Journal of Tourism, Hospitality and Environment Management JTHEM
EISSN: 0128-178X

Volume 9 Issue 36 (June 2024) PP. 18-39
DOI 10/35631/JTHEM.936002

JOURNAL OF TOURISM, HOSPITALITY AND ENVIRONMENT MANAGEMENT (JTHEM)
www.jthem.com

GLOBAL ACADEMIC EXCELLENCE

NEXUS BETWEEN RENEWABLE ENERGY AND CARBON DIOXIDE EMISSIONS: EVIDENCE FROM THE INSTITUTIONAL THRESHOLD EFFECT

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Article Info:

Article history:
Received date: 29.02.2024
Revised date: 15.04.2024
Accepted date: 15.05.2024
Published date: 25.06.2024

To cite this document:

Keh, C. G., Tan, Y. T., Tang, S. E., & Gan, P. T. (2024). Nexus Between Renewable Energy And Carbon Dioxide Emissions: Evidence From The Institutional Threshold Effect. *Journal of Tourism Hospitality and Environment Management, 9* (36), 18-39.

DOI: 10.35631/JTHEM.936002.

Abstract:

A remarkable feature of empirical investigations on the renewable energy effect on carbon dioxide is that not many studies reveal the distinct levels of institutional development; in other words, the precise alignment of institutions in mediating the influence of renewable energy on carbon dioxide emissions. To overcome this shortcoming, this paper examines the role of institutions in mediating the influence of renewable energy on carbon dioxide emissions. Forty-six selected countries are included in this study. The data are collected yearly from 1998 to 2019. Using the dynamic panel threshold methods, the results show a threshold effect in the relationship between renewable energy and carbon dioxide emissions; renewable energy impacts carbon dioxide emissions after institutional development attained a certain threshold level. The findings suggest that strong institutions may promote the nexus between renewable energy and carbon dioxide emissions and that policymaker supports the functioning of renewable energy in hindering long-run $CO2$ emissions intensity.

Keywords:

Carbon Dioxide Emissions, Dynamic Panel Threshold Model, Institutional Quality, Renewable Energy, Threshold Effect

EISSN: 0128-178X
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Introduction

Renewable energy refers to the energy that is obtained from nondepletable natural resources. Opting for renewable energy and improving energy efficiency can contribute to mitigating climate change and reducing disaster risk (United Nations, 2015). The seminal Brundtland report by United Nations (1987) first described the potential role of renewable energy in accomplishing sustainable development associated with reducing greenhouse gases and the pollution produced by fossil fuels. Since then, it has shaped the evolution of international environmental policy and greenhouse gas emissions of research-related activities. Too much emphasis has been placed on explaining and predicting the role of renewable energy under carbon dioxide ($CO2$) emissions; however, the research examining whether the renewable energy effect of $CO2$ in countries with distinct levels of institutional development differs remains unknown. Well-functioning institutions could contribute to the goal of environmental sustainability (Haldar and Sethi, 2021). An open question remains as to whether research in this area could improve our knowledge of the renewable energy effect of $CO2$ in the context of environmental economics.

The issue that arose was that many countries are working hard to reduce CO2 emissions, with renewable energy playing a pivotal role. The United States (Langevin et al., 2019), China (Yang et al., 2017) and European Union countries (Bayer & Aklin, 2020) and many others have all set targets to decrease their carbon emissions. For instance, the European Union has committed to cutting greenhouse gas emissions by at least 55% by 2023 compared to 1990 levels (Cifuentes-Faura, 2022). However, challenges persist concerning both renewable energy deployment and the institutional frameworks governing it. The availability of renewable energy sources such as solar and wind power varies across nations, leading some to rely heavily on fossil fuels with high CO2 emissions. Moreover, institutional factors, including governmental policies and regulations often hinder the widespread adoption of renewables. Subsidies favouring fossil fuels and outdated regulations that prioritize traditional energy sources contribute to this challenge. Therefore, addressing CO2 emissions requires not only expanding renewable energy infrastructure but also reforming institutional frameworks to promote cleaner energy alternatives effectively.

A remarkable feature of empirical investigations on the renewable energy effect on $CO2$ is that not many studies reveal the distinct levels of institutional development; in other words, the precise alignment of institutions in mediating the influence of renewable energy on $CO2$ emissions. For example, Asoni (2008) suggests that institutions ineffectiveness may promote the private sector to create a dysfunctional bureaucracy and encourage corruption that induces poor environmental rules. In line with this, Wong et al. (2010) reveal that institutions can play an essential role in tackling environmental issues through the implementation of laws such as the elimination of subsidies for fossil fuels, carbon taxes, and feed-in tariffs. By reducing energy use or adopting technology to lessen energy intensity, Glass and Newig (2019) find that a good functioning of institutions may influence the degree of energy use efficiency. Thereby, the government's capacity to develop and implement laws and regulations supporting the private sector may enhance contract execution quality, safeguard property rights, uphold a solid legal system, and ensure institutions are free from political interference (Canh et al., 2019).

Numerous country-specific investigations have been done on the impact of institutional quality on increasing energy efficiency to reduce $CO2$ emissions intensity. Mahjabeen et al. (2020) find that in the absence of stable institutions, renewable and non-renewable energy drastically

Journal of Tourism, Hospitality and Environment Management
JTHEM
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Volume 9 Issue 36 (June 2024) PP. 18-39
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degrades the environment in developing countries. Thus, institutional stability is crucial for these countries in executing policies and technological advancements more effectively. Sarkodie and Adams (2018) argue that political institutional quality is essential for structural transformation, which encourages service-oriented economic growth, diversifies energy use, and upholds environmental quality in South Africa. Fossil fuel-rich nations may enhance energy security and environmental sustainability by moving their energy mix toward renewable energy sources. In the study of the energy efficiency performance of 71 developing and developed nations, Sun et al. (2019) reveal that reliable government institution is necessary for the country to transform its perspective toward green technologies to create an environment that is carbon-free or low in carbon. Chen et al. (2022) suggest that developed countries with more excellent institutional quality consume more renewable energy. Consequently, consuming more renewable energy tends to lower $CO2$ emissions.

With a broader perspective, Allard (2016) argues that institutional quality may encompass high-quality governmental regulation and services, individual rights, and the rule of law. Hsu et al. (2017) find that institutional quality greatly influences energy efficiency and energy transition, which measure the negative impact of energy consumption on greenhouse gas emissions, particularly $CO2$ emissions. Bhattacharya et al. (2017) opine that the quality of institutions plays a crucial role in facilitating the energy transition process of using renewable energy to reduce $CO2$ emissions. Saidi et al. (2020) argue that the most resource-rich countries are likely to have a poor institutional quality that limits the amount of effort in setting adequate renewable energy and reducing $CO2$ emissions. However, this shortcoming may indirectly depreciate the environmental quality and increase $CO2$ emissions (Slesman et al., 2015). As stressed by European Environment Agency (2017), one cannot ignore policies and measures designed that are associated with institutional development in reducing emissions, improving energy efficiency, and stimulating the deployment of renewable energy.

This paper aims to examine the role of institutions in mediating the influence of renewable energy on $CO2$, such that strong institutions may promote the nexus between renewable energy and $CO2$ emissions and that policymaker supports the functioning of renewable energy in hindering long-run $CO2$ emissions intensity. Considering the nexus between renewable energy and $CO2$ emissions, it may be contingent on the institutional quality that renewable energy hinders $CO2$ emissions after institutions exceed a certain threshold level. Forty-six selected countries are included in this study (See Section 3.3, the data description). The data are collected yearly from 1998 to 2019. The main innovative attribute of this paper is the use of the dynamic panel threshold model proposed by Seo and Shin (2016). Additionally, two alternative dynamic panel regression models, i.e., Seo et al.'s (2019) dynamic panel threshold regression model with a kink and Kremer et al.'s (2013) dynamic panel threshold regression model, are applied for robustness check tests. These results are expected to be sensible in line with the objective's implication as mentioned above.

The rest of the paper is divided as follows. Section 2 presents the methodology and data description used in this study. Section 3 presents the empirical results of cross-sectional dependence and panel unit root test, together with the results of dynamic threshold estimation, and robustness check tests. Lastly, section 4 concludes and suggests some limitations and future recommendations.

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Methodology and Data Description

The Dynamic Panel Threshold Model

To investigate the effect of the institutional quality threshold level in the relationship between renewable energy and $CO2$ emissions. This study employs the dynamic panel threshold model proposed by Seo and Shin (2016). Hansen's (1999)'s static panel threshold model, which is based on the value of an exogenous static variable and assumes a small number of alternative values for the regression coefficients. However, the accuracy of this static technique is turned into doubt if compared to dynamic technique. By proposing its dynamic technique, several academics have attempted to expand on Hansen's (1999) approach (Caner and Hansen, 2004; Kremer et al., 2013). Despite the fact that all these models are the improvement of Hansen's approach, but they are still flawed as they enforce stringent conditions on the exogeneity of the threshold variable, the predictors, or perhaps both (Seo and Shin, 2016). A model proposed by Seo and Shin (2016) removes the limitations placed on the characteristics of threshold and predictors variables and permits them to be endogenous. Precisely, the reliability of employing dynamic panel threshold is based on the idea that it able to deal effectively with potential endogeneity and estimate the threshold value accurately based on the features of the constraint variables (Seo and Shin, 2016).

General Model

In line with Seo and Shin (2016), we consider the general model of dynamic panel threshold regression as shown in Equation (1):

$$y_{it} = (1, x'_{it})\alpha_1 1\{q_{it} \leq \gamma\} + (1, x'_{it})\alpha_2 1\{q_{it} > \gamma\} + \varepsilon_{it},$$

$$i = 1, \dots, n; t = 1, \dots, T, \quad (1)$$

where a scalar stochastic variable of interest is denoted as y_{it}. The $k_1 \times 1$ vector of time-varying regressors is denoted as x_{it}, which includes the lagged dependent variable. The slope parameters for the different regimes are $\alpha_1$and α_2. $1\{.\}$ is the indicator function stipulating the regime. q_{it} is the transition variable. γ is the threshold parameter. ε_{it} is the error term, which encompasses the individual fixed effect and idiosyncratic error term; the idiosyncratic error term is unobserved factors that change over time and across countries influencing the dependent variable. The dynamic panel threshold model that developed by Seo and Shin (2016) are permitted for lagged dependent variables and endogenous covariates.

Empirical Model

In this section, the empirical model is an extension of the standard model relating emissions and income first described by Grossman and Krueger (1995). Among other researchers, this model is used by Abdalla et al. (2018), Purcel (2020), and Rahman et al. (2020). The empirical model addresses the hypothesis outlined in Section 1. The inputs for the empirical model are given by Equation (2).

$$C02_{it} = \beta_0 + \beta_1 RE_{it} + \beta_2 yg_{it} + \beta_3 TO_{it} + \beta_4 U_{it} + \epsilon_{it} \quad (2)$$

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where $CO2$ is carbon dioxide emissions; RE is renewable energy; yg is economic growth; TO is trade openness, and U is urbanization. The expected sign between the dependent and independent variables are RE<0[1], yg >0[2], TO>0[3], U>0[4].

Accordingly, the specification of a regression model using the dynamic panel threshold approach mentioned in the previous subsection can be modelled as

$$CO2_{it} = (\beta_1 CO2_{it-1} + \beta_2 RE_{it} + \beta_3 yg_{it} + \beta_4 TO_{it} + \beta_5 U_{it})1\{INS_{it} \leq \gamma\} + (\lambda_1 CO2_{it-1} + \lambda_2 RE_{it} + \lambda_3 yg_{it} + \lambda_4 TO_{it} + \lambda_5 U_{it})1\{INS_{it} \geq \gamma\} + \varepsilon_{it} \quad (3)$$

where $CO2$ denotes carbon dioxide emissions, RE denotes renewable energy, yg denotes economic growth, TO denotes trade openness, U denotes urbanization, and INS denotes the level of institutional development. The emission of $CO2$'s past value is the endogenous variable, which includes dynamic data in the model. INS is the threshold variable that splits the sample into groups or regimes; the unknown threshold parameter is represented by γ. The covariate coefficients β and λ denote the lower and upper regimes, respectively.

Equation (3) can potentially capture the presence of contingency effects and offer a meaningful connectivity modelling of the influence of institutional development on the impact of renewable energy in hindering $CO2$ emissions intensity. For this purpose, it is essential to identify if the threshold level is statistically significant. Based on Equation (1), this paper constructs the null hypothesis ($H_0: \alpha_1 = \alpha_2$) that represents the threshold level of institutional quality is absent. In contrast, the alternative hypothesis ($H_0: \alpha_1 \neq \alpha_2$) that represents the threshold level of institutional quality is present.

The Data Description

Forty-six selected renewable energy-consuming countries are taken in this paper; see Appendix A, Table A1 for information on selected countries. The quantitative data are collected annually from 1998 to 2019. This paper uses the real gross domestic product (GDP) per capita as a proxy for economic growth. Institutional quality is used as a variable of institutional development. This paper uses data from various sources, namely the United States (US) Federal Statistical System, *Energy Information Administration (EIA), World Development Indicators (WDI),* and *Worldwide Governance Indicators (WGI)*. The details are as follows:

- Carbon dioxide ($CO2$) emissions: The annual series of $CO2$ emissions (million metric tonnes) is obtained from the EIA.
- Renewable energy (RE): The annual series of RE (billion-kilowatt hours) is obtained from the EIA.
- Economic growth (yg): The annual series of yg (the constant price of 2015 in the US Dollar) is obtained from the WDI.

[1] RE <0 indicates negative relationship between renewable energy and carbon dioxide emissions; see the reasoning of the relationship in Bhattacharya et al. (2017); Sharif et al. (2019).
[2] yg >0 indicates positive relationship between economic growth and carbon dioxide emissions; see the reasoning of the relationship in Jeon (2022); Li and Haneklaus (2021).
[3] TO>0 indicates positive relationship between trade openness and carbon dioxide emissions; see the reasoning of the relationship in Li and Haneklaus (2022); Dou et al. (2021).
[4] U>0 indicates positive relationship between urbanization and carbon dioxide emissions; see the reasoning of the relationship in Wang et al. (2016); Li and Lin (2015).

Journal of Tourism, Hospitality and Environment Management
JTHEM
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- Trade openness (TO): The annual series of TO (percentage of exports and imports of goods and services values as a share of gross domestic product) is obtained from the WDI.
- Urbanization (U): The annual series of U (percentage of people living in the urban areas as a share of the total population) is obtained from the WDI.
- Institutional quality (INS): The INS is calculated by taking the average of government effectiveness and regulatory quality; government effectiveness and regulatory quality are important indicators in the formation and execution of policies influencing economic activity and thus affecting environmental quality (Adekoya et al., 2022). The data of government effectiveness and regulatory quality are obtained from the *WGI*.

In line with the specification as mentioned in the Section 2.1, b, all variables are in the log form, except RE and INS.

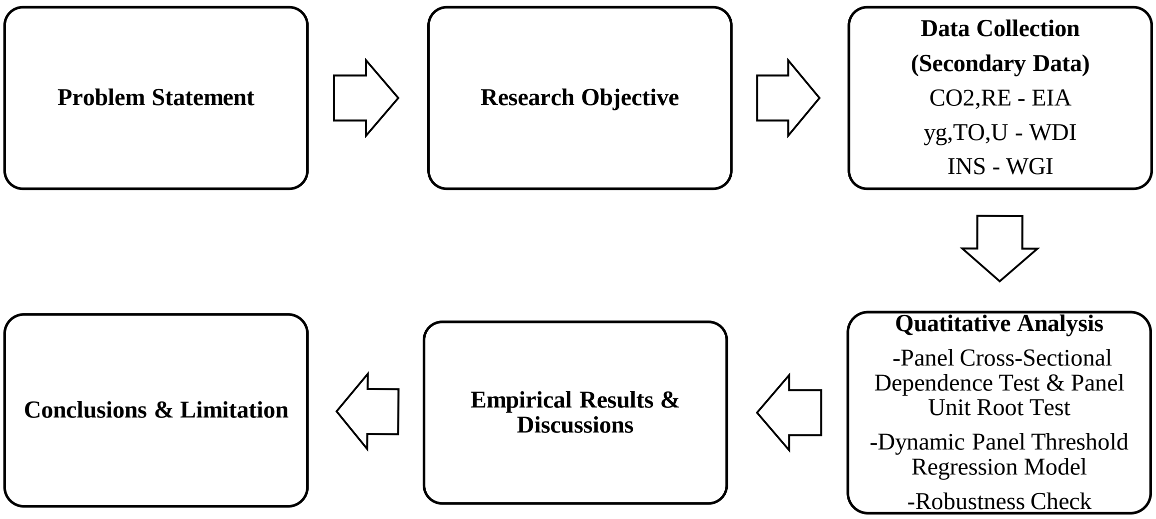

Figure 1: The Flow Chart of the Process

Table 1 illustrates some important descriptive statistics to observe the study variables' distribution and variability. The average value of the $CO2$ emissions is 565 mm tonnes and the ranges between 2.49 mm tonnes and 10773 mm tonnes. This implies a huge gap of $CO2$ emissions among the renewable energy-consuming countries. The country with the most $CO2$ emissions was China, while Iceland has the lowest emissions. In respect to the renewable energy variable, the average value is 82 billion kWh and the ranges between 0.775 billion kWh and 2006 billion kWh. This also displays the vast difference in renewable energy across the nations that use renewable energy. China is the country where consumes highest renewable energy while Morocco had the lowest consumed country. Regarding the institutional quality, the average value is 0.6885 and the ranges of the value is between -1.2241 and 2.1395. This suggests that certain countries have strong institutional quality while others have poor institutional quality. Iran is known to possess low institutional quality, whereas Denmark is rated as having high institutional quality.

Table 2 illustrates the correlation matrix to identify the existence of multicollinearity among study variables. For example, the highest correlation coefficient is 86% between yg and INS and followed by 84% between $CO2$ emissions and RE. These two combinations of correlation consider not severe concern of multicollinearity. This is because link between yg and INS is that the INS variable not included in the regression model and it serve as a threshold variable.

Journal of Tourism, Hospitality and Environment Management
JTHEM
EISSN: 0128-178X
Volume 9 Issue 36 (June 2024) PP. 18-39
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Moreover, the link between $CO2$ emissions and RE serve as dependent-independent relationship. The other combinations of the correlation coefficient value are considered moderate to low level.

Table 1: Descriptive Statistics

Variable	Unit of measurement	Mean	Maximum	Minimum	Std. Dev.	Observations
$CO2$	Mm tonnes	564.7332	10773.25	2.4912	1414.926	1012
RE	Billion kWh	82.4252	2005.877	0.775	173.2677	1012
yg	US$ 2015 constant price	22304.57	88413.19	694.7353	20924.53	1012
TO	% of GDP	68.45504	220.4068	16.4385	33.3321	1012
U	% of total population	68.734	95.426	18.196	18.8415	1012
INS	Scaled from -2.5 to 2.5	0.6885	2.1395	-1.2241	0.8633	1012

Table 2: Correlation Matrix

Variable	$CO2$	RE	yg	TO	U	INS
$CO2$	1.0000					
RE	0.8384	1.0000				
yg	0.0159	0.0752	1.0000			
TO	-0.2433	-0.2454	0.1099	1.0000		
U	-0.0583	0.0411	0.5535	-0.1202	1.0000	
INS	-0.0360	0.0189	0.8601	0.2090	0.5965	1.0000

Notes: $CO2$ = carbon dioxide emissions; RE = renewable energy; yg = economic growth; TO = trade openness; U = urbanization; INS = institutional quality.

Empirical Results and Discussions

Panel Cross-Sectional Dependence Test and Panel Unit Root Test

The preliminary test is required to be conducted before carrying out the suitable panel unit root test. It is a common presumption in panel data analysis that disturbances in panel models are cross-sectionally independent, particularly in cases of a large cross-section (N) is employed. However, cross-sectional dependency in panel data analysis seems to be happed in practice (Pesaran, 2004). As a result, presuming cross-section independence might present major issues that could lead to ineffective estimators and inaccurate test estimates. By this means, this paper begins to employ Breush-Pagan LM test, Pesaran scaled LM test, Bias-corrected scaled LM test and Pesaran CD test to investigate each time series' cross-sectional dependency. In Table 3, the cross-sectional dependence tests results show that null hypothesis of cross-sectional independence is rejected at a 1% significance level for all variables except for institutional quality (INS) variable by using Pesaran CD test. This result suggests that cross-sectional dependence appears in the panel model. This finding implies that the associated effects or linkages among research variables were truly heterogeneous across nations, which may lead to a misleading conclusion about the region if a country-specific aspect was used while studying a reaction to shock.

This study further investigating the stationary of the studied variables by employing selected panel unit root tests given that cross-sectional dependence presence across unit, which demonstrating that the panel was heterogeneous. Hence, this finding directs us to select the second-generation panel unit root test proposed by Pesaran (2007) which is known as cross-

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EISSN: 0128-178X
JTHEM
Volume 9 Issue 36 (June 2024) PP. 18-39
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sectionally augmented IPS (CIPS) test. This CIPS test able to address the issue of cross-sectional dependency. The results of the CIPS test are reported in columns 8 and 9 of Table 4. The test results show that all variables are integrated at I(1) or they are stationary at first difference. Moreover, this paper also continues to perform first generation panel unit root tests by employing LLC test for homogeneous basis whereas the IPS test and ADF-Fisher test for heterogeneous basis. Based on the results of these first generation panel unit root tests in columns 2 to 7 of Table 4, we can conclude that all studied variables are integrated at I(1) or they are stationary at first difference.

Table 3: Cross-Section Dependence Tests Results

Variable	Breush-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
$CO2$	12268.630***	246.908***	245.813***	13.197***
yg	17213.630***	355.596***	354.501***	121.865***
TO	8248.001***	158.537***	157.442***	32.783***
U	17932.240***	371.390***	370.295***	103.561***
RE	13158.850***	266.474***	265.379***	110.663***
INS	3600.102***	56.379***	55.284***	-0.149

Note: *** indicates significance at the levels of 1%.

Table 4: Panel Unit Root Tests Results

Variable	Levin-Lin-Chu (LLC)		Im-Pesaran-Shin (IPS)		ADF-Fisher		CIPS	
	Level	First difference	Level	First difference	Level	First difference	Level	First difference
$CO2$	-0.666	-8.841***	0.717	-10.117***	83.297	271.227***	-2.346	-4.519***
yg	-1.291	-7.495***	-0.187	-6.155***	94.507	190.768***	-2.285	-3.129***
TO	-4.062***	-15.951***	-3.028***	-13.308***	138.093***	337.000***	-2.285	-3.778***
U	-2.032**	-82.891***	-2.251**	-37.333***	175.997***	354.855***	-3.069***	-2.752**
RE	0.068	-10.752***	1.458	-12.875***	106.681	332.420***	-2.947***	-4.886***
INS	-2.044**	-8.031***	-2.563***	-10.517***	141.055***	274.583***	-2.530	-4.512***

Note: *** and ** indicate significance at the levels of 1% and 5%, respectively.

Journal of Tourism, Hospitality and Environment Management
JTHEM
EISSN: 0128-178X
Volume 9 Issue 36 (June 2024) PP. 18-39
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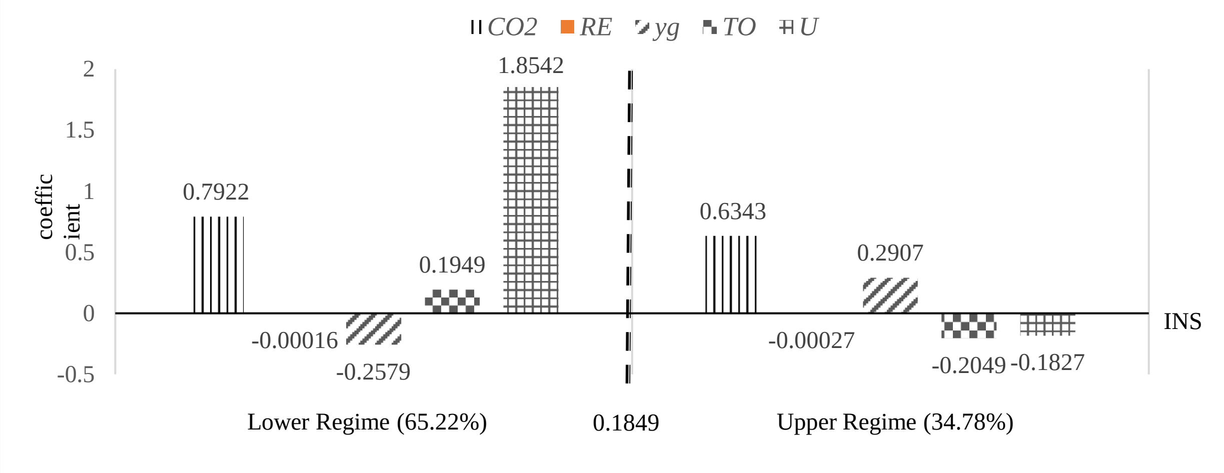

Figure 2: Estimation Results of Dynamic Panel Threshold Model (Threshold Variable: INS)

Source: All authors

Dynamic Panel Threshold Regression Model Results

To investigate the effect of the renewable energy on $CO2$ emissions at different level of institutional quality within the similar structure, a dynamic panel threshold regression model is used.

Figure 2 displays the estimation results of the model for the effect of renewable energy (RE) on $CO2$ emissions ($CO2$) at the lower and upper regimes of institutional quality. Table 5 provides comprehensive information. This paper employs institutional quality as threshold variable with the threshold value (γ) is expected at 0.1849. The presence of a threshold effect is confirmed by the fact that it meets the bootstrap linearity test at the 1% significance level in Table 5. Moreover, Table 5's results reveal that at a 1% level of significance, it has positive and statistically significant effect between the emission of $CO2$'s past value ($CO2_{it-1}$) and present $CO2$ emissions. The paper employs the dynamic panel threshold model instead of static threshold estimation methods as the result of significance of the lagged dependent variable. Besides, 65.22% of the observations came within the lower regime, whereas 34.78% fell under the upper regime.

Renewable energy and $CO2$ emissions are significantly negatively associated as depicted in Figure 2. The renewable energy is beneficial and negatively affects $CO2$ emissions at lower and upper institutional quality threshold levels in a different regime. Moreover, the negative effect of renewable energy on $CO2$ emissions in the upper regime is larger relative to the lower regime. The estimated coefficient of renewable energy in the lower regime is -0.00016. The threshold value is 0.1849, significant at the 1% level. This indicates that a 1 billion kWh increase in the renewable energy will lead to a 0.016% reduction in $CO2$ emissions in the lower institutional quality regime. However, when institutional quality exceeds the threshold (γ=0.1849) and reaches the upper regime, the coefficient of renewable energy is -0.00027. Specifically, every 1 billion kWh increase in the renewable energy, $CO2$ emissions decrease by 0.027%. This result implies that the growth of renewable energy will mitigate $CO2$ emissions greatly in upper institutional quality regime as compared with lower institutional quality regime. This finding is supported by Bhattacharya et al., (2017). They suggest that well institutional arrangement and good institutional quality allow government to enforce

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JTHEM
EISSN: 0128-178X
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appropriate subsidies, tax rates and relevant policies in the energy sector especially speed of adoption of renewable energy to minimize $CO2$ emissions. Countries with higher institutional quality place a higher importance on the adoption of effective policies to discourage the use of conventional fossil fuel energy sources as part of their overall effort to minimize $CO2$ emissions by increasing the amount of renewable energy in their entire energy mix. On the other hand, majority of the developed countries have better quality institutions. Governments and individuals will have greater financial ability to invest and adopt ecologically friendly goods, and they will be more conscious of the environmental impact of their actions. This contributes to a more efficient and natural reduction of $CO2$ emissions.

According to the coefficient of the emission of $CO2$'s past value, which is considerably positive in both regimes, present $CO2$ emissions rise in response to an increase in prior $CO2$ emissions. Specifically, present $CO2$ emissions of lower and upper institutional quality regimes increase by 7.9% and 6.3%, respectively, for every 10.0% increase in the $CO2$ emissions of the preceding period. These findings imply that a decrease in the $CO2$ emissions of the past inhibit an increase in the $CO2$ emissions of the present. With respect to the control variables, the coefficient of economic growth (yg) is significantly negative for lower institutional quality regime but significant and positive relationship in upper institutional quality regime. Precisely, for every 10% improvement in economic growth, the $CO2$ emissions in the lower institutional quality regime decreases by 2.6%. However, when a country surpasses the threshold value and attains the upper institutional quality regime, the $CO2$ emissions increase by 2.9% for every 10% increase in economic growth. This finding is consistent with Abid (2016). The higher quality of institutional indicates that improvements in the rule of law and regulatory quality promote economic growth and raise $CO2$ emissions. The findings show that the scale effect of economic expansion has a negative impact on the environment. This effect shows a rise in economic activity in the lack of technical innovation, which has a significant impact on the environment as higher output uses more natural resources and generates additional costs, such as emissions. Furthermore, our finding reveals that improvement in economic growth would decreases $CO2$ emissions in the lower institutional quality regime. This finding could be caused by the potential of corruption on pollution in the lower quality of institution in which whoever acts first—the bribe provider (polluter) or the bribe taker (enforcing official). In this scenario, it is clear that the majority of bribe givers (polluters) take action first by offering bribes even before emissions actually take place. Polluters can influence enforcement officers to misreport or not record their emissions by offering bribes to them and subsequently the $CO2$ emissions are shown to decline (Cole, 2007; Goel, 2013).

The trade openness (TO) has a significant and positive relationship in lower institutional quality regime but significant and negative relationship in upper institutional quality regime. The coefficient of trade openness in lower regime is 0.1949 whereas for upper regime is – 0.2049. This indicates that a 10% increase in the trade openness leads to increase $CO2$ emissions by 1.9% in lower institutional quality regime while reducing $CO2$ emissions by 2.0% in upper institutional quality regime. Trade openness will not significantly raise overall energy consumption while encouraging foreign investment to support economic growth since countries with good institutional quality and strong renewable energy development have relatively lower reliance on international trade (Yu et al., 2022). As a result, this has a significantly influence on the reduction of $CO2$ emissions for upper institutional quality regime nations. Moreover, countries with a high level of institutional quality and renewable energy development have stricter environmental protection regulations. High-energy-use and high-

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DOI 10/35631/JTHEM.936002
emissions manufacturing industries will move to rural areas or underdeveloped nations. It will be challenging for them to access foreign countries' domestic markets (Färe et al., 2005; Xu, 2000).

The coefficient of urbanization (U) has a significant and positive relationship in lower institutional quality regime but significant and negative relationship in upper institutional quality regime. In other words, the $CO2$ emissions of lower institutional quality regime increase by 1.8% for every 1% increase in urbanization. However, the $CO2$ emissions reduce by 0.18% for every 1 % increase in urbanization for upper institutional quality regime. This finding is in line with Chen et al. (2021). They suggest that the impact of urbanization on carbon emissions has been significantly influenced by the quality of institutions. Good quality of institutions such as government effectiveness is said to have an impact on every aspect of a nation, including energy consumption, environmental protection, rule of law, regulatory quality, and economic growth. Governments tend to successfully embrace environmental protection and sustainable policies through boosting government effectiveness, which includes adopting suitable and sustainable policies, developing compliance methods, and putting into place fair laws (Jayachandran, 2015). Moreover, Lister (2018) reveals that the indirect effects of urbanization on carbon emissions, particularly those caused by government policy involvement, aids in the development of practical mitigation strategies for environmental deterioration. For instance, countries with stronger institutions will need to reintegrate direct carbon reduction recommendations together with indirect supporting climate measures in order to achieve deep decarbonization. Lee et al. (2022) suggest that institutional quality has a crucial role in determining the relationship between urbanization-environment. The basic assumption behind the institutional link between urbanization and environmental pollution is that stronger institutional quality may have an impact on a region's rural-to-urban migration strategy, which in turn may reduce the impact on climate change.

Table 5: Dynamic Panel Threshold Estimations Results

	Lower regime $\boldsymbol{\beta}$	**Difference** $\boldsymbol{\delta = \lambda - \beta}$
$CO2_{it-1}$	0.7922***	-0.1579***
	(0.0234)	(0.0237)
RE_{it}	-0.00016***	-0.00011***
	(0.00002)	(0.00004)
yg_{it}	-0.2579***	0.5486***
	(0.0759)	(0.0847)
TO_{it}	0.1949***	-0.3998***
	(0.0219)	(0.0265)
U_{it}	1.8542***	-2.0369***
	(0.2897)	(0.1982)
constant		6.3729***
		(0.6240)
Threshold value (γ)	0.1849***	
95% confidence interval	[0.0542, 0.3156]	
Percentage (%)	65.22	34.78
Bootstrap p-value for linearity test	0.000***	

Journal of Tourism, Hospitality and Environment Management
EISSN: 0128-178X
JTHEM
Volume 9 Issue 36 (June 2024) PP. 18-39
DOI 10/35631/JTHEM.936002

Number of moment conditions	500
N	46

Notes: ***, ** and * indicate significance at the levels of 1%, 5% and 10%, respectively. The standard errors are reported in parentheses. The value of grid points, bootstrapping and trim rate are set as 50, 100 and 0.4, respectively. The estimation results are obtained using Stata 17 with the commands of "xthenreg".

Robustness Check

This study applies two alternative regression models to examine the robustness of the regression model in the preceding section, namely Seo et al.'s (2019) dynamic panel threshold regression model with a kink and Kremer et al.'s (2013) dynamic panel threshold regression model.

Early empirical works on threshold-based models often presume that the regression function is discontinuous, even though the function may indicate a kink (continued) rather than a discontinued connection (Seo and Shin, 2016; Seo et al., 2019). The threshold approach proposed by Seo et al. (2019) can address this shortcoming; see Appendix B1 for Seo et al.'s (2019) dynamic panel threshold regression model with a kink.[5] Table 6, Model I, presents the threshold estimates using Seo et al.'s (2019) approach. The coefficient of kink slope is statistically significant, which means the presence of a kink in the threshold model. The threshold value ($\hat{\gamma}$) of institutional quality is 0.1472. Besides, the coefficient of renewable energy (RE) in the lower and upper regimes is statistically significant and negative, and these findings are in line with those in Figure 2. Specifically, the coefficient of renewable energy in the lower and upper regimes is -0.00014 and -0.05074, respectively. This suggests that renewable energy has a greater negative impact on $CO2$ emissions in the upper regime than it does in the lower regime. This finding shows that even after taking into account the existence of a kink, the regression findings still confirm the earlier conclusions. In addition, most other variables' signs and significance supports the findings shown in Figure 2, indicating the robustness of the empirical findings in the preceding section.

Additionally, to Seo et al.'s (2019) threshold approach, this study employs the dynamic panel threshold regression model proposed by Kremer et al. (2013); see Appendix B2 for Kremer et al.'s (2013) dynamic panel threshold regression model Specifically, the Kremer et al. (2013) threshold approach solely considers the nonlinear link between renewable energy and $CO2$ emissions. Table 6, Model II, presents the threshold estimates using Kremer et al.'s (2013) approach; this estimation takes the emission of $CO2$'s past value as the instrument variable of the endogenous variable ($CO2_{it-1}$) and institutional quality as the threshold variable. The threshold value ($\hat{\gamma}$) of institutional quality is 0.2840. In both the lower and upper regimes, the coefficients of renewable energy are statistically significant and negative. Overall, the threshold findings in this section corroborate the result in Figure 2. The defined threshold value in the preceding section indicates the influence of institutional development that triggers renewable energy's functioning in hindering long-run $CO2$ emissions intensity.

[5] This threshold approach offers two advantages: it can impact the dependent variable's (i.e., $CO2$'s) starting level on its current level in solving endogeneity problems and illustrate the true relationship pattern (e.g., discontinued or kinked) among variables in the model once the institutional quality exceeds a certain threshold level.

Journal of Tourism, Hospitality and Environment Management
JTHEM
EISSN: 0128-178X
Volume 9 Issue 36 (June 2024) PP. 18-39
DOI 10/35631/JTHEM.936002

Table 6: Alternative Dynamic Panel Threshold Regression Results

	Model I	Model II
Threshold value ($\hat{\gamma}$)	0.1472***	0.2840
95% confidence interval	[0.0784, 0.2160]	[-0.2077, 0.9067]
Impact of RE		
Below the threshold ($\hat{\beta}_1$)		-0.0000903**
		(0.0000409)
Above the threshold ($\hat{\beta}_2$)		-0.0004438***
		(0.0001426)
RE_{it}	-0.00014***	
	(0.000007)	
Impact of covariates		
$CO2_{it-1}$	0.9677***	0.9288***
	(0.0182)	(0.0296)
yg_{it}	-0.0705***	0.0273
	(0.0147)	(0.0461)
TO_{it}	-0.0112***	0.0235
	(0.0048)	(0.0150)
U_{it}	0.6231***	0.1481
	(0.0785)	(0.1870)
constant		-0.5777
		0.4646
Kink slope	-0.0506***	
	(0.0073)	
Bootstrap p-value for linearity test	0.0000	
N	46	46

Notes: *** and ** indicate significance at the levels of 1% and 5%, respectively. The standard errors are reported in parentheses. Model I and II estimate results are obtained using Stata 17 with the commands of "xthenreg" and "xtendothresdpd".

Conclusion

This paper examines the role of institutions in mediating the influence of renewable energy on carbon dioxide emissions; in addition to renewable energy, other control variables are encompassed, namely economic growth, trade openness, and urbanization. This study includes forty-six selected countries. The data are collected yearly from 1998 to 2019. Using the dynamic panel threshold method, i.e., Seo and Shin (2016), the results show a threshold effect in the relationship between renewable energy and carbon dioxide emissions; renewable energy impacts carbon dioxide emissions after institutional development attained a certain threshold level. Renewable energy can only significantly reduce carbon dioxide emissions when institutions, such as laws and regulations, have reached a certain level of development. In other words, for renewable energy to be truly effective in reducing $CO2$emissions, the supporting rules and systems must be strong enough. This contribution is crucial for governments and organizations, as it highlights the importance of not only having renewable energy, but also establishing robust institutions to effectively reduce the $CO2$ emissions. In the future, policymakers may apply this knowledge to prioritize building and strengthening institutions

Journal of Tourism, Hospitality and Environment Management
JTHEM
EISSN: 0128-178X
Volume 9 Issue 36 (June 2024) PP. 18-39
DOI 10/35631/JTHEM.936002
that support renewable energy. This could involve implementing clearer and more supportive regulations, investing in infrastructure, and promoting education and awareness about sustainable practices. By doing so, society may ensure that renewable energy has a more significant and positive impact on reducing carbon dioxide emissions, helping to combat climate change more effectively.

To test the robustness of the results, two alternative dynamic panel regression models, i.e., Seo et al.'s (2019) dynamic panel threshold regression model with a kink and Kremer et al.'s (2013) dynamic panel threshold regression model, are applied. These results are sensible and corroborate the findings mentioned above. With respect to the control variables, the findings propose that economic growth may promote the $CO2$ emissions in the strong institutions whereas economic growth may impede the $CO2$ emissions in the weak institutions. Moreover, trade openness and urbanization may increase the $CO2$ emissions in the weak institutions while both of them will hamper the $CO2$ emissions in the strong institutions. This study cannot be concluded without a consideration of its limitations. Firstly, this study only includes economic growth, trade openness and urbanization as a control variable. Future researchers may include more control variables of $CO2$ emissions in order to obtain more meaningful information. Secondly, this study only considers forty-six renewable energy-consuming countries. It is suggested that future research can collect data from more countries and categorise them as developed or developing countries. Therefore, it can acquire additional outcomes for the research. Lastly, this study only includes renewable energy as a key variable in the model. Both renewable and non-renewable energy sources might be considered for inclusion in the model in the future study.

Declaration of Competing Interest

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

Acknowledgments

We extend our deepest gratitude to anonymous reviewers for their insightful comments and constructive suggestions that considerably contributed to the refining and enhancement of the article.

Appendix A

Table A1 List of 46 countries

Argentina	Australia	Austria	Brazil
Bulgaria	Canada	Chile	China
Colombia	Denmark	Egypt	Finland
France	Germany	Ghana	Greece
Iceland	India	Indonesia	Iran
Italy	Japan	Malaysia	Mexico
Morocco	Netherlands	New Zealand	Norway
Pakistan	Peru	Philippines	Poland
Portugal	Romania	Russia	South Korea

Journal of Tourism, Hospitality and Environment Management JTHEM
EISSN: 0128-178X
Volume 9 Issue 36 (June 2024) PP. 18-39
DOI 10/35631/JTHEM.936002

Spain	Sri Lanka	Sweden	Switzerland
Thailand	Turkey	United Kingdom	United States
Uruguay	Vietnam		

Appendix B1
Seo et al.'s (2019) dynamic panel threshold regression model with a kink

According to Seo and Shin (2016), the discontinuity of the regression function (Jump model) normally occurs on most of the threshold model. With this weakness, Seo et al. (2019) proposed regression function that consists of continued or not a jump relationship (Kink model). The Equation (B1.a) is illustrated the regression function that consists of lagged dependent variable, endogenous covariates and kink restrictions.

$$CO2_{it} = \alpha_i + \mu_i + \beta X'_{it} + (1, X'_{it}) + \delta I(INS_{it} > \gamma) + \varepsilon_{it} \quad \text{(B1.a)}$$

With the first difference transformation through the generalized method of moments estimator, it can eliminate the incidental parameter and individual effects (δ and μ_i). Hence, Equation (B1.a) can be converted to become:

$$CO2_{it} = \alpha_i + \beta X'_{it} + k(INS_{it} - \gamma)I(INS_{it} > \gamma) + \varepsilon_{it} \quad \text{(B1.b)}$$

i = 1, …, n and t = 1, …, T. Sample size (n) is allowed to be large until ∞ and T is supposed to be fixed. X'_{it} consists of parameter of all endogenous variables which comprises the lagged dependent variable ($CO2_{it-1}$). The $k(\cdot)$ denotes as kink restriction. γ is the threshold parameter. INS_{it} is the threshold variable (institutional quality). α_i is the country-specific fixed effect and ε_{it} is the error term.

Appendix B2
Kremer et al.'s (2013) dynamic panel threshold regression model

Using expanded methods of moments type estimators to address endogeneity, Kremer et al. (2013) extend Hansen (1999) original static panel threshold estimate and Caner and Hansen (2004) cross-sectional instrumental variable threshold model. To robustness check the possibility of threshold effects in the relationship between renewable energy and $CO2$ emissions. This study considers the dynamic panel threshold model as follows:

$$\begin{aligned} CO2_{it} = {} & \mu_i + \beta_1 RE_{it} I(INS_{it} \le \lambda) + \delta_1 I(INS_{it} \le \lambda) + \beta_2 RE_{it} I(INS_{it} > \lambda) \\ & + \gamma X_{it} + \theta_{it} + \varepsilon_{it} \end{aligned} \quad \text{(B2.a)}$$

where μ_i is the country specific fixed effect, θ_{it} is the time effect, ε_{it} is the residual which assumed to be $\varepsilon_{it} \sim (0, \sigma^2)$. The institutional quality (INS) is the threshold variable used to split the sample into regimes and λ is the unknown threshold parameter. $I(\cdot)$ is the indicator function, in which takes the value 1 if the argument in parenthesis is valid, and 0 otherwise. When using this type of modelling technique, the influence of renewable energy (RE) can vary depending on whether INS is below or above some unknown level of λ. The term X_{it} refers to a vector of explanatory regressors, for which the slope coefficients are all supposed to be

Journal of Tourism, Hospitality and Environment Management
EISSN: 0128-178X
Volume 9 Issue 36 (June 2024) PP. 18-39
DOI 10/35631/JTHEM.936002

regime independent. These regressors include lagged values of the dependent variable, other endogenous factors, as well as exogenous variables. The impact of renewable energy on $CO2$ emissions will be $\beta_1(\beta_2)$ for countries in a low (high) level of institutional quality regime. We also take into account differences in the regime intercepts (δ_1).

Appendix C

Variables Affecting $CO2$ Emission	Authors	Findings
Renewable Energy	Bilgili et al., 2016; Yuping et al., 2021; Zaman et al., 2021; Kirikkaleli et al., 2021; Haldar and Sethi, 2021; Cai et al., 2018; Zafar et al., 2019.	Renewable energy is able to reduce carbon emission
Institutional Quality (Direct Effect)	Godil et al., 2020; Le and Ozturk, 2020; Yang et al., 2022; Obobisa et al., 2022; Ibrahim and Law, 2015	Institutional quality increases the CO_2 emissions
	Ibrahim and Law, 2015; Salman et al., 2019.	Institutional quality is environmental improving by reducing the carbon emission
Institutional Quality (moderating effect)	Ibrahim and Law, 2015; Godil et al., 2020; Mehmood et al., 2020; Yang et al., 2022.	Institutional quality interacts with other variables to reduce CO2 emission
Economic Growth	Alam et al., 2016; Ahmad et al., 2017; Dong et al., 2018; Marques et al., 2018; Yao et al., 2019; Ridzuan et al., 2020; Sun et al., 2020; Pata and Aydin, 2020.	Inverted U-shaped relationship between economic development and carbon emission
Trade Openness	Zheng and Shi, 2017; Liu et al., 2018; Cai et al., 2018; Sarkodie and Strezov, 2019; Mert and Caglar, 2020.	Pollution haven hypothesis
	Benzerrouk et al., 2021; Kisswani and Zaitouni, 2021.	Mixed result between pollution haven and pollution halo hypothesis
Urbanization	Charfeddine and Mrabet, 2017; Liobikienė and Butkus, 2019.	Either accelerate or ease the emission
	Wang et al., 2021; Shahbaz et al., 2016.	Inverted U-shaped relationship between urbanization and emission

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