Vol. 2(1), 1-10

Journal of Energy & Environmental Policy Options

Influence of Economic Growth and Transport on Carbon Emissions Across Different Income Groups

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Abstract
The purpose of this article is to examine how energy consumption and freight transport influence CO2 emissions across a sample of 65 countries from 2000 to 2019. To ensure a more uniform panel data analysis, the study categorizes the data into three sub-panels: high-income, middle-income, and low-income countries. These categorizations are based on the countries' income levels. By employing the generalized method of moments for analysis, the study reveals that energy consumption significantly and positively affects CO2 emissions. Similarly, the impact of freight transport on CO2 emissions is also positive and significant, with a particularly pronounced effect in high-income countries. Additionally, the study finds that other factors, such as economic growth, also significantly influence carbon emissions. These results underscore the urgent need for adopting new concepts like sustainable development, sustainable transport, and energy efficiency. These policies are seen as essential to combating the severe environmental degradation we face today. The analysis confirms that increased energy consumption directly correlates with higher CO2 emissions, a trend consistent across different income levels of countries. High-income countries, due to their advanced industrial activities and extensive freight transport networks, exhibit a more substantial impact on emissions from freight transport. Middle-income and low-income countries, while also showing significant effects, differ in the extent due to varying levels of industrialization and transport infrastructure. Economic growth emerges as another critical factor influencing CO2 emissions. As countries develop economically, their energy demands and freight transport activities increase, leading to higher emissions. This finding aligns with the Environmental Kuznets Curve hypothesis, which suggests that as an economy grows, environmental degradation increases up to a point before starting to decline as more sustainable practices are adopted. The study's findings emphasize the importance of sustainable practices in mitigating environmental harm. Concepts such as sustainable development advocate for balancing economic growth with environmental preservation. Sustainable transport focuses on reducing the carbon footprint of freight transport through innovations in logistics and vehicle efficiency. Energy efficiency, on the other hand, aims to reduce energy consumption through technological advancements and better energy management practices. These sustainable practices are not just theoretical concepts but are being implemented globally. Countries are increasingly investing in renewable energy sources, improving public transportation systems, and adopting stricter regulations on emissions. The study suggests that such policies are not only beneficial but necessary to curb the adverse effects of energy consumption and freight transport on the environment.
Keywords: CO2 Emissions, Sustainable Development, Energy Efficiency
JEL Codes: Q53, Q56, R41

1. INTRODUCTION

In 2013, the Climatic Change Performance Index (CCPI) published a study evaluating and comparing the climate protection performance of 58 countries. Their conclusions indicate that these countries are responsible for 90% of global energy consumption and are the principal sources of greenhouse gas emissions, especially carbon dioxide (CO2). Inspired by the pioneering work of Kuznets (1955), several researchers have examined the link between real output, energy consumption, carbon dioxide emissions, and their impact on environmental degradation. Studies by Lise (2006), Squalli (2007), Soytas, Sari, and Ewing (2007), Ang (2008), Akbostanci and Turut-Asik (2009), Apergis and Payne (2010), Halicioglu (2009), Soytas and Sari (2009), Lean and Smyth (2009), Zhang and Cheng (2009), Menyah and Wolde-Rufael (2010), Freitas and Kaneko (2011), and Narayan and Popp (2012) have investigated the most important factors of energy consumption and their economic and social impacts. These authors delve into the intricate relationships between economic activities and environmental outcomes, exploring how increased real output and energy use contribute to higher levels of CO2 emissions and environmental degradation. Their analyses often involve econometric models that seek to understand the dynamics of energy consumption and its repercussions on both the economy and the environment.

However, specific studies by Tanczos and Torok (2007), Steenhof, Woudsma, and Sparling (2006), and Steer Davies Gleave (2003) focus more narrowly on the contribution of the transport sector to energy consumption and carbon emissions. These works emphasize the significant role that transportation plays in the overall energy consumption patterns of countries and the subsequent impact on greenhouse gas emissions. The transport sector, with its heavy reliance on fossil fuels, emerges as a critical area for policy intervention aimed at reducing carbon footprints and mitigating climate

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change effects. In the same order of ideas, the main objective of the present work is to investigate the relationship between energy consumption, freight transport, and CO2 emissions for a sample of 65 countries over the period 2000-2014. To distinguish our work from previous studies, we reject the panel unit root and panel co-integration approaches and adopt a dynamic panel data model as our estimation technique. This approach follows the spirit of the conventional growth model framework, ensuring a strong theoretical foundation for our empirical analysis. The paper is structured as follows: it starts with an introduction that outlines the significance of examining the interplay between energy consumption, freight transport, and CO2 emissions. This is followed by a theoretical study where we review previous works related to our subject. Section two explains the methodological framework, detailing the dynamic panel data model used for the analysis. Section three presents the data and the results obtained from the empirical analysis. The final section concludes the study, offering policy implications based on the findings.

The dynamic panel data model we employ allows for the incorporation of time dynamics and individual heterogeneity, providing more robust and reliable estimates. This technique is particularly useful in capturing the short-term dynamics and long-term equilibrium relationships among the variables. By doing so, our study aims to contribute to the existing literature by providing new insights into how energy consumption and freight transport influence CO2 emissions across different countries. In our theoretical review, we discuss the works of researchers like Lise (2006), Squalli (2007), Soytas, Sari, and Ewing (2007), Ang (2008), Akbostanci and Turut-Asik (2009), Apergis and Payne (2010), Halicioglu (2009), Soytas and Sari (2009), Lean and Smyth (2009), Zhang and Cheng (2009), Menyah and Wolde-Rufael (2010), Freitas and Kaneko (2011), Narayan and Popp (2012), Tanczos and Torok (2007), Steenhof, Woudsma, and Sparling (2006), and Steer Davies Gleave (2003). These studies provide a comprehensive backdrop, highlighting the key factors and methodologies used in examining the nexus between economic activities, energy consumption, and environmental impacts.

By adopting a dynamic panel data model, our study aims to address some of the limitations of previous research, such as potential biases and inefficiencies associated with static models. The methodological framework outlined in section two provides a detailed explanation of the model specifications, estimation procedures, and diagnostic tests used to ensure the robustness of our results. In section three, we present the data sources, descriptive statistics, and the empirical findings. The results highlight the significant relationships between energy consumption, freight transport, and CO2 emissions, underscoring the critical role of transport in contributing to environmental degradation. The analysis also reveals variations across countries, suggesting the need for tailored policy interventions. The final section concludes the study by summarizing the key findings and discussing their policy implications. It emphasizes the importance of integrating energy efficiency measures and sustainable transport policies to mitigate CO2 emissions. The study suggests that policymakers should focus on enhancing the efficiency of freight transport systems, promoting the use of cleaner energy sources, and implementing regulatory frameworks that encourage sustainable practices in the transport sector.

2. LITERATURE REVIEW

In recent years, the nexus between energy consumption, CO2 emissions, and environmental degradation has garnered significant attention from researchers. Soytas, Sari, and Ewing (2007) as well as Soytas and Sari (2009) have emphasized the direct and significant impact of energy consumption on carbon emissions. Similarly, Ang (2008) identified a causal relationship running from energy consumption to CO2 emissions. Arouri, Ben Youssef, M'henni, and Rault (2012) conducted a study focusing on 12 Middle Eastern and North African countries, revealing a positive and significant long-term effect of energy consumption on CO2 emissions. In Mauritius, Boopen and Harris (2012) conducted research using annual data spanning from 1960 to 2011 to explore the relationship between energy use, pollutant emissions, and economic growth. Their findings, incorporating other explanatory variables, suggested non-stationarity and cointegration among the variables, indicating a significant long-term relationship. Lean and Smyth (2009) employed a panel vector error correction model (VECM) to examine the connections between carbon emissions, electricity consumption, and income for ASEAN countries. Their results indicated a positive and significant long-run relationship between electricity consumption and CO2 emissions. These studies contribute valuable insights into the complex interplay between energy consumption, CO2 emissions, and environmental sustainability, highlighting the importance of addressing these issues through comprehensive policies and strategies aimed at promoting sustainable development. In other research, Halicioglu (2009) investigated the impact of energy consumption on carbon emissions in Turkey over the period 1960-2005, finding a long-run relationship between these variables. To further examine the causal relationship between output, energy use, and carbon emissions, Apergis and Payne (2010) employed a vector error correction model for a panel of six Central American countries. Their results indicated that, in the long run, CO2 emissions are positively influenced by energy consumption, while output exhibits the Environmental Kuznets Curve (EKC) hypothesis. Additionally, Yang, Wang, Zhou, and Liu (2012) explored the relationships between energy consumption, carbon emissions, and economic growth in Shanghai for the period between 2011 and 2020. Utilizing cointegration and vector correction models, they concluded that a positive long-run equilibrium relationship exists between energy consumption and carbon emissions.

The strong relationship between transport activity, economic activity, and carbon emissions has been intensively and empirically analyzed over the last few years (Banister & Stead, 2002; Gilbert & Nadeau, 2002). Schipper, Scholl, and Price (1997) decomposed energy intensity into three factors: transport activity (ton-kilometer), structure of transport (types of modals), and intensity (energy used per unit of transport). They concluded that the increase in transport demand, especially that of road transport, cannot be compensated by energy efficiency. Indeed, the demand for transport is positively affected by economic activity, and simultaneously, changes in the transport systems affect economic activity, while also causing a rapid increase in carbon emissions. According to CITEPA (2005), the transport sector's share of carbon emissions is higher than those of industrial and service activities, with these sectors generating 21% and 22% of CO2 emissions, respectively. In 2003, transport caused 28% of total CO2 emissions in France. Another matter of concern for CO2 emissions caused by transportation is its high level of growth. Schäfer (2005) indicates that, in France, the volume of carbon dioxide generated by transport increased by 500% over the period 1960-2003.

In a recent report, UNCTAD (2015) states that in 2012, the transportation sector accounted for nearly 64% of final consumption of petroleum in the world. According to projections, it is expected to be the direct cause of 82% of the increase in global energy consumption for the period from 2008 to 2035. Additionally, global energy demand is expected to increase by 70% between 2010 and 2040 due to the effects of commercial transportation. Consequently, the high dependence of transport on petroleum generates significant atmospheric emissions of pollutants and greenhouse gases (GHG). In 2012, the transport sector was responsible for about 25% of global emissions of carbon dioxide from fuel combustion, and this is expected to increase by 1.7% per year until 2030. Moreover, over 80% of this increase is expected in developing countries, generated mainly by land transport. Overall, CO2 emissions from the international transport of commercial cargo are projected to multiply by 3.9 between 2010 and 2050.

To determine the major factors contributing to greenhouse gas emissions in Canada, Steenhof, Woudsma, and Sparling (2006) used decomposition analysis of energy intensity. Their findings indicate that if the share of freight road transport continues to increase, technical progress alone will be insufficient to significantly reduce greenhouse gas emissions. Similarly, Tanczos and Torok (2007) examined the link between road transport, energy use, and CO2 emissions in Austria, highlighting the significant impact of road transport on greenhouse gas emissions. In England, Sorrell et al. (2009) argued that improvements in energy efficiency and reductions in CO2 emissions could be achieved by increasing vehicle transportation capacity and decreasing average vehicle energy consumption. Additionally, Steer Davies Gleave (2003) concluded that reducing the share of freight road transportation in Germany, France, Spain, Italy, and England can effectively lower carbon emissions by enhancing energy efficiency in these countries.

The relationship between economic growth and CO2 emissions has been extensively studied in recent years, with economists focusing on identifying the major factors influencing CO2 emissions and exploring strategies to reduce greenhouse gas emissions and mitigate environmental degradation. One of the prominent concepts in this field is the Environmental Kuznets Curve (EKC) hypothesis, which posits an inverted-U relationship between environmental degradation and income per capita. According to the EKC hypothesis, environmental degradation initially increases with economic growth but eventually decreases as income reaches a higher level, suggesting that economic development can lead to environmental improvements over time. Narayan and Narayan (2010) examined the EKC hypothesis for 43 developing countries, addressing the issue of collinearity between income and income squared in their analysis. Their study found evidence supporting a positive relationship between carbon emissions and income in both the short and long run. This implies that as income increases, carbon emissions also rise, reflecting the ongoing challenges that developing countries face in balancing economic growth with environmental sustainability. The findings from Narayan and Narayan (2010) highlight the complexity of the relationship between economic growth and environmental impact. While economic growth can lead to higher CO2 emissions in the short term, long-term strategies focused on sustainable development, improved energy efficiency, and adoption of cleaner technologies are crucial to mitigate the environmental impact and achieve a balance between growth and sustainability. Other studies have also explored this relationship, using various econometric techniques and data sets to understand the dynamics between economic growth, energy consumption, and CO2 emissions. These studies contribute to a growing body of literature that emphasizes the need for comprehensive and integrated policy approaches to address environmental challenges while promoting economic development. By adopting such strategies, countries can work towards achieving sustainable growth that benefits both the economy and the environment.

The relationship between economic growth and CO2 emissions has been the subject of extensive research, aiming to understand the complexities and nuances of how economic activities impact environmental sustainability. This relationship is often explored through the Environmental Kuznets Curve (EKC) hypothesis, which suggests an inverted-U relationship between environmental degradation and income per capita.

Perman and Stern (2003) conducted an in-depth investigation into the EKC hypothesis using panel unit root and cointegration tests for a panel of 74 countries from 1850 to 1990. Their comprehensive study suggested that the EKC does not exist for CO2 emissions in these countries. This finding challenges the notion that economic growth will naturally lead to environmental improvements after a certain level of income is reached, highlighting the need for proactive environmental policies and interventions. In a more focused study, Jayanthakumaran, Verma, and Liu (2012) analyzed the relationship between CO2 emissions, trade, energy consumption, and income in China and India from 1971 to 2007 using the Autoregressive Distributed Lag (ARDL) methodology. Their results indicated that high levels of carbon emissions negatively and significantly affect a country's production capacity. This study underscores the detrimental impact of excessive carbon emissions on economic productivity, emphasizing the need for sustainable practices and policies to mitigate environmental damage while supporting economic growth.

Similarly, Borhan, Ahmed, and Hitam (2012) investigated the impact of CO2 emissions on economic growth in eight ASEAN countries from 1965 to 2010 using two-stage least square (2SLS) regression. Their findings revealed a negative relationship between CO2 emissions and income, suggesting that higher levels of carbon emissions are associated with lower economic growth in these countries. This relationship points to the potential economic costs of unchecked environmental degradation and the importance of integrating environmental considerations into economic planning and development strategies. Omri and Sassi-Tmar (2014) conducted a comprehensive examination of the relationships between foreign direct investment (FDI) inflows, economic growth, and CO2 emissions across 54 countries from 1990 to

2011. Their study employed a dynamic simultaneous equation model and found evidence of unidirectional causality from CO_2 emissions to economic growth. This finding shed light on the complex dynamics between environmental sustainability, economic development, and global investment flows, suggesting that reducing carbon emissions may positively impact economic growth.

Conversely, other researchers have presented evidence suggesting the statistical insignificance of the relationship between economic growth and CO_2 emissions. Richmond and Kaufmann (2006) investigated whether there exists a turning point in the relationship between income and energy use or carbon emissions. Their findings indicated that the relationship between income and CO_2 emissions may not exhibit a significant turning point, challenging the notion that economic growth inevitably leads to higher carbon emissions. Similarly, in their study focused on the United States, Zhang and Cheng (2009) examined the link between energy consumption, output, and CO_2 emissions from 1960 to 2004. Using the Granger causality test, they concluded that in the long run, CO_2 emissions in the US are not significantly influenced by income, labor, or gross fixed capital formation included in the model. This suggests that economic factors may have limited explanatory power in predicting carbon emissions in certain contexts, highlighting the need for nuanced approaches to addressing environmental challenges.

In Turkey, Soytas and Sari (2009) conducted a study examining the interplay between energy consumption, income, and carbon emissions. Employing a similar methodology and variables as in the case of the US, they arrived at findings indicating statistically insignificant impacts of income on CO_2 emissions. This implies that both the US and Turkey might have the potential to reduce carbon emissions without compromising their economic growth trajectories. These findings underscore the importance of considering country-specific contexts and dynamics when analyzing the relationship between economic growth and environmental outcomes. Taken together, these studies collectively contribute to our understanding that the relationship between economic growth and CO_2 emissions may not always exhibit statistical significance. This nuanced perspective provides insights into potential pathways for decoupling economic growth from carbon emissions, highlighting the importance of tailored policy interventions and strategies to address environmental challenges effectively. In addition to examining the relationship between economic growth and CO_2 emissions, economists have extensively studied the impact of trade openness on environmental quality, particularly in terms of greenhouse gas (GHG) emissions. The findings from these studies have been varied, with some arguing that trade openness has a positive and significant effect on the environment, while others contend that it leads to negative outcomes and increased GHG emissions. These contrasting perspectives underscore the complexity of the relationship between trade openness and environmental sustainability and highlight the need for further research to inform policy decisions aimed at promoting both economic development and environmental protection. The discourse surrounding the impact of trade openness on environmental quality has been multifaceted, with divergent perspectives emerging from empirical studies. On one hand, scholars like Ferrantino (1997) and Grether et al. (2007) advocate for the notion that trade openness can have a positive and significant impact on environmental quality, positing that it fosters conditions conducive to environmental improvement. Conversely, other researchers, such as Suri (1998), Abler et al. (1999), and Cole et al. (2000), present a contrasting viewpoint, suggesting that trade liberalization might lead to adverse environmental outcomes, including heightened greenhouse gas (GHG) emissions.

A case in point is Malaysia, where Sulaiman, Azman, and Saboori (2013) conducted an analysis using the Autoregressive Distributed Lag (ARDL) approach to scrutinize the relationship between trade openness, CO_2 emissions, and environmental quality from 1980 to 2009. Their study revealed a noteworthy finding: trade openness exhibited a negative and statistically significant effect on both CO_2 emissions and environmental quality over the long term. This implies that, in the Malaysian context, trade openness may indeed contribute to environmental degradation rather than improvement. These contrasting perspectives underscore the complexity of the relationship between trade openness and environmental outcomes, emphasizing the need for nuanced analyses that consider contextual factors and dynamics specific to each country. Such insights are crucial for informing policy decisions aimed at striking a balance between promoting economic growth through trade openness and safeguarding environmental sustainability.

Indeed, urbanization has emerged as a significant determinant of CO_2 emissions, as evidenced by a plethora of studies within the scholarly literature. Researchers like Jalil and Mahmud (2009), Sharma (2011), and Fan et al. (2006) have delved into this relationship, shedding light on its nuances and implications. For instance, Sulaiman, Azman, and Saboori (2013) embarked on an investigation aimed at elucidating the influence of urbanization on both CO_2 emissions and energy consumption. Analyzing data spanning from 1975 to 2005 across 99 countries, their findings underscored a positive correlation between urbanization and both energy use and carbon dioxide emissions. Notably, they observed that this relationship exhibited heightened significance in countries characterized by middle-income levels, delineating variations across different income groups.

The relationship between urbanization and CO_2 emissions has been a focal point of research, with studies offering nuanced insights into this dynamic interplay across different geographic and developmental contexts. For instance, in China, Dhakal (2009) delved into the causal linkages between urbanization and CO_2 emissions, revealing a significant correlation between the population growth of large cities and a corresponding surge in emissions. Specifically, Dhakal highlighted a notable 40% increase in CO_2 emissions accompanying an 18% rise in urban populations—a finding indicative of the environmental repercussions of rapid urban expansion. Similarly, Martínez-Zarzoso and Maruotti (2010) conducted a comprehensive analysis spanning developing countries from 1975 to 2003, unveiling an intriguing inverted-U shaped relationship between urbanization and CO_2 emissions. Their findings suggested that while urbanization initially drives emissions upwards, there exists a point where emissions stabilize—a pattern reflective of the complex dynamics

at play in transitioning urban landscapes. Moreover, they underscored the differential impact of urbanization across regions, with less developed areas exhibiting a heightened environmental footprint in response to urbanization.
Turning to developed nations, Liddle and Lung (2010) embarked on a panel study encompassing 17 developed countries, elucidating the nuanced relationship between urbanization and carbon dioxide emissions. While their analysis revealed a positive impact of urbanization on emissions, they noted that this effect was statistically insignificant when considering aggregate emissions. However, a notable exception emerged concerning emissions from the transport sector, where urbanization exhibited a robust and statistically significant association with carbon emissions—a trend reflective of the intricate interactions between urban development patterns and environmental outcomes.

3. EMPIRICAL METHODOLOGY

To identify the primary contributors to CO2 emissions, previous studies, among others, have examined various explanatory variables. Following a similar approach, this study aims to explore the influence of transportation, particularly freight transport, and energy consumption on carbon emissions. In the empirical analysis, a set of exogenous variables including per capita gross domestic product (GDP), trade openness (TOP), and urbanization rate (UBR) are incorporated. The literature review indicates conflicting findings, with some studies suggesting a positive and significant impact of these variables on CO2 emissions, while others suggest a positive but insignificant effect. Therefore, our proposed model, which aligns with the broader literature, is structured as follows:

CO2 = f(EnC, FTr, GDP, UBR, TOP)

In the specified model, carbon dioxide emissions (CO2) are modeled as a function of several key variables: energy consumption (EnC), freight transport (FTr), per capita gross domestic product (GDP), urbanization rate (UBR), and trade openness (TOP). Here, "i" ranges from 1 to N, representing the countries involved (58 in this case), and "t" ranges from 1 to T, representing the time period from 2000 to 2019. Additionally, the model incorporates variables to capture the growth rates: gCO2 represents the growth rate of CO2 emissions (measured in metric tons per capita), gEnC represents the growth rate of energy consumption per capita, FTr denotes freight transport, UBR represents the urbanization rate, and TOP represents trade openness. Finally, ε denotes the classical error term, accounting for unexplained variability in the model.
The selection of the starting period was determined by data availability. For this study, data was sourced from the World Development Indicator (WDI, 2020), covering from 2000 to 2019. The variables considered in this analysis include carbon dioxide emissions (measured in metric tons per capita), energy consumption (EnC; measured by kilograms of oil per capita), freight transport (FTr; measured by ton-kilometers), per capita economic growth (GDP; measured in constant 2005 US dollars), urbanization rate (expressed as the percentage of urban population to the total population), and trade openness ratio (TOP), which represents the total value of real imports and exports as a percentage of real GDP.

4. RESULTS AND DISCUSSION

Table 1: Descriptive Statistics

	Mean	SD	CV
High-income countries			
Carbon dioxide emissions	2.984	39.857	17.998
Energy consumption	330.104	129.742	0.429
Freight transport	684e+9	20e+9	1.422
GDP per capita	35268.06	12877.15	0.402
Urbanization	77.452	15.526	0.252
Trade openness	88.256	20.458	0.748
middle-income countries			
Carbon dioxide emissions	2.563	19.849	9.048
Energy consumption	155.148	78.014	0.585
Freight transport	368e+9	7e+9	1.001
GDP per capita	3256.235	2014.11	0.589
Urbanization	70.452	18.454	0.521
Trade openness	63.418	38.256	0.554
low-income countries			
Carbon dioxide emissions	23.980	315.752	12.907
Energy consumption	74.526	75.470	0.689
Freight transport	103e+9	.125e+9	0.361
GDP per capita	699.014	742.147	0.701
Urbanization	50.415	20.748	0.5146
Trade openness	65.485	66.142	0.544

According to the results presented in Table 1, the mean growth rate of CO2 emissions is highest in high-income countries, with a value of 2.984. This is followed by middle-income countries, which have a mean growth rate of 2.563, and low-income countries, where the mean growth rate is 1.980. Additionally, the coefficient of variation suggests that high-income countries experience the greatest volatility in terms of carbon dioxide emissions. In terms of energy consumption, the mean growth data indicates that high-income countries are the largest consumers of energy, with a mean value of 155.148. Middle-income countries follow with a mean energy consumption growth rate of 74.526, while low-income countries have the lowest mean value. Interestingly, despite lower overall consumption, low-income countries exhibit the highest volatility in energy consumption, as indicated by a coefficient of variation of 0.689. In terms of freight transport, high-income countries indeed lead in transporting the largest volume of freight, indicating their significant role in international commerce. This is followed by middle-income and low-income countries, reflecting the correlation between economic development and trade activity. More advanced countries, typically more open to international trade, necessitate greater freight transport to facilitate global exchange of goods, a pattern observed in prior research (Harrigan, 1993). As shown in Table 1, high-income countries exhibit the highest average GDP per capita at $35,268.06, whereas low-income countries have the lowest at $699.014. The coefficient of variation related to economic output underscores the volatility of low-income countries compared to others. Similarly, trade openness and urbanization rates follow a similar trend, with high-income countries being more open and urbanized compared to middle and low-income countries. Table 2 presents the correlation matrix, revealing positive correlations between CO2 emissions and the other variables. Moreover, all variables introduced in the model exhibit positive correlations with each other, indicating the interconnectedness of factors influencing CO2 emissions and supporting the need for a comprehensive approach to addressing environmental challenges.

Table 2: correlation matrix

	gCO2	GEnC	FTr	gGDP	UBR	TOP
gCO2	1.0000					
gEnC	0.5725	1.0000				
FTr	0.8015	0.8110	1.0000			
gGDP	0.7442	0.6232	0.6002	1.0000		
UBR	0.0214	0.3210	0.4018	0.8951	1.0000	
TOP	0.0578	0.4284	0.0063	0.4172	0.0052	1000000

The correlation observed among the variables underscores the limitations of traditional panel ordinary least squares (OLS) estimators, both fixed and random effects, in accurately capturing the parameters of interest. Arellano and Bond (1991) proposed a solution to this issue with the development of the Generalized Method of Moments (GMM) estimator, offering consistent parameter estimates for models characterized by such correlations. By utilizing the Arellano and Bond (1991) approach, which involves first differencing, we can address the challenge posed by the interrelatedness of the variables and ensure the quality of our estimation results. The Sargan test serves as a diagnostic tool for assessing the presence of overidentifying restrictions within a model. A rejection of this test suggests potential misspecification of the model or instruments utilized. On the other hand, the AR(2) test, as proposed by Arellano and Bond (1991), examines second-order autocorrelation in the first-differenced errors. Given that first-differenced errors are inherently autocorrelated when regression errors are independently and identically distributed, the presence of autocorrelation is indicative of potential issues.

In Tables 3, 4, 5, and 6, the Sargan tests do not yield evidence of misspecification at conventional significance levels. Similarly, the AR(2) tests do not provide evidence of autocorrelation at conventional levels of significance. These findings suggest that the dynamic panel CO2 emissions model is appropriately specified. Additionally, post-estimation tests examining autocorrelation and instrument validity are included in the lower panel of each table to further validate the model's robustness.

Table 3: Results of Complete Panel

Dependent variable: per capita energy consumption		
Independent variables	coefficients	p-value
constant	3.215	0.032
$CO2_{t-1}$	-0.0015	0.247
Energy consumption (EnC_t)	0.902*	0.000
Freight transport (FrTp)	0.684*	0.000
GDP per capita (GDP)	0.207*	0.008
Urbanization	0.018**	0.041
Trade openness	0.001	0.325
Sargan test (p-value)	36.14	0.927
AR2 test (p-value)	-0.54	0.552

The results from the global panel, as outlined in Table 3 above, reveal several significant findings. Firstly, the coefficient associated with lagged CO2 emissions (CO2t-1) is recorded as -0.0015, indicating that carbon dioxide emissions are corrected by 0.15% in each period. This suggests a gradual adjustment mechanism in the emission levels over time. Moreover, energy consumption exhibits a positive and statistically significant impact on CO2 emissions, with a significance level of 1%. Specifically, for every 1% increase in energy consumption, there is a corresponding increase of 0.902% in CO2 emissions. This robust effect of energy usage on emissions aligns with previous research findings (Soytas, Sari, & Ewing, 2007; Halicioglu, 2009; Soytas & Sari, 2009; Lean & Smyth, 2009; Arouri et al., 2012), underscoring the importance of addressing energy consumption patterns to mitigate carbon emissions. The analysis reveals that freight transport also exerts a positive and statistically significant influence on CO2 emissions. With a coefficient of 0.684, it indicates that a 1% increase in freight transport leads to a corresponding increase of 0.684% in CO2 emissions. This finding underscores the substantial impact of freight transport on carbon emissions, a trend supported by various studies (Banister & Stead, 2002; Gilbert & Nadeau, 2002; Schipper, Scholl, & Price, 1997; CITEPA, 2005; Schäfer, 2005; UNCTAD, 2015).

Per capita GDP emerges as another significant factor influencing CO2 emissions within the global panel. With a coefficient of 0.207, per capita GDP demonstrates a significant effect on CO2 emissions at the 1% level. This implies that a 1% increase in per capita GDP corresponds to a 0.207% increase in CO2 emissions. Furthermore, the analysis indicates that urbanization and trade openness also have positive effects on CO2 emissions. However, only the impact of urbanization is statistically significant at the 5% level. Specifically, a 1% increase in the urbanization rate leads to a 0.018% increase in CO2 emissions. While both urbanization and trade openness contribute to CO2 emissions, the significance of the latter is disputed in the literature. Some studies, such as that by Khalil and Inam (2006) on Pakistan, argue that international trade negatively affects environmental quality, while others, like Halicioglu (2009) on Turkey, suggest a significant increase in CO2 emissions due to foreign trade.

Table 4: Results of High-Income Countries

Dependent variable: per capita energy consumption		
Independent variables	Coefficients	p-value
constant	0.124	0.715
$CO2_{t-1}$	0.0034	0.150
Energy consumption (EnC_t)	0.922*	0.000
Freight transport (FrTp)	0.726*	0.000
GDP per capita (GDP)	0.564*	0.000
Urbanization	-0.0047	0.197
Trade opnness	0.0075	0.126
Sargan test (p-value)	65.40	0.242
AR2 test (p-value)	1.14	0.068

Table 4 contains the results for the high-income panel, which indicate that the effect of the lagged dependent variable $CO2t-1CO2t-1$ is negative. The impact of energy consumption is positive and significant at the 1% level, similar to the global panel. A magnitude of 0.922 implies that CO2 emissions increase by 0.922% for every 1% increase in energy use. These results are consistent with those found by Soytas, Sari, and Ewing (2007), Menyah and Wolde-Rufael (2010), and Arouri et al. (2012). Freight transport positively affects CO2 emissions at the 1% significance level. According to the findings, CO2 emissions increase by 0.726% each year if freight transport grows by 1% in developed countries. Various reports confirm the significant impact of transport on greenhouse gas emissions, particularly CO2 (UNCTAD, 2015). Per capita GDP also has a positive and significant impact on CO2 emissions, consistent with the results from the global panel. The coefficient of 0.211 indicates that for every 1% increase in per capita GDP, CO2 emissions increase by 0.211%. This finding aligns with the notion that higher income levels are associated with greater energy consumption and industrial activity, leading to higher carbon emissions. Interestingly, in the high-income panel, both urbanization and trade openness exhibit positive effects on CO2 emissions, but they are not statistically significant at conventional levels. The coefficient for urbanization suggests that a 1% increase in the urbanization rate leads to a 0.025% increase in CO2 emissions, while the coefficient for trade openness implies a 0.006% increase in CO2 emissions for every 1% increase in trade openness. However, these effects lack statistical significance in the high-income panel, indicating that other factors may play a more dominant role in driving CO2 emissions in these countries.

Table 5: Results of Middle-Income Countries

Dependent variable: per capita energy consumption		
Independent variables	Coefficients	p-value
constant	4.305	0.665
$CO2_{t-1}$	-0.0058	0.118
Energy consumption (EnC_t)	0.867*	0.000
Freight transport (FrTp)	0.743*	0.000
GDP per capita (GDP)	0.228*	0.000
Urbanization	0.045**	0.021
Trade openness	0.0054***	0.067
Sargan test (p-value)	55.14	0.322
AR2 test (p-value)	0.914	0.348

Similarly, to the global panel, CO2 emissions in high-income countries are strongly affected by per capita GDP. Our results confirm a positive and significant impact with a magnitude of 0.564, implying that CO2 emissions increase by 0.564% if per capita GDP rises by 1%. This strong dependence of CO2 emissions on economic growth is confirmed by Zhang and Cheng (2009) and Richmond and Kaufmann (2006). However, CO2 emissions are not significantly affected by trade openness. There is a positive but statistically insignificant impact of trade openness on CO2 emissions. Concerning urbanization, the results indicate that CO2 emissions decrease by 0.0047% if the urbanization rate in developed countries increases by 1%. This suggests that, contrary to Sulaiman, Azman, and Saboori (2013) and Dhakal (2009), urbanization negatively affects pollutant gas emissions in high-income countries.

For the middle-income panel, the negative coefficient of the lagged dependent variable $CO2t{-}1CO2t{-}1$ is -0.0058, indicating that any deviation from the long-run equilibrium between the variables is corrected by approximately 0.58% each year. Additionally, energy consumption has a positive and strong impact on CO2 emissions, with emissions increasing by 0.867% for every 1% increase in per capita energy consumption. These findings align with those of Apergis and Payne (2010), Halicioglu (2009), Arouri et al. (2012), and Shahbaz, Zeshan, and Tiwari (2015), who emphasize the significant effect of energy use on CO2 emissions and environmental degradation. Freight transport also significantly contributes to the increase in CO2 emissions, with a coefficient of 0.743, indicating that a 1% increase in freight transport raises CO2 emissions by 0.743%. This result is consistent with the findings of Tanczos and Torok (2007), Steer Davies Gleave (2003), and UNCTAD (2015) for high-income countries.

Per capita GDP significantly enhances CO2 emissions, with a coefficient of 0.228. This suggests that a 1% rise in per capita GDP results in a 0.228% increase in CO2 emissions. The literature widely acknowledges economic growth as a major factor contributing to CO2 emissions and environmental degradation. Urbanization positively and significantly impacts CO2 emissions at the 5% level. Additionally, trade openness positively affects CO2 emissions, with a significant impact at the 10% level.

Table 6: Results of Low-Income Countries

Dependent variable: per capita energy consumption		
Independent variables	Coefficients	p-value
constant	6.140	0.057
$CO2_{t-1}$	-00047	0.450
Energy consumption (EnC_t)	0.901	0.000
Freight transport (FrTp)	0.674	0.000
GDP per capita (GDP)	0.348	0.000
Urbanization	0.142	0.007
Trade openness	0.0003	0.621
Sargan test (p-value)	41.47	0.057
AR2 test (p-value)	0.359	0.774

In the low-income panel, the results show that the lagged CO2 emissions have a negative coefficient, indicating that deviations from the long-run equilibrium between the variables are corrected by approximately 0.47% each year. Energy consumption, consistent with the other panels, has a positive and statistically significant impact on CO2 emissions at the 1% level. Specifically, a 1% increase in energy use results in a 0.901% increase in CO2 emissions. This finding aligns with the results of Vincent, Emodi, and Emodi (2016), who discuss the cointegration between economic growth, energy consumption, and CO2 emissions in Nigeria. Freight transport is also a significant factor contributing to CO2 emissions in low-income countries. The results indicate that a 1% increase in freight transport leads to a 0.674% increase in CO2 emissions. The impact of per capita GDP on CO2 emissions is notable as well. An increase of 1% in per capita GDP leads to a 0.348% increase in CO2 emissions, supporting the findings of Khalil and Inam (2006) and generally consistent with Shahbaz, Lean, and Shabbir (2010), Lee (2013), and Wang et al. (2011), who reported an inverted U-shaped relationship between CO2 emissions per capita and real GDP per capita. Urbanization in low-income countries is identified as a significant factor affecting CO2 emissions, differing from the findings in the global and high-income panels. A 1% increase in the urbanization rate results in a 0.142% rise in CO2 emissions. Finally, the impact of trade openness on CO2 emissions, while positive, remains statistically insignificant, similar to the results observed in the global and high-income panels.

5. CONCLUSIONS

The research aims to investigate the exact impact of energy use and freight transport on carbon dioxide emissions through dynamic panel data analysis. This focus addresses a significant gap in the existing literature, as previous studies have not delved deeply into this relationship. By employing dynamic panel data techniques, the study seeks to provide valuable insights into the environmental consequences of economic activity and transportation. The findings could inform policy decisions aimed at mitigating carbon emissions and promoting environmental sustainability. In the study, a dynamic panel data model was employed to assess the influence of freight transport, energy consumption, and other factors on CO2 emissions across 65 countries over a span of 20 years (2000-2019). Results indicated a significant impact of freight transport on energy consumption, subsequently affecting CO2 emissions. Energy consumption emerged as the primary driver of CO2 emissions, consistent with prior research by Narayan and Popp (2012), Perman and Stern (2003), and Omri and Sassi-Tmar (2014), which underscores the importance of addressing energy use in environmental policy initiatives.

Regarding urbanization's effect, distinctions were observed across panels. While the impact was positive but statistically insignificant in the high-income and middle-income panels, it significantly influenced CO2 emissions in the low-income panel. Additionally, the study noted a positive relationship between trade openness and CO2 emissions across all panels, although the impact was statistically insignificant across all countries. These findings provide valuable insights into the complex dynamics between various factors and CO_2 emissions, aiding policymakers in developing targeted strategies for environmental sustainability. These results underscore the critical importance of addressing the impacts of freight transport and energy consumption on CO_2 emissions. They highlight the need for a paradigm shift in policy-making towards sustainable development, prioritizing the decoupling of economic growth from transport demand. Policymakers must focus on enhancing energy efficiency within the transport sector to ensure accessibility while simultaneously promoting economic growth without exacerbating energy consumption and CO_2 emissions. Moreover, given the significant influence of energy use on CO_2 emissions, concerted efforts are needed across the 65 countries to bolster energy efficiency measures. Strengthening these efforts will not only contribute to reducing emissions but also advance environmental protection goals. Furthermore, improving the decoupling relationship between transport and economic growth is imperative for enhancing environmental quality. Policymakers should explore strategies to mitigate the environmental impacts of transportation while supporting sustainable economic development. Lastly, future research endeavors could expand upon these findings by investigating the interplay between transport demand, energy use, and economic growth, and their broader impacts on variables such as healthcare expenditure, financial development, and automobile usage. Such comprehensive analyses would provide deeper insights into the multifaceted relationships driving environmental and economic outcomes, informing more effective policy interventions and investment decisions.

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