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Assessing the Impact of Energy Efficiency and Natural Resource Rents on Carbon Emissions: Evidence from Major Carbon Emitting Countries

Abstract

The preservation of natural resources, ecosystem balance, and long term economic growth, are essential for environmental sustainability, and well-being for future generations. This study attempts to investigate the factors responsible for carbon dioxide emissions, in ten major carbon emitting countries. Using panel data from 1990–2021, the study applies co-integration, slope homogeneity, and cross-section dependency tests. Results reveal a long-run relationship between CO_2 emissions, energy efficiency, and resource rents. Energy efficiency and renewable energy consumption significantly reduce CO_2 emissions, whereas natural resource rents, urbanization, and economic growth increase emissions, reflecting environmental trade-offs. Moreover, Granger causality analysis shows the results are robust and confirms a bidirectional causal relationships between CO_2-emissions and economic growth, renewable energy, and energy efficiency, while unidirectional linkage between natural resource rents and urbanization.

Keywords: Energy Efficiency, Natural Resources Rents, Carbon Emissions, Major Carbon Emitting Countries

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Assessing the Impact of Energy Efficiency and Natural Resource Rents on Carbon Emissions: Evidence from Major Carbon Emitting Countries

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Contents

Abstract

The preservation of natural resources, ecosystem balance, and long term economic growth, are essential for environmental sustainability, and well-being for future generations. This study attempts to investigate the factors responsible for carbon dioxide emissions, in ten major carbon emitting countries. Using panel data from 1990–2021, the study applies co-integration, slope homogeneity, and cross-section dependency tests. Results reveal a long-run relationship between CO_2 emissions, energy efficiency, and resource rents. Energy efficiency and renewable energy consumption significantly reduce CO_2 emissions, whereas natural resource rents, urbanization, and economic growth increase emissions, reflecting environmental trade-offs. Moreover, Granger causality analysis shows the results are robust and confirms a bidirectional causal relationships between CO_2-emissions and economic growth, renewable energy, and energy efficiency, while unidirectional linkage between natural resource rents and urbanization.

Keywords:

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Introduction

In recent decades, a significant global economic concern has been the impact of climate change. According to Miralles-Quirós and Miralles-Quirós (2022), the primary cause of global warming is the reliance on fossil fuels. The strong emphasis on the use of fossil fuels makes carbon dioxide CO_2 released into the atmosphere trap heat, contributing to global warming, as highlighted by Mathew (2022) and Millar et al. (2017). The fossil fuels account for approximately 90% of global CO_2 emissions (Olivier et al., 2012; Shayanmehr et al., 2020). "Carbon dioxide (CO_2) emissions have risen by 88% over the past decade, where the levels have increased from 25 million kilotons in 1990 to 40.84 million kilotons in 2020" (World Bank, 2020).

As per CO_2 top emissions are largely developed nations, with nine belonging to the G20 members. As per the 2003 report of "Emissions Database for Global Atmospheric Research"

In this context, China ranks 1st in the list with 12,666.43 million tons of emissions, whereas the United States and India were at 2nd and 3rd place with 4,853.78 million tons and I2,693.03 million tons of emissions respectively (Crippa et al., 2023).

Carbon dioxide emission differs across countries due to specific economic characteristics of each country in shaping CO_2 emission levels (Disli et al., 2016). Major factors driving these CO_2 emissions include growth in population, energy usage, economic development, and technological changes (Bouri et al., 2023; Lee et al., 2022; Li et al., 2023; Ma et al., 2023). Though economic growth is the key driver of CO_2 emissions, due to differences in the growth trajectories, we may see different results (Grossman & Krueger, 1991, 1995). A well-known concept of "Environmental Kuznets Curve" (hereafter EKC) establishes a link between income and environmental quality in the form of a U-shaped curve (inverted). According to EKC, carbon emissions increase as economic growth increases to a certain tipping point and then decline. This hypothesis has been widely tested over the last twenty years (Ahmad et al., 2017; Lee, 2019; Wang et al., 2023, etc).

In addition, most of the existing literature focuses on growth, energy sources (including both renewable and non-renewable), trade openness, and other macroeconomic factors (Dauda et al., 2021; Mahmood et al., 2019); Mukhtarov et al. (2022), Radmehr et al. (2021); and Naz et al. (2018). A study assessing CO_2 emissions due to energy efficiency was done in the UK and Scotland, where it was found that the role of energy efficiency is significant in lowering CO_2 emissions in Scotland as compared to the UK. Results also suggest that energy efficiency, which would further reduce CO_2 emissions, should be the main priority of Scotland and the United Kingdom (Kelly, 2006). Similarly, a study was done to check the impact of energy efficiency standards on CO_2 emissions in Germany. The study results have shown that energy efficiency standards are important in reducing CO_2 emissions, while the highest abatement rate could be attained in the building and transportation sectors. Moreover, the research has portrayed that energy efficiency standards incur low economic cost and would not hinder economic growth in Germany. The analysis indicates that energy efficiency standards will remain a critical driver of reducing CO_2 emissions and enabling the German economy to meet its targets to overcome the challenges of climate change (Blesl et al., 2007).

Another study was done in Thailand, where an attempt was made to investigate how low-carbon efficiency and renewable energy plans affect energy consumption and emissions (particularly in the long run). The findings reveal that the proposed plan will dampen energy demand, resulting in reduced CO_2 emissions. Results of the study also show that this plan will be helpful in meeting its energy and climate goals (Wongsapai et al., 2016). Results also suggest that natural resource rents increase CO_2 emissions, thereby benefiting the natural environment (Joshua & Bekun, 2020).

It is very important to examine the role of carbon emissions and environmental sustainability while examining the role of resource rents. The economies that are rich in the form of natural resources are expected to grow at a faster rate compared to those lacking the availability of capital and human resources(Huang et al., 2020; Ncube & Koloba, 2020; Umar et al., 2020). The issue of CO_2 emissions has always remained a big challenge across the globe, particularly in emerging economies, in terms of global share. The increase in CO_2 emissions is largely due to the reliance on fossil fuels in these countries, which is adding to the challenges the world is facing in the form of climate change, environmental degradation, and global warming. It is very surprising to note that the relationship between economic growth and CO_2 emissions is much complex since the findings contradict across countries due to the differences in technological progress, energy usage, and the structure of the economy. The well-known Kuznets curve links this relationship, where at a certain threshold point of development, emissions begin to decline. This paper is an attempt to investigate the factors contributing to CO_2 emission in major carbon-emitting countries with special attention to energy efficiency and natural resource rents.

Statement of Problem

Major high-carbon-emitting economies are usually caught in a dilemma between economic growth on one hand and the call for environmental sustainability on the other. Although the improvement in energy efficiency remains critical for reducing the rate of emissions, these economies are often heavily dependent on natural resource rents, which raises the tendency for higher emissions due to the extraction and usage of such resources. Although energy efficiency and natural resource rents are debated, how these factors affect carbon emissions, along with other critical factors like economic growth, urbanization, and renewable energy adoption, is not very clear. The existing literature hardly explores the effect of both energy efficiency & resource rents, which is largely focused on individual effects, either of energy efficiency alone or natural resource rents, on carbon emissions. While focusing on the existing studies, the majority of the literature suggests that energy efficiency can bring a reduction in emissions through the availability of better technologies with less energy consumption, with fewer studies available, which highlights the role of resource rents in supporting or hindering environmental sustainability. The relations of economic growth, urbanization, and adoption of renewable energy, on one hand, and energy efficiency and natural resource rents, on the other, have been studied in isolation, but not in one single study. Therefore, this present study will address this lacuna by investigating how both energy efficiency and natural resource rents, along with economic growth, urbanization, and renewable energy, interactively determine the CO_2 emissions in the world's 10 major carbon-emitting economies. Consequently, this study will fill that knowledge gap and provide critical insight into the numerous complicated interactions among these factors to better inform climate policy.

The rest of the paper is synthesized as follows: Chapter 2 provides a brief literature review, Chapter 3 explains the data and methodology used in the paper, Chapter 4 outlines the results of the analysis, and lastly, Chapter 5 discusses the conclusion and offers policy recommendations.

Literature Review

Over time, the issue of rising levels of carbon dioxide (CO_2) emissions has gained significant attention across academic, policy, and global levels. A significant amount of literature has been written to explore the various factors affecting CO_2 emissions with special emphasis on the role of energy efficiency, renewable energy adoption, resource rents, etc. The findings of this research highlight the role energy efficiency is playing in reducing CO_2 emissions, especially in developed countries where the role of economic and behavioral factors is very important in shaping these outcomes. At the same time, it has been shown that natural resource rents in resource-rich countries often contribute to higher emissions, although the impact varies across the countries depending on institutional quality and the extent of renewable energy integration.

In addition, it has been widely recognized that renewable energy has a significant potential in lowering CO_2 emissions, but its effectiveness is constrained by the level of economic development, regulatory frameworks, institutional capacity, and human capital. Overall, the existing literature suggests that while technological and environmental strategies like energy efficiency and renewable energy are important, their role is significantly influenced by socio-economic and geographical factors.

Theoretical Review

Most existing studies in developing countries have emphasized the impact of energy efficiency as a key factor in reducing CO_2 emissions. For instance, Tajudeen et al. (2018) revealed that energy efficiency improved in the OECD countries solely as a means of reducing carbon intensity in ways that would ensure significant reductions in CO_2 emissions. According to their study, they have gone further to note that factors outside the economic scope, such as consumer behavior and environmental consciousness, are as crucial to the effect of energy efficiency on emissions as economic considerations, such as cost. Akram et al. (2020) in their study emphasized the role of EKC in this area and observed that energy efficiency helps in reducing

CO_2 emissions. In the case of developing economies like Malaysia, it is also observed that energy efficiency can be helpful in reducing CO_2 emissions while proposing some "Millennium Development Goals" (hereafter MDGs) by aligning them with their " Sustainable Development Goals" (hereafter SGDs (Zaid et al, 2014). The study also explained how crucial it is to reduce energy consumption when it comes to emissions of greenhouse gas (GHG). According to Xu & Xu (2022) and Yang & Song (2023), the prevalence of mental disorders has been rapidly increasing. Energy has a significant share in the world's GHG emissions, substantially because of how it is utilized. Therefore, if people pay more attention to attaining energy-efficient standards, we can genuinely reduce them and foster adequate growth. According to the studies conducted by Korkut Pata et al. (2023), climate change is real, and there are many opportunities to reduce our power consumption. For instance, good improvements such as enhancing the buildings and the use of appliances are very helpful! Another thing about which much needs to be done is modifying the current transport infrastructure to become less energy-intensive. Consequently, due to the above facts, it may be stated that the application of energy efficiency is indeed pivotal when it comes to the issue of carbon neutrality. Reducing energy consumption is crucial for reducing CO_2 emissions; basically, everyone knows this. It also works to combat the consequences of climate change!

There is a plethora of evidence that describes the connection between natural resource rents and CO_2 emissions as a convoluted affair, with some works pointing to more often positive connections, and other works pointing to negative connections as well. Thus, due to the extraction and use of natural resources like oil, gas, and minerals, and because they are mostly located in developing nations, resource-endowed nations exhibit higher CO_2 emissions; hence, the environmental menace. In general, there are a variety of ways in which natural resource rents influence CO_2 emissions, primarily depending on a higher or lower level of resource utilization, legislation, and utilization of renewable energy resources. Based on these findings, one can get the view that natural resources can derive economic growth, at the same time, the environment pays its cost. So, there is a need to formulate such policies that will help to bring balance in the use of resources and environmental sustainability. Therefore, transitioning to renewable energy sources is important for eliminating the negative effects of resource rents on the environment. Thus, this study stresses the importance of finding policies that combine environmental and resource policies, primarily in areas that are geopolitically risky and involve high exploitation of the resources.

While varied in different areas in terms of their institutional frameworks and levels of economic development, a big plus of renewable energy is that it has a significant effect on CO_2 emission reduction. There are several studies that show that renewable energy in both developed and developing nations has led to a reduction in CO_2 emissions, but it is often moderated by certain country-level characteristics like economic growth, technological progress, institutional strength, human capital, etc. These factors hinder the effectiveness of the use of renewable energy in achieving its emission targets. For example, those countries that have a strong governance system and a well-established regulatory framework are in a better position to implement and sustain clean energy initiatives. Apart from human capital, there is also a very important factor that plays a role in reducing emissions of renewable energy (both in developed and developing countries) (Shabani, 2024). An educated and skilled labor force is more likely to adopt, maintain, and innovate clean energy solutions. In the case of BRICS countries, though it is seen that renewable energy and human capital have a positive impact on the reduction in emissions, there is a possibility that a favorable business climate, if not properly regulated, can have paradoxical results leading to higher emissions due to increased industrial activities (Sezgin et al, 2024). This paradox highlights the complexity of policymaking in the context of economic incentives and environmental objectives. In general, the integration of renewable energy with supportive policies, effective regulations, and institutional frameworks is crucial for realizing its maximum environmental benefits and ensuring long-term sustainability.

Empirical Review

A similar acknowledgement on an international scale is Javid & Khan (2020), which mainly aims at focusing on the five top countries in the emission of greenhouse gases. They also note that energy efficiency improvements do lower emissions, although the levels of emission do not come down equally. Similarly, for China and India, for instance, the emission growth was higher than energy use, while energy efficiency improvements failed to bring down these trends. Another study done by Razzaq et al. (2021) attempts to examine the correlation between energy efficiency, solid waste recycling, and CO_2 emissions in the USA for the period between 1990 and 2017. Their findings show that energy efficiency increases economic growth and causes CO_2 emissions to fall. In a similar way, Akdag & Yıldırım (2020) investigated how efficiency in energy relates to emissions from the 1995-2016 period by applying Fixed Modified OLS (FMOLS) & Dynamic OLS (DOLS). They were also able to demonstrate that an improvement in energy efficiency means reduced emissions of greenhouse gases (GHG). From the literature, we can conclude that energy efficiency negatively affects carbon dioxide emissions.

For instance, a study concerning the BRICS countries established that the higher natural resource rents, particularly from the forest and non-renewable sources of energy, increase the CO_2 emissions caused by deforestation and changes in land use for industrial usage. Yet, Huang et al. (2023), the studies conducted for the G7 countries point out that while at lower levels of natural rents, the emissions decline sharply, specifically when environmental rules and renewable sources' implementation are added to the mix (Khaddage-Soboh et al., 2023). CO_2 emissions in thirty-eight developing and industrialized countries in the period between 1970 and 2021. The results also confirm the hypothesis that natural resource rents and geopolitical risks positively influence CO_2 emissions; it ensures that the exploitation of natural resources, together with geopolitical hazards, results in environmental pollution. However, the study also discovers that the coefficient of renewable energy shares has a mitigating effect by lowering emissions in these countries. The findings may offer important lessons to policymakers as to how natural resources may be better managed and the number of emissions lowered (Chen et al., 2023).

Empirical evidence from a variety of cross-country studies supports the theoretical claims about renewable energy's impact on CO_2 emissions. For instance, as per findings of a panel study covering 20 industrialized and 35 developing countries, renewable energy led to a reduction in CO_2 emissions, where its efficiency and impact are conditioned to the nation's economic and technological constraints (Jie & Rabnawaz, 2004). It implies that developed nations deploy renewable energy resources more effectively, whereas poor nations struggle hard to achieve the same outcome with weaker infrastructure, limited investment, and less access to technology.

Identifying threshold effects where the effectiveness of renewable energy reduces CO_2 at a certain threshold of institutional development is seen in one study. The findings emphasize the need for strong institutions with a good governance system, necessary for having an impact on energy efficiency in mitigating emissions. The findings also give useful insights that can help in making energy initiatives to succeed, thereby suggesting policy measures specific to the country's economic context and institutions.

To be brief, renewable energy is shown to effectively reduce emissions, but its success hinges on economic development, institutional strength, human capital, and supportive policies. Empirical evidence across various countries confirms these relationships, yet current studies tend to analyze these variables in isolation. The review identifies a gap in integrated analyses combining energy efficiency and resource rents with economic growth, urbanization, and renewable energy. The present study attempts to fill this gap by exploring their combined effects on CO_2 emissions in the world's top ten emitting economies, offering valuable insights for holistic climate policy development.

Data and Methodology:

Theoretical Framework

There is a need to point out fundamental economic and environmental theories that are particularly helpful in explaining the existing relationships between carbon emissions and their determinants in major carbon-emitting economies. The theoretical framework of this analysis consists of conceptions derived from the EKC hypothesis and was written by Glover (1999) based on the idea that economic growth degrades the environment. In theory, carbon emissions rise with the economic growth caused by industrialization, but ultimately fall as income levels rise and investments in cleaner technologies improve, along with the stringency of environmental regulations.

Natural resource rents are included in the Resource Curse Hypothesis (Ding & Field, 2011), which postulates that rich natural resource-rich countries fall prey to mismanagement and over-exploitation, leading to degradation in the environment and general economic progress. This highlights the fact that dependency on extraction can hamper the sustainable level of development, which worsens CO_2 emissions.

To capture the effect of energy consumption (renewable) and energy efficiency, the energy efficiency theory is applied in the analysis. According to the theory, there must be a shift to take place from fossil fuels to cleaner sources of energy, which technological changes can foster to attain sustainability in energy usage (Sovacol, 2016). The urbanization and environmental change framework considers urbanization contribution to be an important factor in releasing carbon in the atmosphere, which helps to analyze the role of growth of urban area population in affecting intercity infrastructure, energy need, and changes in lifestyles (Seto et al, 2018). This framework spells out direct and indirect factors that drive urbanization in increasing CO_2 emissions in congested regions, which are in the process of rapid industrialization.

Description of Data and Variables

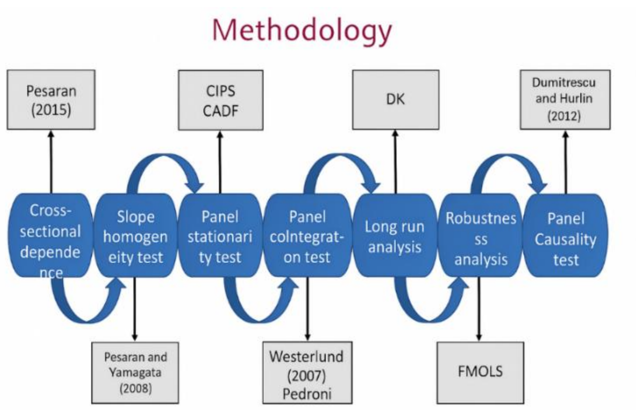
The study is a panel study. Based on the global carbon emissions worldwide, the top 10 carbon-emitting countries are selected. The time span for the study is from 1990 to 2021. Most of the data is gleaned from the World Bank database. The variables consist of "Carbon dioxide CO_2 emissions measured in metric tons per capita", "Energy Efficiency Measured in GDP per unit of energy use", "Resource Rent Total natural resource rents taken as percentage of GDP", "Renewable Energy Consumption Renewable energy consumption taken as percentage of total finalenergy consumption (% of total final energy consumption)", "Economic Growth GDP per capita (constant 2015 US$)", and "Urbanization Total urban population taken as percent of total population". Data is gleaned through the World Development Indicators database of the World Bank.

Estimation Technique

The study has employed panel data techniques. Properties of panel data, like "Slope Homogeneity" (hereafter SH) and "Cross-section Dependence" (hereafter CD), are examined first before moving to further models. Once SH and CD have been determined, unit root tests (panel) have been used to find out the trend in the behavior of the series (if any). To investigate a long-run relationship(if any) between CO_2 emissions and the other variables, the standard co-integration analysis is applied to find possible long-term linkages. Lastly, causal links between the variables are investigated, frequently by means of dynamic panel model estimates or other relevant econometric techniques. Figure 1 depicts the research methodology in brief as follows,

Figure 1

Estimation Techniques



Cross-Sectional Dependence(CD) & Slope Homogeneity (SH) Test

In the context of this study, first, the key characteristics of the panel data, including SH and CD, are discussed. Cross-sectional reliance may result from the integration of economic growth and energy efficiency in these economies, which may be caused by unobserved factors, including globalization, economic integration, and shocks that occur regionally or internationally. Before unit root testing, these issues must be resolved because skipping diagnostic tests can produce skewed findings (Breitung, 2005; Daellenbach et al., 2020). This study employs Hashem, Pesaran & Yamagata (2008) test for slope homogeneity and Pesaran (2015) test for CD, where the null hypothesis shows that there is cross-sectional independence.

Panel Unit Root Test

After examining CD and SH, stationarity of the variables is checked by applying various panel unit root tests, including CIPS and CADF tests. An estimator that can manage both panel data issues may be used in this section. The test by Im et al. (2003) assists in resolving the heterogeneous slope issue, but it is unable to resolve cross-section dependence. Therefore, the study has used the CIPS proposed by Pesaran (2007). Pesaran (2006) suggested factor modelling as a solution for cross-section dependence before Pesaran (2007). Taking common unobserved components as a representation, this tool uses averages of cross-sections. Pesaran (2007) improves the ADF regression by applying the first difference and the mean of lagged cross-sections. This strategy works well for mitigating cross-sectional dependency despite the imbalance in the panel.

Panel Cointegration Tests

The study has employed standard panel cointegration tests to investigate the long-run relationship between CO_2 emissions and their determinants, with special attention to natural resource rents and energy efficiency. Even though traditional panel cointegration methods include the Pedroni (2004) and Kao (1999) tests, their performance is relatively poor when cross-sectional dependence is present. The study also employed a panel unit root test (second-generation) like Westerlund's (2007), which assumes dependency of cross sections as it explicitly allows for unobserved common factors driving the correlations across panel units. The test considers a null hypothesis of no cointegration against alternatives: (1) cointegration in some panels, and (2) cointegration across all panels.

After confirming the long-run relationship between CO_2 emission and other explanatory variables, we initially employed the Driscoll & Kraay (hereafter DK) model for analyzing long-run results. The reason for using the DK model as the main model is that it counters the autocorrelation, heteroscedasticity, and cross-sectional problems in the panel data. For robustness analysis, we have used “Fully Modified OLS” (hereafter FMOLS) as this model solves the issues of endogeneity in the panel data. For assessing causal linkages between the variables, the study has also employed Granger causality tests (panel). The study has employed Hurlin & Dumitrescu's (2012) panel causality test to examine causal linkage (if any) between CO_2 emissions and other explanatory variables. This technique is appropriate as it solves cross-sectional dependence problems and provides reliable results. A panel causality test is done for better policy recommendations.

Results and Discussion

The analysis of descriptive statistics of the underlying variables selected for the study is depicted in Table 1. Carbon Dioxide Emissions have a mean value of about 1.836 with a standard deviation of 0.920. The same happens when for EE, whose average is around 6.471, and a standard deviation of 2.567. The variable NRR has an average value of 11.911 with a standard deviation of 14.738. It can be observed that GDP per capita has a mean of 9.160 with a standard deviation of 1.298. The variable RECS indicates the share of renewable energies in consumption, with a mean value of 12.895, and the standard deviation is 16.062. Lastly, UR has a mean of 66.150, a standard deviation of 19.143. These descriptive statistics show a clear picture of central tendency, dispersion, and range of data, hence forming a basis for further analysis.

Table 1

Descriptive Statistics

Variables	Obs	Mean Value	Median Value	Standard deviation	Minimum value	Maximum Value
CO_2	320	1.836	2.218	0.920	-0.434	3.018
EE	320	6.471	6.268	2.567	1.268	12.471
NRR	320	11.911	5.129	14.738	0.012	55.024
GDP	320	9.160	9.241	1.298	6.270	11.046
RECS	320	12.895	4.4	16.062	0	59.2
UR	320	66.150	74.368	19.143	25.547	91.867

Notes. "CO_2 and GDP are taken in log form. All other variables are measured in their respective ratio scales. EE is the energy efficiency, NRR represents natural resource rents, GDP is the Gross Domestic Product, RECS is renewable energy consumption, and UR is the urbanization rate.

Cross-Sectional Dependence and Slope Homogeneity Test Results

CD test results are reported in Table 2, which clearly shows cross-sectional dependence in the panel. Among the several available CD test statistics, most of the variables under study return significant test statistics for at least one of CO2, EE, NRR, GDP, and UR, such as CD, CDw, CDw+, and CD*. The main reason for cross-sectional dependence among the major carbon-emitting economies in the world arises due to global interdependencies. In any economy, the economic activities, environmental policies, and energy use of a country are very likely to influence others through interlinking networks of trade, technology diffusion, and environmental spillovers. These results stress the importance of accounting for CD in analyzing panel datasets. An analysis that does not account for this might make biased and unreliable conclusions, particularly for panel data analyses concerned with global phenomena like CO_2 and energy efficiency.

Table 2

CD Test Results

Variables	Statistic	CDw	CDw+	CD*
CO_2	3.27***	-2.56**	157.05***	3.10***
EE	23.33***	11.36***	169.41***	4.95***
NRR	14.34***	-0.95	121.84***	1.36
GDP	31.53***	3.77***	215.30***	0.19
RECS	0.15	-1.56	149.19***	-1.46
UR	34.85***	1.48	235.27***	-1.07

*Note: *** indicates significant at the 1% level, while ** and * denote significant at the 5% and 10% levels, respectively. "CO2 and GDP are taken in log form. All other variables are measured in their respective ratio scales. EE is the energy efficiency, NRR represents natural resource rents, GDP is the Gross Domestic Product, RECS is renewable energy consumption, and UR is the urbanization rate.*

After checking the presence of cross-sectional dependency, the results of the slope homogeneity test are shown in Table 3. From the results, it is evident that we can reject the null hypothesis of homogeneous slopes, thereby implying heterogeneous slopes. The primary explanation for this may be the differential socio-economic, political, and environmental situation of the economies considered in the study.

Table 3

Slope Homogeneity Test Results

Statistic	Value	Prob
Δ	19.766***	0.0000
Δ adjusted	22.363***	0.0000

*Notes: *** indicates significant at the 1% level, while ** and * denote significant at the 5% and 10% levels, respectively.*

Since both the CD and SH tests reject the null hypothesis of homogeneous slopes. Rather, second-generation econometric approaches considering cross-sectional dependence together with slope heterogeneity should be applied for further analysis to obtain robust and reliable results.

Unit Root Test Results

Since the results of the CD test clearly show cross-section dependency, it is suitable to employ panel unit root (second-generation) tests. The study has employed Pesaran's (2003) CADF and Pesaran's (2007) CIPS tests to account for the degree of integration among the variables. In fact, for one and for the other, the null hypothesis assumes a unit root.

The results of CADF and CIPS unit root tests for the selected variables are presented in Table 4 below. From this table, it is observed that CO_2, EE, NRR, and GDP are found to be stationary at the level, whereas RECS and UR are not stationary at levels, but are at first difference. The congruence of the test results by CADF and of CIPS strengthens the reliability of these results.

Table 4

Unit Root Test Results

Variable	CIPS		CADF	
	1(0)	1(1)	1(0)	1(1)
CO_2	-2.574***	-4.402***	-1.827**	-4.103***
EE	-2.322*	-5.329***	-0.798	-7.295***
NRR	-2.535**	-5.154***	-3.131***	-8.815***
GDP	-2.329*	-4.189***	-3.404***	-3.497***
RECS	-1.579	-4.683***	0.904	-5.437***
UR	-1.210	-1.678	2.305	0.380

*Notes: *** indicates significant at the 1% level, while ** and * denote significant at the 5% and 10% levels, respectively. "CO_2 and GDP are taken in log form. All other variables are measured in their respective ratio scales. EE is the energy efficiency, NRR represents natural resource rents, GDP is the Gross Domestic Product, RECS is renewable energy consumption, and UR is the urbanization rate.*

Co-integration Tests Results

After conducting the stationary tests, we move to check whether a long-run relationship (if any) exists between the variables present in the model. Since heterogeneous slope coefficients and CD are present among the variables, tests that consider these conditions would be expected to provide more realistic results.

The most recent of the various cointegration techniques is the Westerlund approach. It is considered to have greater power compared to earlier panel cointegration tests (based on residuals). It is more robust since it tests for the alternative hypothesis (i.e, panel is cointegrated). It provides two panel statistics, while the other two test procedures, with the assumption of at least one unit being cointegrated, result in group statistics. Table 5 depicts the results from the "Westerlund" (2007) tests for panel cointegration. The output from the model shows that all four test statistics, Gt, Ga, Pt, and Pa, are significant at 1% level with their respective p-values below 0.05. From these analyses, the results allow us to reject the null hypothesis of no cointegration, which supports the fact that there exists a long-run equilibrium relationship between the variables CO_2, EE, NRR, GDP, RECS, and UR.

Precisely, the Gt and Ga statistics show strong evidence for a cointegrated panel, indicating that there are bindings of series in the long run. The Pt and Pa statistics, which accommodate group heterogeneity when testing for cointegration, confirm further that the totality of the variables making up the panel are bound together. This means that the results of these Westerlund (2007) panel cointegration tests are supportive of a significant long-run relationship in the variables studied, further confirming that the discussed variables are cointegrated across the whole panel of economies. In other words, these results are supportive of the fact that there exists a stable long-term equilibrium linking these variables and, as such, justifies an analysis of their dynamic relationships.

Table 5

Cointegration Test Results

Statistic	Coefficient	Z-value	P-value
Gt	-4.375^{***}	-6.766	0.000
Ga	-19.375^{***}	-3.151	0.001
Pt	-13.802^{***}	-6.426	0.000
Pa	-19.438^{***}	-4.536	0.000

*Notes: *** indicates significant at the 1% level, while ** and * denote significant at the 5% and 10% levels, respectively*

Results in the Long Run

Table 6 shows the results of the long-run analysis. The DK estimation results indicate that the explanatory variables are significantly related to CO_2 emissions. Energy efficiency (EE) has a negative and significant impact on CO_2 emissions with a value of -0.080, which implies that for every 1 unit rise in energy efficiency, CO_2 emissions decrease by 0.08%; thus, forming energy-saving habits is quite important to prevent environmental decay.

On the contrary, the coefficient on NRR is positive and also significant with a value of 0.007, indicating that economies reliant on natural resource extraction tend to increase their emissions as resource rents rise. The coefficient GDP per capita is 0.457, which shows that a 1% increase in economic growth corresponds to a 0.457% rise in emissions. This highlights the environmental costs associated with growing economic activity.

The coefficient of RECS is negative as well as significant with a value of -0.020, which can be interpreted as that with increased renewable energy adoption, CO_2 emissions are brought down, while on the other hand, urbanization positively relates to emission, estimated at a coefficient of 0.005, signifying that with increased urbanization there is an increase in carbon emissions due to a rise in energy needs and transportation.

To check if the results were robust, the FMOLS method was applied. The results generally confirm the estimation made with DK, therefore further strengthening the reliability of this analysis. Energy efficiency still exerts a negative effect on CO_2 emissions with its coefficient of 0.053. Natural resource rents continue to have a positive effect of 0.003, thus confirming once more the resource reliance-emissions-increasing impact. The findings of FMOLS explain the positive relationship between GDP per capita and CO_2 emissions with a significant coefficient of 0.480. The effects of RECS and UR remained at -0.012 and 0.015, respectively, with appropriate significance. The findings are also examined by the consistency of the results between the Driscoll-Kraay and the FMOLS models. Results of both models clearly show that improvements in energy efficiency and a switch to renewable energy are the important determinants of CO_2 emissions. The negative relationship between urbanization and CO_2 emissions and the environmental trade-off associated with growth are serious challenges. These findings indicate that there is a need to devise such policies that lead to sustainable urban planning, energy transition, and growth that maintains a balance between development and environmental protection.

Table 6

Long-run Estimation Results

Variable	DK		FMOLS	
	Value	S.E	Value	S.E
EE	-0.080**	0.0071	-0.053**	0.0070
NRR	0.007**	0.0003	0.003**	0.001
GDP	0.457**	0.013	0.480**	0.047
RECS	- 0.020**	0.002	-0.012**	0.0021
UR	0.005**	0.002	0.015**	0.003

*Note: *** indicates significant at the 1% level, while ** and * denote significant at the 5% and 10% levels, respectively. "CO2 and GDP are taken in log form. All other variables are measured in their respective ratio scales. EE is the energy efficiency, NRR represents natural resource rents, GDP is the Gross Domestic Product, RECS is renewable energy consumption, and UR is the urbanization rate.*

Panel Causality Results

Establishing causality is the most important thing in coming up with effective policy recommendations from an empirical study. In this perspective, the study has applied the "Dumitrescu and Hurlin" (2012) Granger causality test to establish the effect of causality between the variables. The summarized results of the panel causality test for the model are given in Table 7.

The result brings out some important causal linkages in the CO_2 emission model. Energy efficiency and CO_2 emission are thus related bidirectionally, which, of course, means interdependence. The two-way causality between growth and CO_2 emissions shows the feedback mechanism between economic activities and their environmental cost. Renewable energy consumption and CO_2 emission also show bidirectional causality, implying again that changes in renewable energy adoption affect CO_2 emission and vice versa. Apart from the findings of the study, one-way causality between natural resource rents and CO_2 emissions. The causation between urbanization and CO_2 emission is also found to be bidirectional.

Table 7

Causality Test Results

H_0	W-Stat	Z-bar Stat	Prob
EE ≠ CO_2	3.725	5.185	0.000
CO_2 ≠ EE	2.314	2.421	0.015
NRR ≠ CO_2	2.266	2.327	0.020
CO_2 ≠ NRR	1.745	1.307	0.191
GDP ≠ CO_2	3.940	5.605	0.000
CO_2 ≠ GDP	4.229	6.171	0.000
RECS ≠ CO_2	3.991	5.705	0.000
CO_2 ≠ RECS	4.153	6.022	0.000
UR ≠ CO_2	1.972	1.752	0.080
CO_2 ≠ UR	4.780	7.287	0.000

Note. "CO_2 and GDP are taken in log form. All other variables are measured in their respective ratio scales. EE is the energy efficiency, NRR represents natural resource rents, GDP is the Gross Domestic Product, RECS is renewable energy consumption, and UR is the urbanization rate.

Conclusion and Policy Recommendations:

Conclusion

The study aims to identify the determinants of CO_2 emissions in the top ten major carbon-emitting countries over the period 1990 to 2021. For the analysis, the study has employed standard panel data techniques, including slope homogeneity and panel cointegration tests. The findings of this study unveil several interesting findings that indicate the complexity in the relationship between the variables. The result of the study finds that there exists cross-sectional dependency in the panel with slope heterogeneity. According to the unit root and cointegration test results, a long-run relationship exists between CO_2 emissions and their determinants.

In addition, estimates of DK and FMOLS (in the long run) models also show nuanced insights. Energy efficiency has a negative and significant impact on CO_2 emissions, which clearly shows the role of sustainable energy use in mitigating environmental degradation. In a similar way, renewable energy consumption showed negative effects on CO_2 emissions, which align with the global efforts of transition to cleaner energy sources. In contrast, the level of CO_2 emission is found to be positively related to economic growth and urbanization, which reflects the environmental trade-off accompanying urban expansion and industrialization. The role of natural resources was found to be a positive factor in driving CO_2 emissions, which highlights the environmental cost of resource extraction. Panel causality test results also confirm these relationships.

Policy Recommendations

Based on these results, we propose some key recommendations for policymakers as follows,

1. Since it is clearly shown that energy efficiency reduces CO_2 emissions. There must be certain environmental policies that industries must strictly follow to ensure energy efficiency standards. Fiscal incentives in the form of grants and tax credits may be provided to businesses and households to adopt energy-efficient technologies.
2. Among the key determinants, natural resource rents are found to be the key determinant. High carbon-emitting economies must reinvest these rents in key projects like the development of renewable energy and carbon capture technologies, which, together with conservation programs, can offset the environmental costs of the exploitation of these resources.
3. Urban planning policies must focus on sustainable city designs, enhanced use of public transportation, green belts, and energy efficiencies in buildings to lessen the effect of urban population growth on the environment.
4. There is a need for a sustainable growth strategy and diversification of carbon-intensive industries into low environmental impact manufacturing and service sectors.

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