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Economic Growth and Environmental Sustainability in Developed Nations: A Panel Data Analysis

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Abstract
This study examines the long-standing debate over whether economic expansion and greater trade integration support or undermine environmental sustainability in developed economies. Spanning the period from 1975 to 2024, this study employs panel data techniques to examine the evolving relationships between income growth, trade activity, and carbon emissions. The central concern is to understand whether the pursuit of higher GDP and increased openness to global markets contributes to cleaner production and greener technologies, or whether it continues to be associated with rising ecological pressures. To address this question, the analysis examines not only overall correlations but also the dynamic relationships among the variables, distinguishing between short-run adjustments and long-run trends. Advanced panel econometric approaches are employed to test for causality and to capture how trade and growth interact in shaping patterns of environmental quality. The results suggest that the connections are neither linear nor uniform; while some phases of growth and trade expansion appear to foster improvements in sustainability, others coincide with significant increases in emissions. These findings carry important implications for policy in high-income countries. They point to the need for carefully designed frameworks that allow economies to benefit from trade and growth while at the same time meeting international climate commitments. In practical terms, this research reflect the role of green trade policies, climate regulation, and forward-looking strategies in reconciling economic and environmental goals.

Keywords: Economic Growth, Environmental Sustainability, CO_2 Emissions, Trade Growth, Panel Data, Developed Nations.

Introduction

Economic growth and environmental sustainability have emerged as one of the most debated issues in present research. Rapid industrialization, rising income levels, and expansion of international trade have significantly increased economic activity in developed nations, but these developments have also intensified environmental challenges, particularly through higher levels of CO_2 emissions. Balancing growth with environmental protection has therefore become a critical concern for policymakers, economists, and environmentalists alike.

In recent decades, the discourse has shifted from a growth-centric approach to a sustainability-oriented perspective, where the quality of growth is considered as important as its pace. Developed countries, being among the largest contributors to greenhouse gas emissions, play a decisive role in shaping global sustainability outcomes. The environmental implications of economic and trade growth in these nations provide crucial lessons for the rest of the world. While several studies have led stress on the associations between economic activity and environmental destruction, most of the existing literature has focused either on global datasets or on developing countries, with relatively less emphasis on developed nations as a separate category (Shahbaz et al., 2015)

This study attempts to build this interval by analyzing the association between economic expansion, trade growth, and carbon emissions in developed nations over the time 1975–2024. Using panel data econometric techniques, the study investigates both long and short-run adjustment as well as causality patterns among the variables. The findings aim to provide evidence-based insights into whether sustained economic and trade expansion in developed nations aligns with environmental sustainability goals, and how policy interventions can enhance the compatibility between growth and environmental protection.

Literature Review

Economic growth and environmental sustainability have been widely studied, but findings remain inconsistent across nations and time periods. Earlier studies often highlight that economic expansion leads to environmental ruin, but recent studies reveal the structural shift due to the role of technological advancement and regulatory policy. (Stern, 2004).

In the context of developed nations, several studies show that in the beginning, economic expansion leads to environmental degradation, but in the long run, they adopt clean technologies and strict environmental regulation policies that tackle the degradation aspect and promote sustainability. Shahbaz et al. (2015) show that globalization and growth in high-income OECD countries exert complex influences on CO_2 emissions, where trade liberalization may improve efficiency but also encourage energy-intensive production. Similarly, Lean and Smyth (2010), examining G-7 countries, found that energy consumption and trade strongly affect CO_2 emissions, underlining the importance of effective energy policies.

Recent empirical research has also stressed the usefulness of panel econometric methods in identifying both short- and long-run dynamics. Haug and Ucal (2019) demonstrate that trade integration in OECD countries can support environmental sustainability when backed by strong regulations. Likewise, Bilgili,et.al (2016) highlight how green energy use plays a critical role in reducing CO_2 emissions within the broader framework of economic growth in developed economies.

Taken together, the literature indicates that the growth–environment–trade nexus is highly context-specific. For developed nations, the interplay of trade policies, technological progress, and renewable energy adoption critically determines whether economic expansion aligns with sustainability goals. However, despite extensive research, there remains a need for updated evidence covering recent decades, particularly given the rapid changes in trade patterns, climate policies, and environmental commitments. This study provide a vision to existing literature by analyzing panel data from 1975 to 2024, focusing specifically on the experiences of developed nations.

Objective of this study

1) To examine the dynamic relationship between economic growth, trade growth, and Co_2 emissions in developed nations.

Research Methodology

This study employ annual panel data for developed countries over the periods 1975-2024, with carbon emissions (metric tons) representing environmental sustainability, GDP growth (annual %) capturing economic growth, and trade growth (annual % of trade openness) indicating trade performance, all data from the WDI. To ensure robust and consistent results, the analysis follows a stepwise econometric approach: first, the occurrence of cross-country dependence is assessed to examine the common shocks across nations; second, the time-series properties of each variable are examined to determine their order of integration; third, slope homogeneity is tested to evaluate whether the relationships differ across countries; fourth, long-run associations among the variables are explored through cointegration analysis; fifth, both short- and long-run dynamics are captured using a panel ARDL framework; and finally, causal linkages are analyzed to define the direction of influence among economic expansion, trade openness, and sustainability.

Result and Discussion

In this section, the results are presented to examine the dynamic association between trade (TR), economic expansion (GDP), and carbon emissions (CO2) across developed nations during 1975–2024. The analysis begins with descriptive statistics, followed by panel-based tests to check the stationarity of variables, examine slope heterogeneity, and explore long-run associations through cointegration. After establishing these foundations, both short and long term dynamics are estimated using the PMG approach, while the Dumitrescu–Hurlin panel causality test is applied to identify the direction of influence among the variables.

Table 1: Statistical Summary of Variables (1975–2024)

Variable	Obs	Mean	std. dev.	Min	Max
lnCO2	478	2.36972	0.46343	1.34815	3.38057
lnGDP	478	10.3471	0.65013	7.1935	11.5192
lnTR	478	4.13546	0.50098	2.76066	5.25718

The descriptive statistics for the panel of 16 countries over 1975–2024 indicate that carbon emissions (lnCO2) have a mean of 2.370 and moderate variability (std. dev. = 0.463), reflecting differences in environmental outcomes across countries. Economic growth (lnGDP) shows a higher mean of 10.347 with relatively larger dispersion (std. dev. = 0.650), suggesting varying levels of economic activity. Trade (lnTR) has a mean of 4.135 and moderate variation (std. dev. = 0.501), indicating heterogeneity in trade volumes among countries. The minimum and maximum values further highlight cross-country differences, providing sufficient variation to justify panel econometric analysis. Overall, these statistics suggest a diverse panel suitable for examining the interactions among growth, trade, and emissions.

Table2: Hausman test

	Chi²	Statistic	df	p-value	Preferred Model
Hausman Test	12		4	0.0174	Fixed Effects

Null Hypothesis H_0: *Difference in coefficients between fixed effect and random effect estimator is not systematic.*

This test is used to contrast the fixed effects (FE) and random effects (RE) estimators. The results show a chi-square statistic of χ^2 (4) = 12.00 with a p-value of .0174. P-value is well below the conventional significance level 5%, which indicate rejection of H_0, which means no systematic differences between the estimators. RE model is not suitable, and the FE model is preferred. Hence, the FE estimator is considered more reliable because it examine the correlation between individual-specific factors and the explanatory variables.

Table 3: Slope Homogeneity Test (Pesaran & Yamagata, 2008)

Test Statistic	Value	p-value	Interpretation
Delta	21.850	0.000	Reject H_0 → Slopes are heterogeneous
Adjusted Delta	23.478	0.000	Reject H_0 → Slopes are heterogeneous

Null Hypothesis H_0: *slope coefficients are homogeneous across panels.*

The Pesaran–Yamagata (2008) slope homogeneity test is used among lnCO2, lnGDP, and lnTR to examine whether the slope coefficients are identical across the 16 countries. Both the Delta (21.850) and adjusted Delta (23.478) statistics are highly significant ($p < 0.01$), which suggests that the slope homogeneity assumption is rejected. This shows the impact of trade activity and economics expansion on carbon emissions varies significantly across countries, explaining the reason behind the use of heterogeneous panel estimators such as the PMG approach rather than assuming uniform slopes.

Table 4: IPS Unit Root Test Results for Panel Variables

Variable	Level / Difference	Z-t-tilde-bar	p-value	Stationarity
lnCO2	Level	7.3886	1	Non-stationary (I(1))
ΔlnCO2	First Difference	–11.8253	0	Stationary
lnGDP	Level	2.8825	0.998	Non-stationary (I(1))
ΔlnGDP	First Difference	–9.9258	0	Stationary
lnTR	Level	–0.2758	0.3914	Non-stationary (I(1))
ΔlnTR	First Difference	–11.7541	0	Stationary

Null Hypothesis (H_0): *Panel series contains a unit root (non-stationary).*

This test is employed to examine the stationarity of lnCO2, lnGDP, and lnTR across 16 countries over 1975–2024. The results indicate that at these levels, the variables are non-stationary, with p-values well

above conventional significance levels, confirming that unit roots are present. However, the first-differenced ΔlnCO2, ΔlnGDP, and ΔlnTR are stationary, with Z-t-tilde-bar statistics highly significant ($p < 0.001$). The findings revealed that entire set of variables are synthesized of order one [I(1)], justifying the application of panel cointegration techniques and the use of panel ARDL (PMG) models for analyzing long and short-run associations.

Table: 5 Kao Panel Cointegration test

Test Statistic	Value	p-value
Modified Dickey–Fuller t	1.5102	.0655
Dickey–Fuller t	2.2511	.0122
Augmented Dickey–Fuller t	2.8533	.0022
Unadjusted modified Dickey–Fuller t	1.1946	.1161
Unadjusted Dickey–Fuller t	1.9124	.0279

Null hypothesis (H_0): *No cointegration among lnCO2, lnGDP, and lnTR.*

This test is employed to analyze the long-run association among InCO2, lnGDP, and lnTR. As shown in Table X, three out of the five statistics—namely the DFT, ADFT, and UDFT are under the significant regime of 5%, which indicates rejecting the assumption (H_0) of no cointegration. Although the MDFT and UMDFT statistics are insignificant, the majority of the results provide strong evidence in favor of cointegration. These findings confirm the evidence of a constant long-term association within the variables across the panel of 16 countries during 1975–2024. This suggests that CO2 emission, economic expansion, and trade are interdependent in the long term, suggesting that policies targeting growth and trade patterns will have persistent implications for environmental sustainability.

Table 6: Panel ARDL Results – Long-Run and Short-Run Estimates

D.lnCO2	**Coefficient**	**Std. err.**	**z**	**P>|z|**	**[95% conf. interval]**	
Trend						
lnTR	-10.67593	7.927335	-1.35	0.178	-26.21322	4.861361
SR						
Trend	-.0045593	.0022631	-2.01	0.044	-.008995	-.0001237
lnGDP						
D1.	.1184643	.0457291	2.59	0.010	.0288369	.2080918
lnTR						
D1.	.1993401	.0405204	4.92	0.000	.1199216	.2787586
_cons	.2360154	.1306887	1.81	0.071	-.0201298	.4921605

Null Hypothesis H_0: *The explanatory variables (lnGDP, lnTR) have no statistically significant effect on CO_2 emissions.*

The PMG estimation results revealed that in the short run, both ΔlnGDP and ΔlnTR significantly increase CO_2 emissions, with a coefficient. of 0.118 ($p = 0.010$) and 0.199 ($p < 0.001$), accordingly. The negative and significant trend coefficient (–0.0046, $p = 0.044$) suggests a gradual reduction in emissions over time, possibly due to technological improvements or environmental policies. In contrast, the trade's effect in the long term on CO2 emissions is not statistically significant, indicating that its impact is more pronounced in the short term. Overall, these findings highlight that short-term economic and trade activities drive environmental pressures, emphasizing the need for policy interventions to balance growth with sustainability.

Table 7: Panel Granger Causality Results (Dumitrescu–Hurlin Test)

Causal Direction	W-bar	Z-bar	Z-bar tilde	p-value	Causality
GDP → CO_2	5.2118	11.9127	10.3492	0	Yes (1% level)
CO_2 → GDP	1.007	0.0197	-0.1612	0.9843	No
Trade → CO_2	4.8112	10.7796	9.3478	0	Yes (1% level)
CO_2 → Trade	2.0492	2.9677	2.4441	0.003	Yes (5% level)

Null Hypothesis: *Variable X does not Granger-cause Variable Y across panel units.*

This test was conducted for 16 countries over 1975–2024 to explore the interactions together with carbon emissions (lnCO2), economic growth (lnGDP), and trade growth (lnTR). The analysis reveals unidirectional causality flowing from GDP toward CO2 emissions, while the reverse is insignificant, suggesting that economic growth drives environmental degradation without feedback from emissions. In contrast, trade and CO_2 exhibit bidirectional causality, implying that trade expansion raises emissions, and higher emissions also affect trade dynamics. Overall, these findings highlight GDP as a primary driver of emissions and a mutually reinforcing relationship between trade and the environment, emphasizing the need to incorporate environmental considerations into growth and trade policies for long-term sustainability.

Conclusion

This study investigated the associations among CO2 emission, economic growth, and trade across 16 developed countries during 1975–2024. Descriptive statistics showed sufficient variation in all variables to support panel analysis. The slope heterogeneity test confirmed that the effects of GDP and trade on emissions differ over countries, explaining the suitability of heterogeneous panel estimators. IPS unit root tests showed that level within all variables are non-stationary, but after first differences they are stationary, supporting panel cointegration analysis. The Kao test revealed that all the variables are correlated with each other in the long horizon. PMG estimation revealed that economic growth and trade significantly increase carbon release in the short run, however trade's long-run effect is not statistically significant. Dumitrescu–Hurlin Granger causality tests showed one way causality from GDP to CO_2 and two way causality between trade and CO_2, indicating complex short-run interactions. Overall, the findings highlight that economic growth and trade are key drivers of environmental degradation, and policy measures

integrating environmental sustainability with growth and trade strategies are essential for long-term climate mitigation.

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