8

Panel EC-test ve Pesaran (2015) CD-test

d.y	Coef	T-bar	P-val*
y(t-1)	-0.747	-15.793	<=0.01

Variable	CD	P-val
RES	1.663	0.096
CO_2	-1.932	0.053
lnGDP	3.844	0.000
lnGreenpatent	1.248	0.212
e	0.131	0.895

Note: Root mean square error: 0.0466
Number of observations: 85
Number of groups: 5

The variables are cointegrated according to the Gengenbach, Urbain, and Westerlund (2016) cointegration test above. It is understood that the cointegration test removes the correlation between units from the residue according to the Pesaran (2015) CD test.

When investigating long-term relationships, the model should take the inter-unit correlation into account. Models that allow heterogeneity should also be tested for correlation between units. First-generation tests can be used when there is no correlation between teams in the remnants of the cointegration model (Tatoğlu, 2018). In this context, we investigated the long-term effects of the variables by considering models that allow heterogeneity. These relations were obtained from Pedroni's (1996, 2000) FMOLS and Pesaran and Smith's (1995) MG estimator. Both tests allow heterogeneity.

Table 9

Group-coefficients

	FMOLS		MG(Mean Group)	
	Coef.	**t-stat**	Coef.	P>z
CO_2	-4.83	-49.75***	-4.848**	0.028
lnGDP	1.74	10.39***	1.919	0.613
lnGreenpatent	0.85	13.32***	0.709	0.131
Constant			-31.099	0.763

Table 10

Group-Specific Coefficients

		Coef.	t-stat	Coef.	P>z
Brazil	CO_2	-10.78***	-42.42	-10.751***	0.000
	lnGDP	2.11 ***	9.97	1.960	0.103
	lnGreenpatent	2.18***	14.67	2.326***	0.003
	constant			-1.457	0.960
China	CO_2	-8.55***	-45.50	-8.271***	0.000
	lnGDP	19.31***	65.00	20.147***	0.000
	lnGreenpatent	0.59*	2.70	-0.432	0.857
	constant			-530.657***	0.000

		Coef.	t-stat	Coef.	P>z
India	CO_2	-9.84 ***	-15.94	-10.059***	0.000
	lnGDP	-2.34***	-6.72	-2.155**	0.028
	lnGreenpatent	-0.14*	-2.15	-0.157	0.433
	constant			101.545***	0.000
Russian Federation	CO_2	-0.25***	-18.03	-0.255*	0.080
	lnGDP	-0.10***	-12.33	-0.107	0.175
	lnGreenpatent	0.08***	4.65	0.097	0.582
	constant			7.927***	0.000
South Africa	CO_2	-0.41*	-2.97	-0.528*	0.075
	lnGDP	-2.48 ***	-16.06	-2.412***	0.000
	lnGreenpatent	0.45**	3.41	0.483	0.184
	constant			73.126***	0.000
Turkey	CO_2	0.85*	2.98	0.779	0.301
	lnGDP	-6.06 ***	-14.40	-5.917***	0.000
	lnGreenpatent	1.97***	9.36	1.937***	0.000
	constant			162.920***	0.000
			Root Mean Squared Error (sigma): 0.7494 Wald chi2(3) = 7.68 Prob > chi2 =0.05		

Note: **** p<.01, ** p<.05, * p<.1*

Hausman's (1978) test was used to choose between the MG and FMOLS estimators, and again the inter-unit correlation test was performed for the residue. Accordingly, the average correlation coefficient & Pesaran (2004) CD test and the Hausman (1978) specification test are presented in Table 11 below. According to the results, the MG estimator is more consistent than the FMOLS estimator. Therefore, it was decided that there is no correlation between units for MG. In this context, it has been understood that there is no need for estimators that reveal second-generation long-term relationships that consider the correlation between units.

Table 11

Specification Tests

Average correlation coefficients & Pesaran (2004) CD test			
Variable	**CD-test**	**prob**	**corr**
MG	-0.560	0.577	-0.032
FMOLS	11.510	0.000	0.720
Hausman (1978) test			
			Coef.
Chi-square			1546.872
Prob			0.00

It is understood that the coefficients of FMOLS and MG estimators in Tables 9-10 are very close to each other. The results show that the CO_2 emission for the whole sample has a negative effect on RES. According to MG, while the impact of green innovation is positive, it is statistically insignificant. On a country basis, it shows that green innovation has a positive and robust relationship with RES in Brazil and Turkey. The effect of green innovation on RES in Russia shows a positive but statistically weak relationship. We found no significant relationship in China, India, and South Africa. CO_2 emissions indicate a negative effect on RES as a whole sample. It can be seen that economic growth has increased RES for China. While the exact relationship is in question for Brazil, it is statistically insignificant. In all other countries, economic growth has been found to have a negative effect on RES.

Finally, we decided to perform an optional causality test. It is essential to choose methods that take into account the heterogeneous structure of the model while performing the causality test. In this context, we used Dumitrescu and Hurlin's (2012)[2] Granger non-causality test. This test also gives excellent results in small panels, even if it includes cross-sectional dependence. The delay of the model was chosen according to the AIC information criterion.

This inference takes place under two hypotheses:

H_0: $\nrightarrow$ (X is not the granger cause of Y).

H_1: $\rightarrow$ (X is the granger cause of Y).

Table 12

Dumitrescu & Hurlin (2012) Granger Non-Causality Test Results

	W-bar	**Z-bar**	**Optimal number of lags (AIC)**	**Decision**
Null Hypothesis				
$CO_2 \nrightarrow$ RES	11.0353	6.0928***	4	$CO_2 \rightarrow$ RES
RES $\nrightarrow CO_2$	2.1159	1.9328*	1	RES $\rightarrow CO_2$
RES $\nrightarrow$ lnGDP	7.7340	11.6636 ***	1	RES $\rightarrow$ lnGDP
lnGDP $\nrightarrow$ RES	4.0898	1.0898	3	lnGDP $\nrightarrow$ RES
RES $\nrightarrow$ Greenpatent	21.7189	15.3450***	4	RES $\rightarrow$ Greenpatent
Greenpatent $\nrightarrow$ RES	3.2860	3.9594***	1	Greenpatent $\rightarrow$ RES
$CO_2 \nrightarrow$ Greepatent	8.3217	5.3646 ***	4	$CO_2 \rightarrow$ Greepatent
Greepatent $\nrightarrow CO_2$	10.1945	5.3646***	4	Greepatent $\rightarrow CO_2$
Greenpatent $\nrightarrow$ lnGDP	1.1077	0.1866	4	Greenpatent $\nrightarrow$ lnGDP
lnGDP $\nrightarrow$ Greenpatent	10.8469	5.9296***	4	lnGDP $\rightarrow$ Greenpatent
lnGDP $\nrightarrow CO_2$	12.4548	7.3220 ***	4	lnGDP $\rightarrow CO_2$
$CO_2 \nrightarrow$ lnGDP	4.9558	6.8516 ***	1	$CO_2 \rightarrow$ lnGDP

Note: **** $p<.01$, ** $p<.05$, * $p<.1$*

According to the Granger non-causality test, there is a mutual causality relationship between RES and CO_2. It also revealed a one-way causality relationship between RES to economic growth. Furthermore, there appeared to be a bidirectional causality between RES and green innovation, with CO_2 emissions and green innovation. Unidirectional causality from economic growth to green innovation can be observed. Finally, according to the results, there is a bidirectional causality relationship between economic growth and CO_2 emissions.

2 Since the logarithm of the variable "lngreenpatent" causes the missing value, we used the non-logarithmic version to perform the Granger causality test.

Conclusion

This study has investigated the impact of CO_2 emissions, GDP, and green innovation on RES, and the causality relationship between green innovation, CO_2 emissions, GDP, and RES. We believe that discussing the determinants of RES within the scope of BRICS-T co-untries in the study contributes to the literature. Also, this study presents green innovation as a determinant of RES for the first time in the literature.

Econometric results confirm that there was a causality relationship between CO_2 and RES. These findings are similar to Dogan and Seker's (2016) paper. Dogan and Seker (2016) state that the EU should support universities and researchers to produce cheaper RE. Also, according to our findings in this study, CO_2 emissions affect RES negatively. Bilan et al. (2019) and Waheed et al. (2018) found similar results to ours, that CO_2 emissions reduced the use of RE.

Dogan and Seker's (2016) study also emphasizes the necessity of environmental technologies for environmental sustainability. Furthermore, Khan et al. (2020) state that green innovation and renewable energy help improve environmental sustainability. We found that green innovation had a positive effect on RES for Brazil and Turkey, in parallel with Kılınc & Sahbaz's (2021) views. Similarly, Khattak et al. 2020, stated that innovation activities do not affect CO_2 in other BRICS countries, except Brazil. In this study, it was seen that there is a causal relationship between CO_2 and green innovation for BRICS-T. This view is indirectly similar to our findings that green innovation only affects RES for Brazil and Turkey.

Bilan et al. (2019) found the effect of economic growth on RES to be positive in European Union member countries but negative for candidate or potential candidate countries. Whereas in our findings, economic growth reduced RES in India, Turkey and South Africa, this effect was positive in Brazil and China. Furthermore, the literature discussion results also showed that economic growth positively affects CO_2 emissions (Chiu & Chang, 2009; Dong, Hochman, et al., 2018; Dong, Sun, et al., 2018; Kesgingöz & Karamelikli, 2015; Özbay & Pehlivan, 2021; Pata & Yurtkuran, 2018). Our study shows that there is a reciprocal causality relationship between CO_2 and economic growth.

The OECD (2020) emphasized that the main task for implementing national and international low carbon strategies and tackling climate change is to further decouple GHG emissions from economic growth. Based on the OECD view, we understand that the BRICS-T countries, except Brazil, do not make sufficient efforts on climate change. These findings reveal important implications for the literature. At the same time, one of the main goals to limit climate change is to reduce energy intensity by adopting energy-efficient production processes, which means increased energy efficiency. Environmental patents can measure the effectiveness and efficiency here. According to our findings, the statistically positive effect of green innovations on RES in Brazil and Turkey shows the efforts of these countries to increase energy efficiency.

For environmental sustainability, the following summary findings emerge with the literature review and statistical results:

1. There was an inverse relationship between CO_2 and RES. In this context, strengthening incentives and sanctions for RES will create a more sustainable environment.

2. While GDP is growing, if it is positively related to CO_2 and negative with RE, this growth is dangerous for environmental sustainability. For this, policymakers and researchers should put demand-pull policies on the agenda for the price mechanism and the demand for RE supply.

3. It is seen that environmental patents are far from the desired level. For this, a great responsibility falls on researchers and policymakers.

Note for future work

Renewable energy remains the most critical factor for environmental sustainability. However, studies on renewable energy show that its determinants have been ignored. In this context, this model should be developed for future studies by associating the price policy discussed in the literature and renewable energy supply. For this, researchers can use both RE and non-RE prices. At the same time, it is necessary to investigate why green innovation does not show the expected effect in some countries. As such, new studies are necessary.

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APP-1.

Summarize Statistic

Variable		Mean	Std. Dev.	Min	Max	observations
RES	Overall	17.33796	14.024	2.45	45.71	N =108
	Between		15.02679	2.708889	41.75	n = 6
	Within		2.596826	11.07907	25.72574	T = 18
CO_2	Ov.	4.998148	3.366214	.8	11.2	N =108
	Bet.		3.58338	1.194444	10.56111	n = 6
	Wit.		.7286169	2.453704	6.753704	T = 18
lnGDP	Ov.	27.63708	1.044173	25.47238	30.14147	N =108
	Bet.		.9286339	26.29472	29.08769	n = 6
	Wit.		.6041085	26.27673	28.69086	T = 18
lnGreenpatent	Ov.	3.69973	1.702722	-1.609438	7.579934	N =105
	Bet.		1.6968	.7626755	5.922481	n = 6
	Wit.		.8059962	1.327617	5.357183	T = 17.5