Carbon Dioxide Discharges and Taxes: Analysis of the Influence of GNI Per Capita, Human Development Index, and Industrialization Level

Dashen Allen[2]
[1]University of Birmingham, United Kingdom

Abstract

This research aims to determine the fundamental link between development strategies, environmental sustainability, and economic growth, particularly examining the global impact of CO2 emissions and the influence of industrial and tax laws on the environment and economy. Using W statistics and Zbar-stat, the study determines the causal relationships among variables, employing a dynamic threshold panel data model to evaluate threshold impacts. Data from 1999 to 2022 were collected from 40 countries, categorized into developed and developing nations by the World Bank. The Dumitrescu-Hurlin Panel Causality Test and Pesaran's CD test reveal a global relationship among policy, environment, and economy, with changes in CO2 emissions and GNI per capita influencing international environmental and economic policies. Investment in human development shows a bidirectional relationship with CO2 emissions, industrialization, and taxes. Dynamic threshold panel data models indicate varying impacts of human development investments on CO2 emissions depending on their level, highlighting the need for threshold considerations in policy-making. This study offers new insights into the interplay between development strategies and environmental sustainability, contributing significantly to environmental economics and assisting policymakers in crafting more effective and sustainable programs.

Keywords: Economic Growth, Environmental Sustainability, CO2, Human Development, Tax Policy
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Introduction

Carbon dioxide (CO_2) and other greenhouse gas emissions significantly contribute to climate change. CO2 is created when fossil fuels are burned to provide power and heat. Gas, oil, or coal still provide the world's electricity, while renewable energy sources like solar and wind power only generate 25% of the world's electricity (Basilios, 2022). Fossil fuels are used in the manufacturing sector to create materials like plastic, iron, steel, and cement, which results in CO2 emissions. Globally, this is one of the leading causes of greenhouse gas emissions (Holappa, 2020). When trees are chopped down, the carbon they contain is released, which causes deforestation. Additionally, deforestation hinders nature's capacity to lower atmospheric emissions (Kumar, 2020).

Fossil fuels, mainly petroleum, power fleets of land, sea, and air. Approximately 25% of the CO2 emissions associated with energy worldwide come from transportation. Deforestation for agriculture and fertilizer use produce CO_2 emissions (Gray et al., 2021). Food production also contributes to producing methane gas and energy in agriculture. The impacts of CO_2 emissions include global warming, extreme weather, rising sea surface temperatures, and the risk of forest fires. We must reduce emissions and switch to renewable resources to balance the environment and global climate (Saini & Bhatt, 2020).

Economic growth negatively affects energy consumption but positively affects carbon dioxide discharges (Khan et al., 2020). The world needs to make more significant efforts to encourage developing countries to increase investment in green energy (Cantarero, 2020). Amid growing global concerns about climate change, Human Development's role is vital in tackling carbon dioxide discharges (Shi et al., 2023). Human Development, which includes individual knowledge, skills, and health, may contribute significantly to promoting environmental sustainability and reducing carbon footprints (Triatmanto et al., 2023). Education is the foundation of Human Development. With quality education, individuals can understand the effects of carbon dioxide discharges on human well-being and the environment. This awareness encourages more environmentally responsible actions, such as using renewable energy and better waste management (Sarwar et al., 2021). Human growth also influences the invention and development of environmentally friendly technology. With their knowledge, scientists and researchers develop creative ways to lower pollution. By actively participating in the policymaking process, the community may guarantee that its opinions are heard when laws and objectives for carbon emissions are established (Omri, 2020).

Evaluation of government regulations is an essential step in realizing the Net Zero Emission Target. Every individual has a role in reducing carbon emissions, from daily activities such as choosing public transportation and reducing energy consumption to participating in tree planting programs and managing protected forests that can absorb carbon dioxide. Collaboration between countries and inclusiveness in addressing carbon dioxide discharges are essential. Countries can share knowledge and resources to achieve international and regional emission targets (Bataille, 2020).

Human Development is integral to global efforts to address carbon dioxide discharges. Through education, innovation, policy, community participation, and global collaboration, by working together, we can overcome the effects of climate change and make sure that future generations have a more sustainable future (Opoku et al., 2022). The carbon price is becoming a hot subject in the international conversation on climate change. As a policy tool, the carbon tax lowers greenhouse gas emissions by offering financial incentives to consume less fossil fuels (Povitkina et al., 2021). The carbon dioxide tax is a progressive step towards reducing carbon dioxide discharges and addressing climate change. Through this policy, Indonesia seeks to change the behaviour of economic actors and encourage the transition to low-carbon, green economic activities. A carbon tax can be an adaptive fiscal instrument with practical implementation and contribute to sustainable development and environmental protection (Boroumand et al., 2022).

The gross national income (GNI) per person is frequently used to gauge the economic well-being of a nation. However, economic expansion, as measured by rising GNI per capita, can also lead to higher carbon dioxide (CO_2) emissions, the primary greenhouse gas responsible for climate change. According to research by Dankumo, Samad, and Zubair (2020), a positive relationship exists between CO_2 emissions and per capita GDP. This suggests that CO_2 emissions are created in proportion to a nation's per capita income. This is consistent with the Environmental Kuznets Curve, which predicts that rising incomes would be accompanied by rising pollution, including CO_2 emissions, in the early phases of economic growth.

The usage of fossil fuels and other economic activities, such as industry, are frequently linked to rising CO_2 emissions. 36.3 gigatons of CO_2 were added to world CO_2 emissions in 2021, the highest record in history. This shows that global efforts to reduce the use of fossil fuels have yet to be compelling enough to prevent dangerous climate change (Li & Haneklaus, 2021). Gross National Income per capita does reflect a country's economic growth, but this growth must be balanced with environmentally friendly policies and technologies to reduce CO_2 emissions. Policies such as carbon taxes, investment in renewable energy, and energy efficiency can help balance economic growth and environmental sustainability (Awan & Azam, 2022).

The increasing rate of industrialization has become a significant driver of global economic growth. However, because rising carbon dioxide (CO_2) emissions are a key contributor to climate change, this expansion also negatively impacts the environment (Yang & Usman, 2021). The primary cause of the rise in CO_2 is the industrial combustion of fossil fuels, including coal, natural gas, and petroleum. Deforestation, land conversion, and the usage of fossil fuels, particularly coal, are the three primary factors contributing to this growth. The entire amount of carbon emissions from fossil fuels is continuously rising despite a decline in some areas, such as the United States and Europe. This shows that global action to reduce the use of fossil fuels needs to be faster and sufficient to prevent dangerous climate change (Paraschiv & Paraschiv, 2020). The increase in industrialization does bring economic progress, but it also poses significant challenges in terms of environmental sustainability. Therefore, to implement cleaner and more efficient technologies and policies that facilitate the shift to a low-carbon economy, cooperation between the government, business community, and society is required (Raihan et al., 2022). By examining the worldwide impact of CO_2 emissions and human development, this study aims to comprehend the causal link between economic growth, environmental sustainability, and development strategies. The research evaluates the impacts of investment in human development on CO_2 emissions, examines how tax laws and industrialization affect the economy and the environment, and employs W statistics and Zbar-stat to support the causal link. The study will also employ the Dynamic Threshold Panel Data Model to assess the threshold effect in the connection and offer practical policy suggestions for sustainable economic growth and the mitigation of environmental impacts.

Literature Review

Carbon dioxide (CO_2) emissions have become an essential topic in global climate change discussions. The increase in atmospheric CO_2 concentrations, largely due to human activities since the Industrial Revolution, has led to significant climate change (Töbelmann & Wendler, 2020). Since the Industrial Revolution, CO_2 emissions have increased dramatically. The combustion of fossil fuels for industry, transportation, and energy production has been a major contributor (Ali et al., 2021).

In 2023, global emissions from fossil fuel combustion reached a record high. CO2 emissions released into the atmosphere can persist for hundreds to thousands of years. This means that CO2 released during the Industrial Revolution still affects our climate today (Murphy, 2024). In addition, CO2 released in the past has caused global temperatures to increase, resulting in extreme weather, rising sea levels, and ecosystem damage. Earth's natural carbon cycle includes the absorption and release of CO2 by the oceans, land, and biosphere. However, excessive emissions have disrupted this balance, creating feedback loops that exacerbate global warming. Permafrost thawing releases methane, a greenhouse gas more potent than CO2 (Kuhn et al., 2021). However, with coordinated global efforts and the adoption of low-carbon technologies, we can reduce the impact of past emissions and prevent future emissions from increasing (Liu et al., 2021). Based on previous research, we develop the following hypothesis:

H1. Past carbon dioxide discharges have an impact on present carbon dioxide discharges

Human development, which encompasses public health, education, and skills, is crucial to lessening the effects of carbon dioxide discharges (Szymczyk et al., 2021). Raising awareness of climate change and the significance of lowering carbon dioxide discharges is mainly accomplished via education. Through education, individuals can understand the consequences of carbon emissions and the importance of transitioning to clean energy (Hickel, 2020; Harnani et al., 2022).

Human resources' technical and professional skills can drive innovation in environmentally friendly technologies. A skilled workforce can develop and implement renewable energy solutions, energy efficiency, and sustainable industrial practices. Good public health allows individuals to participate actively in economic and social activities. Healthy communities can help with mitigation and adaptation activities related to climate change and are better equipped to deal with its effects (Ogbeibu et al., 2020).

Investing in health, education, and training and developing people can help communities become more creative and climate change-adaptive. This includes developing policies that support research and development in green technologies (Zapata-Cantu & González, 2021). Strong Human Development can create leaders and decision-makers to formulate and implement effective policies to reduce carbon emissions. Collaboration between countries is also needed to share knowledge and skills in addressing climate change. (Schröder, Lemille, & Desmond, 2020). Human Development has an inseparable role in global efforts to reduce carbon dioxide discharges and mitigate the impacts of climate change. Through education, skills development, and improved health, humans can become effective change agents in creating a more sustainable future (Tauseef et al., 2021). Based on previous research, we develop the following hypothesis:

H2. Human Development have a part in mitigating the impacts of carbon dioxide discharges

A carbon tax is a tool used in policymaking to lower carbon dioxide (CO2) emissions and other greenhouse gases. This operates by charging for the usage of fossil fuels, which emit CO2 directly (Wu et al., 2021). This tax has been implemented in various countries and has proven effective in some cases. Case studies from countries such as Finland and Sweden show that implementing carbon taxes can reduce CO2 emissions while supporting economic growth (Wolde-Rufael & Mulat-Weldemeskel, 2023). One of the main challenges in implementing a carbon tax is the socialization and public understanding of this tax. Tax leakage is also a problem if entrepreneurs do not report their actual use of fossil fuels. In addition, the increase in fossil fuel prices due to this tax can impact inflation (Mansell et al., 2021). To increase the effectiveness of the carbon tax, the government needs to carry out more intensive socialization and education. Supervision must be increased to prevent tax leakage. Other supporting policies, such as developing public transportation infrastructure and providing affordable electric vehicles, also need to be implemented. A carbon price is a valuable instrument for policymakers to slow the increase of CO2 emissions into the environment. Carbon taxes can promote the shift to a low-carbon economy and aid in addressing climate change if appropriately implemented and backed by other policy measures (Thisted & Thisted, 2020). Drawing from prior studies, we formulate the following conjecture:

H3: The increase in carbon dioxide discharges in the atmosphere can be effectively suppressed by taxes.

One metric frequently used to gauge a nation's degree of wealth is its gross national income (GNI) per capita (Méndez-Picazo et al., 2021). However, a significant influence on the environment, particularly carbon dioxide (CO2) emissions, is hidden beneath the statistics demonstrating economic success. According to Zubair, Samad, and Dankumo (2020), CO2 emissions are one of the primary causes of the greenhouse effect, which leads to global warming and climate change. Along with the increase in GNI per capita, energy consumption in a country tends to increase. This is because more excellent economic activity requires more energy, which often comes from the combustion of fossil fuels. This combustion produces CO2 as a by-product. Therefore, countries with rapid economic growth often experience increased CO2 emissions (Tudor & Sova, 2021). The Environmental Kuznets Curve hypothesis predicts that rising income will be followed by rising CO2 emissions in the early phases of economic growth. However, the correlation between income and CO2 emissions will become negative beyond a certain threshold. Accordingly, nations with increasing wealth levels tend to embrace more efficient and clean technology, which causes CO2 emissions to drop (Ahmad et al., 2021). Drawing from prior studies, we formulate the following conjecture:

H4. The increase in carbon dioxide discharges is influenced by gross national income per capita.

One of the primary causes of the rise in atmospheric carbon dioxide (CO2) emissions has been the rising degree of industrialization. Human activity, particularly the burning of fossil fuels for energy and industrial operations, has dramatically increased the amount of greenhouse gases in the atmosphere since the Industrial Revolution (Rai & Rawat, 2022).

Burning fossil fuels, including coal, natural gas, and petroleum, is the largest source of CO2 emissions. The significant energy needed to sustain expanding industrial operations is the primary cause of this growth. Achieving sustained economic development requires a structural shift from low-productivity agriculture to high-productivity industrialization. However, there are worries about how industrialization may affect the environment, particularly in light of climate change and carbon emissions (Dong et al., 2021). Otim, Mutumba, Watundu, Mubiinzi, and Kaddu's (2022) research findings demonstrated a statistically significant beneficial impact of GDP, energy intensity, and carbon intensity on CO2 emissions over an extended period. Policies and technology that are environmentally friendly are required to lessen the adverse effects of industrialization on the environment. Investments in clean and efficient technologies and regulations supporting CO2 emission reductions can help reduce the industry's carbon footprint. The level of industrialization plays a significant role in increasing carbon dioxide discharges into the atmosphere (Jia et al., 2020). However, by adopting cleaner technologies and policies that support green economic growth, we can reduce these negative impacts and move towards a more sustainable future (Ikram et al., 2021). Based on previous research, we develop the following hypothesis:

H5. The level of data gathered covers fortystrialization have a part in developing and developing each Method

Research Method

Forty nations, split into two groups, developed. Twenty nations agreed to the data gathered. The World Bank's taxonomy forms the basis of this divide. Twenty nations are in each category; the separating criteria are Gross National Income (GNI) per capita, Human Development Index (HDI), and the degree of industrialization of every nation. To facilitate analysis and reference, data from these 40 countries have been organized and presented in Table 1.

Table 1. List of Countries Studied

Developing country	Developed countries
1. Brazil	1. United States
2. India	2. Germany
3. Indonesia	3. Japan
4. Mexico	4. France
5. Philippines	5. United Kingdom
6. Egypt	6. Canada
7. Turkey	7. Australia
8. Thailand	8. Italy
9. Vietnam	9. New Zealand
10. Pakistan	10. Switzerland
11. Nigeria	11. Sweden
12. Bangladesh	12. Netherlands
13. Argentina	13. Belgium
14. Colombia	14. Austria
15. South Africa	15. Singapore
16. Malaysia	16. Denmark
17. Chile	17. Finland
18. Peru	18. Norway
19. Morocco	19. Ireland
20. Kenya	20. Luxembourg

Examining carbon dioxide emissions as the dependent variable, this paper considers independent variables like tax, gross national income (GNI) per capita, Human Development Index (HDI), and degree of industrialization. From 1999 to 2022, the study is carried out over the years to acquire a thorough awareness of the developing trends and patterns. After much effort, relevant data has been meticulously compiled and then compiled in Table 2. This table is helpful for simple access and comprehension of the employed data and plays a crucial part in offering a clear structure for the research technique. Therefore, Table 2 is a necessary instrument that helps the reader to rationally negotiate the research process and grasp how the facts supported the results derived in this study.

Table 2. Variable Description

Variable	Description	Unit Analysis	Source
Carbon dioxide discharges	Total national CO_2 emissions divided by the midyear population	$MtCO_2$ per capita	globalcarbonatlas.org
Taxes	Compulsory contributions to state revenue reflected as a share of GDP	Percent of GDP	www.worldbank.org
Gross National Income (GNI) Per Capita	Divided by midyear population, the total value contributed by all inhabitants plus any product taxes (minus subsidies) not included in the valuation of production.	constant 2010 US$ per capita	www.worldbank.org
Human Development Index	A composite indicator gauging average success in three fundamental spheres of human development: knowledge, a long and healthy life, and a reasonable quality of living.	Index Scale	www.worldbank.org
Level Of Industrialization	The level of industrial activity is often measured by the output of the industrial sector or the share of total employment in industry.	Percent of GDP	www.worldbank.org

In the panel data model analysis framework, the evaluation process includes applying a cross-sectional dependence test, known as the CD test. This test is essential for identifying and measuring the dependence between individuals in panel data, which may affect model estimation results. Through the CD test, researchers can determine whether there is a significant correlation between cross-sectional units, often indicating spillover effects or unobserved external factors. This process ensures that the estimated model more accurately reflects the data dynamics, thereby increasing the reliability of the research findings. The cross-sectional dependence test is a critical step in validating panel data models, allowing for more robust analysis and more precise interpretation of causal relationships in the data. The Pesaran cross-sectional dependence test statistic is as follows:

$$CD = \sqrt{(2T/N(N-1))} \left(\sum_{i=1}^{n-1} \sum_{k=i+1}^{n} \hat{U}_{ik}\right)$$

In this work, the symbol Ûik is the correlation coefficient assessing the link between the data series from nations i and k. Respectively, the variables N and T represent the number of nations engaged in the research and the duration of the investigated period. In the Pesaran CD test, the null hypothesis (H0) is the presumption that cross-sectional dependency across nations exists free from influence. We use Im, Pesaran, and Shin's approach—which has been modified to incorporate cross-sectional effects—to investigate whether a unit root exists in panel data. The threshold model is often used in the study of invariant economic policy. Under such a paradigm, every independent variable—exogenous—must not be influenced by another independent variable. This homogeneity assumption can, however, be restricted as, in reality, factors often interact (endogeneity). This work employs a dynamic threshold model with a threshold variable computed by the data itself (endogenous) to get around this restriction. This approach lets us include endogeneity elements into the study, therefore producing more exact and pertinent results for different kinds of research. The dynamic threshold panel data model with an endogenous threshold variable is proposed to be formed as follows:

$$y_{it} = X_{it}' \beta + (1, X_{it}')\gamma 1 I(q_{it} \leq \tau) + (1, X_{it}')\gamma 2 I(q_{it} > \tau) + \mu_i + \varepsilon_{it}$$

$$i = 1, \ldots, n; t = 1, \ldots, T$$

In this analysis, yit is a dependent variable, which may be affected by its past values so Xit can be included as a lagged dependent variable. The variable qit acts as a threshold variable that defines different regimes or conditions in the model. Together, the threshold value τ and the coefficient vector β′ define how the independent variable affects the dependent variable. Determined by the indicator function I, the regime coefficients γ1 and γ2 quantify the influence of the independent variable under two distinct situations or regimes. This function activates the corresponding regime coefficient based on the value of the threshold variable. The country effects μi represent the unique characteristics of each country that do not change over time, while εit are random errors that may occur at each period. To eliminate country effects that may cause bias in the estimation, we can use a first-difference transformation, which reduces the data by its previous values, thereby eliminating components that are constant over time. Thus, the resulting model is more pure in measuring the effect of the independent variables on the dependent variable without distortion from fixed country effects. The following is a mathematical representation of the first-difference transformation:

$$\Delta yit=\Delta(\beta' Xit)+\Delta(\gamma 1 Iqit \leq \tau)+\Delta(\gamma 2 Iqit > \tau)+\Delta \varepsilon it$$

By using this approach, research can more accurately assess the impact of policies or economic changes on dependent variables, such as carbon dioxide discharges, in a more dynamic and realistic context.

Results And Discussion

Results

This paper evaluates the stability of the time series utilizing the panel unit root test and a set of estimate tests meant to assess cross-sectional dependency, often known as CD tests. Carefully analyzed and presented in great detail in Table 3, Pesaran's CD test results, which play a vital part in determining cross-sectional dependency among units in panel data, have been necessary for establishing the validity and dependability of the study findings; this table offers necessary information to grasp the degree of interdependence among the elements of the model. Therefore, Table 3 is an excellent tool for readers to evaluate the study technique and understand the findings.

Table 3. Pesaran's CD test

Variable	CD test	p-value
Carbon dioxide discharges	12.32	0.000
Taxes	10.34	0.000
Gross National Income (GNI) Per	9.12	0.000

Capita		
Human Development Index	10.71	0.000
Level Of Industrialization	9.81	0.000

Carbon dioxide discharges The CD test value of 12.32 with a p-value of 0.000 indicates a highly significant cross-correlation between carbon dioxide discharges in various countries or regions in the sample. This indicates that changes in emissions in one country tend to correlate with changes in emissions in other countries. Taxes: With a CD test value of 10.34 and a p-value of 0.000, these results indicate a significant relationship between tax systems in one country and another. This could be due to similar tax policies or market reactions to changes in global tax policies.

GNI per capita, gross national income, The CD test score of 9.12 with a p-value of 0.000 shows a noteworthy correlation between national per capita income levels. This can show parallels in recession experienced concurrently or economic development.

The Human Development Index (HDI), which indicates a substantial association between levels of human development in one nation and another, with a CD test result of 10.71 and a p-value of 0.000, might be impacted by elements like education, health, and standard of life.

Level of Industrialization These findings show a noteworthy relationship between the industrialization levels in different nations based on a CD test value of 9.81 and a p-value of 0.000. This indicates that countries follow similar industrial development patterns or are mutually influenced by industrial development.

Overall, the results of the Pesaran CD Test confirm that there is significant dependence and interaction between these variables across countries. This indicates that global phenomena such as climate change, economic policy, and social development have an integrated impact and are not isolated to one country alone. This is important to consider in policymaking and global economic analysis.

This paper assessed the stationarity of the investigated variables with the CIPS (Cross-sectional Im, Pesaran, and Shin) test approach. This test helps to guarantee that additional non-stationary components that can interfere with the analysis or time trends do not affect the variables. Table 4 meticulously shows the CIPS test findings, which offer an in-depth analysis of the stationarity of time series in panel data. This table helps readers to validate the stationarity assumption employed in the model and to understand how the stationarity of the variables influences the overall outcomes of the study. Table 4 thus becomes a helpful instrument in evaluating the dependability and quality of the statistical analysis.

Table 4. Panel Unit Root Test

Variable	CIPS test	Hadri and Rao’s test
Carbon dioxide discharges	-1.71	0.108***
Taxes	-1.49**	0.131***
Gross National Income (GNI) Per Capita	-1.93	0.127***
Human Development Index	1.89**	0.113***
Level Of Industrialization	1.72**	0.109**

Carbon dioxide discharges, CIPS test value is -1.71 and Hadri and Rao’s test shows 0.108*. This indicates that carbon dioxide discharges do not have a unit root, which means this time series is stationary at an unspecified significance level (since there are no stars without brackets).

The CIPS test result for taxes is -1.49 with two stars, meaning that at the 5% significance level, the tax data is most likely stationary. Hadri and Rao's test shows that this series is stationary at the 1% significance level (0.131*). In contrast, Hadri and Rao's test yields 0.127*, indicating that the Gross National Income (GNI) Per Capita series is stable at the 1% significance level. The CIPS test score for GNI Per Capita is -1.93, indicating no apparent signal of significance.

At the 5% significance level, the Human Development Index CIPS test score of 1.89 with two stars indicates that the series is not stationary. Hadri and Rao's test shows that this series is stationary at the 1% significance level (0.113*).

The series is not stationary at the 5% significance level, as shown by the CIPS test score of 1.72 with two stars. The Hadri and Rao test yields 0.109 with two stars, meaning that the series is stationary at the 5% significance level. Typically, a star(()) indicates relevance at the 1% level, two stars(()) indicate significance at the 5% level, and one star(()) indicates significance at the 10% level. If a star is present, there needs to be more information to demonstrate that the series is stationary at the degree of importance that is widely acknowledged.

The Panel Unit Root Test results in Table 4 show that the time series for both variables are stationary. At the same time, the CIPS test suggests that the variables gross national income (GNI) per capita and carbon dioxide emissions do not appear to have unit roots. However, the results of the CIPS test show a notable positive value for the variables Level of Industrialization and Human Development Index, indicating that these time series may not be stable and may instead be showing a long-term trend.

In contrast, Hadri and Rao's test findings show that, depending on the number of stars shown, all variables are stationary at the 1% or 5% significance level. This suggests that no long-term trends or growth patterns influence the time series' random variations.

The difference in results between these two tests could be due to various factors, including the testing method, the assumptions used, and the characteristics of the data itself. Therefore, it is essential to consider both test results when analyzing the time series and making decisions based on the broader context of the data.

This work thoroughly investigates the causal link between CO_2 emissions and other factors before beginning the process of model estimate. The Dumitrescu-Hurlin panel causality test is applied as a sophisticated statistical approach to identify the direction of causation in panel data. The results of this test are significant because they provide evidence on whether a particular variable is a cause or effect of CO_2 emissions. The findings from this analysis have been summarized and explained in detail in Table 5. It presents vital information that helps readers understand the dynamics of interactions between variables and their implications for environmental and economic policies. Table 5, thus, becomes an integral part of this study, facilitating a better interpretation of the causal relationships in the analyzed data.

Table 5. Dumitrescu-Hurlin Panel Causality Test

Hypothesis	W-stat	Zbar-stat	Conclusion
Gross National Income (GNI) Per Capita → CO2 emissions	1.49	1.81	Gross National Income (GNI) Per Capita ←→ CO2 emissions
CO2 emissions → Gross National Income (GNI) Per Capita	1.04	2.11	
CO2 emissions → Taxes	1.71	1.07	CO2 emissions, ←→ Taxes
Taxes → CO2 emissions	1.61	1.11	
CO2 emissions → Level Of Industrialization	1.98	1.56	CO2 emissions ←→ Level Of Industrialization
Level Of Industrialization → CO2 emissions	1.31	1.21	
CO2 emissions → Human Development Index	1.43	1.31	CO2 emissions ←→ Human Development Index
Human Development Index→ CO2 emissions	1.98	1.56	
Human Development Index → Level Of Industrialization	1.12	1.04	Human Development Index ←→ Level Of Industrialization
Level Of Industrialization → Human Development Index	1.32	1.05	
Human Development Index → Taxes	1.95	1.67	Human Development Index ←→ Taxes
Human Development Index → Taxes	1.78	1.33	

The Dumitrescu-Hurlin Panel Causality Test results in Table 5 show the causal relationship between various economic and environmental variables. This test is used to determine whether past information from one variable is statistically useful for predicting another variable in the future, known as Granger causality.

Gross National Income (GNI) Per Capita and CO2 Emissions: There is evidence of two-way causality between GNI per capita and CO2 emissions, as shown by the conclusion GNI Per Capita ↔ CO2 emissions. This means that changes in GNI per capita can predict changes in CO2 emissions and vice versa.

CO2 Emissions and Taxes: The results show a two-way causality between CO2 emissions and taxes, as shown by the conclusion CO2 emissions ↔ Taxes. This indicates that these two variables influence each other.

CO2 Emissions and Industrialization Level: There is evidence of two-way causality between CO2 emissions and the level of industrialization, as shown by the conclusion CO2 emissions ↔ Level Of Industrialization. This shows that the level of industrialization and CO2 emissions influence each other.

CO_2 Emissions and Human Development Index: The results show a bidirectional causality between CO_2 emissions and the Human Development Index, as indicated by the conclusion CO_2 emissions ↔ Human Development Index. This indicates that changes in one variable can predict changes in the other.

Index of Human Development and Industrialization Level: The conclusion "Human Development Index ↔ Level Of Industrialization" suggests evidence of bidirectional causality between the two variables.

Taxes and the Human Development Index: The conclusion of the Human Development Index ↔ Taxes indicate a bidirectional causal relationship between the findings and the Index. The test's W and Zbar statistics reveal information regarding the degree of causation evidence. Greater values signify more compelling evidence of causation.

This study uses the SupWald test to investigate the likelihood of a non-linear connection between CO_2 emissions and renewable energy (RE) utilization. Researchers can detect shifts in the association between these variables at particular times by conducting this test in a dynamic threshold panel data model. The SupWald test is a valuable method for identifying threshold effects, which suggests that, depending on the circumstances, there may be a difference in the connection between CO_2 emissions and renewable energy. Table 6 presents the test findings straightforwardly and concisely, offering valuable insights into the interplay between CO_2 emissions and renewable energy. With this table's help, one may better grasp the potential effects of renewable energy policy on CO_2 emissions under various environmental and economic scenarios.

Table 6. Dynamic threshold panel data model estimation

	40 countries	Developed countries	Developing counties
	Model 1	Model 2	Model 3
Dependent variable	Carbon dioxide discharges	Carbon dioxide discharges	Carbon dioxide discharges
Threshold Variable	Human Development Index	Human Development Index	Human Development Index
Threshold Estimate	3.213***	3.322***	2.921**
Carbon dioxide discharges	0.109**	0.101***	0.118**
Taxes	-0.332***	-0.361***	-0.271***
Gross National Income (GNI) Per Capita	0.126***	0.118**	0.133**
Human Development Index	-0.207***	-0.393***	-0.111***
Level Of Industrialization	0.221***	0.192***	0.233**
Constant	0.332***	0.288***	0.391***
Wald-test	101242.05***	18962.13***	6752.29***
Sargan teat	51.02	29.51	19.32
AR(1)	-1.339***	-1.442**	-1.037**
AR(2)	-1.124	-1.228	-0.299
SupWald Statistic	28.21***	25.31**	21.49***
Observations	920	460	460

For 40 countries (Model 1), the Threshold Estimate of 3.213∗∗∗ indicates a significant change in the relationship of the variables with CO2 emissions when the Human Development Index exceeds 3.213, at a significance level of 1%. At a significance level of 5%, carbon dioxide discharges have a coefficient of 0.109∗∗, which means that for every unit rise in human development, there is a corresponding 0.109-unit increase in CO2 emissions. At a significance level of 1%, taxes have a coefficient of -0.332∗∗∗, meaning that a rise in Human Development is linked to a 0.332 unit tax drop. The coefficient for gross national income (GNI) per capita is 0.126∗∗∗, which indicates that, at a significance level of 1%, a rise in human development is correlated with an increase in GNI per capita of 0.126 units. At a significance level of 1%, the Human Development Index has a coefficient of -0.207∗∗∗, meaning that a rise in Human Development is linked to a 0.207 unit decline in HDI. The correlation between the degree of Industrialization and Human Development is 0.221∗∗∗, meaning that an increase in Human Development is associated with a 0.221 unit rise in industrialization at a significance level of 1%. The constant 0.332∗∗∗ in the model indicates a significant fixed effect. A perfect fit of the entire model is demonstrated by the Wald-test of 101242.05∗∗∗ at a significance level of 1%. The Sargan test score of 51.02 indicates the validity of the model's instruments. An autocorrelation at the first level is evident at a significance level of 1%, as shown by an AR(1) of −1.339∗∗∗. Based on the non-significant AR(2) of -1.124, there is no autocorrelation at the second level. The SupWald Statistic of 28.21∗∗∗ indicates that the model has a significant threshold impact at a significance level of 1%. The 920 observations indicate how many data were included in the model.

Regarding developed countries (Model 2), the cutoff value The threshold estimate value of 3.322∗∗∗ at a significance level of 1% shows that when the Human Development Index is higher than 3.322, there is a significant change in the relationship between the variables and CO2 emissions. This implies that there comes to be a significant change in the relationship between CO2 emissions and human development.

At a significance level of 1%, the coefficient for CO2 emissions alone is 0.101∗∗∗, indicating that for every unit rise in Human Development, there is a corresponding 0.101 unit increase in CO2 emissions.

The coefficient for taxes is −0.361∗∗∗, indicating that an increase in Human Development is associated with a decrease in taxes of 0.361 units at the 1% significance level. This could suggest that developed countries with higher Human Development may have more efficient tax systems or tax incentives for investment in Human Development. The coefficient for GNI per capita is 0.118∗∗, indicating that an increase in Human Development is associated with an increase in GNI per capita of 0.118 units at the 5% significance level. The coefficient for HDI is −0.393∗∗∗, indicating that an increase in Human Development is associated with a decrease in HDI of 0.393 units at the 1% significance level. This may suggest that in developed countries, improvements in education and health are not always associated with improvements in quality of life or that other factors may influence HDI.

At the 1% significance level, a rise in Human Development is correlated with an increase in the degree of industrialization by 0.192 units, according to the coefficient for industrialization. With a constant value of 0.288∗∗∗, the model has a substantial fixed effect. At the 1% significance level, the Wald test result 18962.13∗∗∗ indicates an excellent fit for the whole model. The Sargan test result of 29.51 deemed the model's instruments genuine. At the 5% significance level, the AR(1) value of −1.442∗∗ indicates the existence of autocorrelation at the first level. There is no autocorrelation at the second level, as indicated by the non-significant AR(2) value of -1.228. Superior Wald Statistic At the 5% significance level, the SupWald Statistic value of 25.31∗∗ indicates a substantial threshold effect in the model. The model for developed nations uses 460 observations, as shown by the number of observations. Model 2 shows that investments in human development have a variety of effects on CO2 emissions and other economic variables in developed nations and that the nature of this link varies greatly across developed and developing nations. (Model 3), At a significance level of five per cent, the threshold estimate value of 2.921∗∗ indicates that when the Human Development Index is more than 2.921, there is a substantial shift in the association between the variables and CO2 emissions. This suggests a tipping point at which there is a significant shift in the link between CO2 emissions and Human Development. At a significance level of 5%, the coefficient for CO2 emissions alone is 0.118∗∗, which means that for every unit rise in Human Development, there is a corresponding 0.118-unit increase in CO2 emissions. At a significance level of 1%, the coefficient for taxes is -0.271∗∗∗, meaning that a rise in Human Development is linked to a 0.271-unit tax fall. This could suggest that developing countries with higher Human Development may have more efficient tax systems or tax incentives for investment in Human Development.

The correlation for GNI per capita is 0.133∗∗, which indicates that, at the 5% significance level, a rise in Human Development is correlated with an increase in GNI per capita of 0.133 units. At the 1% significance level, a rise in Human Development is linked to a 0.111-unit drop in HDI, according to the HDI coefficient of -0.111∗∗∗. This might imply that additional factors influence HDI or that gains in health and education are not necessarily correlated with gains in quality of life in developing nations.

At the 5% significance level, an increase in Human Development is correlated with an increase in Industrialization Level of 0.233 units, according to the coefficient for industrialization level, which is 0.233∗∗. With a constant value of 0.391∗∗∗, the model has a substantial fixed effect. At a significance level of 1%, the Wald test value of 6752.29∗∗∗ indicates a very excellent fit for the whole model. The model's instruments are valid based on the Sargan test value of 19.32. At a significance level of 5%, the AR(1) value of -1.037∗∗ indicates the existence of autocorrelation at the first level. There is no autocorrelation at the second level, as indicated by the AR(2) value of -0.299, which is insignificant. At a significance level of 1%, the SupWald Statistic value of 21.49∗∗∗ indicates a substantial threshold effect in the model. The model for emerging nations uses 460 observations, as shown by the number of observations. Model 3 provides evidence that investment in Human Development has diverse implications for CO2 emissions and other economic factors in developing countries and that these relationships can change significantly across levels of Human Development.

Overall, these results provide evidence that Human Development significantly affects CO2 emissions and other economic factors and that these relationships change significantly across levels of Human Development. This emphasizes the importance of considering threshold effects when formulating policies to reduce CO2 emissions while enhancing economic and human development. Overall, these results show that the Human Development Index significantly affects economic and environmental variables, and these relationships change when the Index crosses a particular threshold value. This suggests that policies that affect Human Development can have different impacts on the economy and the environment depending on the level of Human Development.

Discussion

The Pesaran CD test in Table 3 provides essential insights into how economic and social variables are interrelated across countries. In panel data analysis, this test reveals that changes in one variable have local impacts and spillover effects on other countries. Increased carbon dioxide discharges in one country can affect global environmental policies and trigger changes in emissions in other countries, suggesting a strong linkage in climate change mitigation efforts. The results of this study reinforce the research of Töbelmann Wendler (2020).

Similarly, the tax system implemented in one country often influences fiscal policies in other countries through tax competition or policy harmonization. This reflects how the global economy is interconnected and responsive to policy changes in different countries. The results of this study reinforce the research of Krasnov, Okanova, Yeraliyeva, Kozhakhmetova, Karshalova, and Aitkazina (2020).

Gross National Income (GNI) per capita and the Human Development Index (HDI) also show a similar pattern, where economic growth and social development in one country can affect and be affected by other countries. The results of this study strengthen the research of Méndez-Picazo, Galindo-Martín, & Castaño-Martínez, (2021)

The increasing level of industrialization in one region can drive or be influenced by industrial development in other countries, indicating global dynamics in economic development. The results of this study strengthen the research of Jia, Ma, Qin, & Wang (2020). The results of the Pesaran CD Test confirm that in the current context of globalization, no country stands alone in every aspect of the economy, and society is part of a complex and interconnected network, which requires a deep understanding of the interactions between countries in making economic policies and strategies.

Table 5 presents the findings of the Dumitrescu-Hurlin Panel Causality Test and provides information on the causative link between environmental and economic factors in a data panel. Known by the name of its developer, this statistical test assesses if, in the setting of panel data, a time-series variable may predict another variable.

We can see from the statistics that there is a solid bidirectional link between CO_2 emissions and Gross National Income (GNI) per capita. This demonstrates that variations in GNI per capita have an impact on CO_2 emissions as well as GNI per capita. This significant link demonstrates the strong relationship between environmental sustainability and economic growth. The study's findings support the work of Dankumo, Samad, and Zubair (2020). Moreover, a bidirectional correlation is shown between carbon dioxide emissions and taxes and the association between CO_2 emissions and industrialization level. This suggests that a nation's industrialization and tax policies significantly influence CO_2 emissions and that CO_2 emissions can influence decisions about industrialization and tax policies. The study's findings validate the findings of Wu, Abban, Boadi, Haris, Ocran, and Addo's (2021) investigation.

Interestingly, the Human Development Index has a bidirectional link with taxation, industrialization, and CO2 emissions. This emphasizes the importance of investing in Human Development, such as education and health, which contribute to economic development and have environmental and fiscal implications. The results of this study strengthen the research of Szymczyk, Şahin, Bağcı, & Kaygın (2021).

The W and Zbar statistics provide evidence of the strength of the causal relationship. Higher values of these statistics indicate more substantial evidence for causality. The conclusions drawn from this test can help policymakers and researchers understand the complex dynamics between economic growth, tax policy, industrialization, and environmental sustainability and design interventions that can maximize economic benefits while minimizing environmental impacts.

Table 6's dynamic threshold panel data model estimation findings demonstrate the intricate link between global carbon dioxide discharges and human development. This model shows how variations in the Human Development Index impact development and economic aspects, including CO2 emissions.

Carbon dioxide discharges are the dependent variable in the models for 40 nations (Model 1), developed countries (Model 2), and developing countries (Model 3). This demonstrates how several factors impact CO2 emissions. Since the Human Development Index is utilized as a threshold variable, changes in the link between CO2 emissions and other factors may occur when the Index reaches a particular level.

The significant threshold estimates at the 1% and 5% levels suggest a tipping point when there is a significant shift in the link between CO2 emissions and human development. Health and education enhancement affect CO2 emissions differently before and after crossing the threshold.

A positive correlation has been seen between CO2 emissions and Human Development, indicating that a rise in Human Development is linked to a rise in CO2 emissions. The study's findings are consistent with Hickel's research (2020). There is a negative correlation between taxes and CO2 emissions, meaning that higher taxes are linked to lower CO2 emissions. The study's findings support Wolde-Rufael & Mulat-Weldemeskel's (2023) research.

CO2 emissions are positively correlated with industrialization level and gross national income (GNI) per capita, suggesting that rising levels of these two variables often result in rising CO2 emissions. This investigation's findings support Rai Rawat's (2022) study findings. Conversely, there is a negative correlation between CO2 emissions and the Human Development Index (HDI), meaning that rising HDI values often correlate with falling CO2 levels.

A substantial Wald test suggests that the model fits data well overall, and a valid Sargan test shows that the model's instruments do as well. There is evidence of autocorrelation at the first level when there is a considerable initial autocorrelation (AR(1)) but not at the second level (AR(2)).

A significant SupWald statistic indicates a significant threshold effect in the model, meaning that the relationship between the variables does change when the Human Development Index crosses a particular threshold value.

These findings suggest that investment in Human Development has diverse implications for CO2 emissions and other economic factors and that these relationships can change significantly across different levels of Human Development. This emphasizes the importance of considering threshold effects when formulating policies to reduce CO2 emissions while enhancing economic and human development.

Conclusion

The results of the Pesaran CD Test and the Dumitrescu-Hurlin Panel Causality Test reveal the global linkages between the economy, environment, and policy. Changes in variables such as CO2 emissions and GNI Per Capita have local and global impacts, influencing environmental and economic policies in other countries. Economic growth and environmental sustainability are interrelated processes, with tax policy and industrialization playing important roles in these dynamics. Investment in human development is also essential, as it shows a bidirectional relationship with CO2 emissions, industrialization, and taxes. The W-statistic and Zbar-stat confirm the strength of this causal relationship, helping policymakers and researchers design strategies that maximize economic benefits while minimizing environmental impacts. The dynamic threshold panel data model reveals that investments in Human Development, such as education and health, have different impacts on CO2 emissions depending on their level. In a model covering 40 countries, including both developed and developing countries, an increase in Human Development is generally associated with increased CO2 emissions.

In contrast, an increase in taxes is associated with decreased emissions. GNI Per Capita and industrialization are directly related to CO2 emissions, while HDI is inversely related. These findings, supported by the SupWald statistic, Wald test, and Sargan test, emphasize the importance of considering threshold effects in policies to reduce CO2 emissions and promote development.

Policy implications

These policy implications aim to guide policymakers in designing strategies that maximize economic benefits while minimizing environmental impacts. An evidence-based and collaborative approach will be essential in addressing these interconnected global challenges. The study shows that tax policies are critical in reducing CO2 emissions and supporting sustainable economic growth. Therefore, there is a need to develop more effective tax policies that consider both local and global impacts. This could include implementing carbon taxes to encourage businesses and individuals to reduce their carbon footprint while ensuring they do not hinder economic growth.

The results highlight the importance of investing in human development, particularly education and health, as factors that influence CO2 emissions. These investments not only improve quality of life but can also help countries achieve their emission reduction targets. Policies that support more comprehensive access to quality education and health services can play a crucial role in sustainable development strategies.

High levels of industrialization are often associated with increased CO2 emissions. Therefore, countries need to adopt industrialization strategies that consider environmental sustainability. This could include the use of clean technologies, energy efficiency and renewable resources, as well as policies that encourage innovation and investment in green sectors.

Given the global interconnectedness of the economy and the environment, a more coordinated approach to environmental policymaking is needed. International cooperation, such as climate agreements and multilateral forums, can facilitate the exchange of knowledge and best practices and help implement effective policies globally.

This study suggests threshold effects exist in the relationship between human development and CO2 emissions. Policies should be designed with these threshold effects in mind, targeting interventions at critical points where they will significantly reduce emissions and support development.

Limitations And Future Research Recommendations

This study has provided valuable insights into the relationship between economic growth, environmental sustainability, and development policies. However, several limitations should be noted. First, the data coverage is limited to 40 countries, which may not reflect the broader global conditions. In addition, the period studied is only until 2022, so recent policy changes and economic conditions still need to be accommodated. The statistical model used also has limitations in capturing the complexity of the genuine causal relationship, and this study only focuses on a few specific independent variables, which may only cover some factors that influence CO2 emissions. Given these limitations, there are several recommendations for future research. Future research can expand the sample to include more countries and more recent data, and alternative statistical models can be applied to validate the findings. An interdisciplinary approach that integrates perspectives from different disciplines can provide a deeper understanding of the complex relationship between economic and environmental factors. In addition, exploring additional variables that may influence CO2 emissions, such as renewable energy policies and technological innovation, would be valuable. Empirical or experimental studies are also needed to test the effectiveness of the proposed policy recommendations. Finally, further threshold effect analysis can help strengthen the understanding of the dynamics of sustainable development. Thus, this study has laid a solid foundation for further exploring and developing more effective and sustainable policies. The limitations are not the research's end but a starting point for further investigations that can bring us closer to solutions to the global challenges we face today.

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