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Impact of Population Growth on CO_2 Emissions in Export-Driven Global Transport: A 30-Country Analysis (2011-2020)

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Abstract: This study explores the complex relationship between population growth and CO2 emissions in an export-driven sector focused on global transportation. It addresses a gap in the existing literature by how demographic trends may influence the environmental impact of international trade. By using a robust dataset of 30 countries from 2011-2020. Advanced methods, including the CIPS, CADF Kao Test, Pedroni Test, and GMM tests, were applied to examine the relationships among trade activities, population growth, and CO2 emissions. Results show that export activity can significantly increase CO2 emissions through increased energy consumption associated with the production and transportation of goods. Further, population growth has been strengthened by increased demand for transportation services, leading to higher CO2 emissions. Furthermore, it underscores the importance of including demographic factors in the formulation of sustainable transportation policies. Policymakers, urban planners, and stakeholders can develop more effective strategies to reduce transportation's carbon footprint and promote environmental sustainability by understanding the moderating role of population growth. Finally, it provides valuable insights into the complex connections among trade, population growth, and environmental impact, which contribute to the broader discussion of sustainable development and climate change mitigation.

Keywords: Population Growth; CO2 Emissions; Global Transportation Sector; International Trade; Sustainable Development.[1]

1. Introduction

The global transportation sector plays an essential role in supporting economic activities and global trade (De Silva et al., 2016). Over many years, advances in the transportation framework and coordinated efforts have driven significant growth in cross-border service and product development. Furthermore, this development has been associated with a surge in carbon dioxide (CO2) emissions, primarily due to the burning of non-renewable energy sources in vehicles and other transportation-related activities (Grossman & Krueger, 1991).

According to the World Trade Organization, trade significantly affects GHG emissions, extending beyond production and international transportation. It influences where creation occurs and, if the carbon intensity of creation isn't uniform, it likewise influences the level of emissions. Significantly, trade likewise plays a fundamental role in diffusing green innovation and can help nations transition to lower-carbon, more sustainable economic activities. Consequently, trade diversely affects fossil fuel byproducts. Reducing trade-related discharges is feasible through technological advancements and global environmental cooperation. People depend heavily on petroleum derivatives as their primary energy source, leading to a concerning rise in global levels of ozone-depleting substances. As uncertainties over environmental change and sustainability continue to rise, there is a pressing need to understand the environmental consequences of transportation and to identify ways to mitigate its carbon footprint.

The global transportation sector remains a foundation of modern progress, supporting economic activities, facilitating global trade, and fostering cultural connections (Shahbaz et al., 2017). Since the onset of industrialization, transportation networks have continually expanded and evolved, driven by technological advances and globalization. From the improvement of rail line frameworks in the nineteenth century to the

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cutting-edge multiplication of air travel and container delivery, transportation plays have had an immediate impact in molding the shapes of the worldwide economy and empowering the trading of merchandise, services, and thoughts across huge distances; however, this development and network have come at a critical environmental cost (Peters et al., 2012). The dependence on petroleum products, especially in road vehicles, aircraft, and marine vessels, has led to a significant increase in carbon dioxide (CO2) emissions from the transportation sector (Knight & Schor, 2014). According to the International Energy Agency (IEA, 2020), transportation accounts for roughly one-fourth of global CO2 emissions, making it one of the largest contributors to human-caused ozone-depleting substance emissions. The effects of transportation extend beyond CO2 emissions alone. Different contaminants, such as nitrogen oxides (NOx), particulate matter (PM), and sulfur dioxide (SO2), emitted by vehicles and transport infrastructure, contribute to air pollution, respiratory illnesses, and environmental degradation (Heil & Selden, 2001).

Lately, concerns over environmental change and ecological sustainability have intensified, prompting calls for drastic measures to mitigate the effects of transportation on the climate. State-run administrations, worldwide associations, and civil society groups have increasingly focused on implementing measures and initiatives to reduce transportation emissions and advance cleaner, more efficient technologies (Jiborn et al., 2018). However, during these activities, there is a fundamental gap in how we might understand the complex interplay among transportation activities, demographic trends, and environmental consequences.

While past exploration has examined the effects of transportation-related issues, little attention has been paid to the role of population factors, such as population growth, in this relationship. Population growth significantly affects various aspects of economic and social development, including urbanization, consumption patterns, and transportation demand (Hossain, 2012). However, its implications for transportation discharges are certainly not known. As the worldwide population continues to grow, especially in urban areas, understanding how sectoral elements interact with transportation systems and emissions becomes increasingly significant for developing effective strategies to address climate change and advance sustainable development.

Despite the growing interest in the environmental impacts of transportation, there remains a gap in our understanding of the complex interactions between goods and service transport, CO2 emissions, and demographic factors such as population growth (Grossman & Krueger, 1991). While previous research has examined the relationship between transportation and emissions, relatively little attention has been paid to the moderating role of population. Understanding how population growth influences the environmental footprint of transportation is crucial for devising effective policies and strategies to promote sustainable transportation systems and mitigate climate change.

This examination aims to explore the effects of merchandise and administrative transport on CO2 emissions, specifically focusing on the moderating role of population growth. The targets incorporate looking at the connection between transportation exercises, CO2 discharges, and demographic factors; recognizing the components through which population growth directs the connection among transport and CO2 discharges; evaluating the results of population growth on the environmental sustainability of transportation frameworks; and giving proof-based suggestions to policymakers, urban planners, and transportation partners to advance manageable transportation practices with regards to population development and natural difficulties.
This study will address the following question.

RQ1: How does population growth impact CO2 emissions from global transport?
RQ2: What's the role of population growth in moderating transportation's CO2 emissions?
RQ3: How can grasping population growth's effect on transport emissions guide sustainable policy and planning?

This exploration is critical considering multiple factors. Firstly, by examining the intricate interactions among transportation, population factors, and environmental sustainability, the evaluation advances theoretical understanding of these fundamental issues. By revealing the nuanced ways in which population growth shapes transportation's environmental impacts, the examination fills a pivotal role in the existing literature. It gives significant insight into future research endeavors. Moreover, the findings have practical implications for policymakers, urban planners, and transportation stakeholders seeking to address environmental change and achieve practical outcomes (Heil & Selden, 2001). The practical implications of this study extend to various areas and stakeholders. Firstly, policymakers can use the findings to develop designated transportation and natural approaches, considering demographic trends. Urban planners and infrastructure developers can integrate this knowledge into their techniques, aiming to limit the environmental impacts of transportation in rapidly developing urban areas. Organizations in the transportation and strategy areas can streamline tasks and reduce their carbon footprint by adopting advanced technologies and efficient operational practices informed by research. Community engagement and collaborator-coordinated effort are fundamental for fruitful execution, supported by discourse, as outlined in this study's insight.

Eventually, the study contributes to the broader objective of achieving long-term environmental sustainability by highlighting the importance of comprehensive methodologies in transportation planning and environmental management. Through purposeful undertakings, collaborators can make progress toward an additional, sustainable, and adaptable future.

The following chapters of this study are sequenced in the following order: Section 1 covers the introduction part, i.e., background of the study, problem statement, objective, and significance of the study, followed by possible practical implications of the study. Section 2 thoroughly reviews existing literature to support the study and establish the theoretical context of the research. Sections 3 and 4 describe research techniques, including data gathering, data analysis, and discussion. The following sections present and evaluate the data, then end with Section 4, which covers implications, limitations, and future research directions, followed by the reference section. The study's thorough examination aims to contribute to the expanding conversation on the impact of goods and service transport on CO2 emissions, specifically focusing on the moderating role of population growth.

1.1 Literature review

One of the greatest threats to the environment is the rising global temperature. inciting humanities in this modern era. At the core of this emergency lies the increasing concentration of carbon dioxide (CO2) and other greenhouse gases in Earth's atmosphere, which has emerged as the primary agent (Majumder et al., 2022). In recent years, carbon dioxide emissions have been closely linked to the global economy's dependence on non-sustainable power sources, a pattern that has sparked significant global concern (Luo et al., 2017).

As the population grows and economic activities continue unabated, environmental pressures increase, driven by the push for industrialization and economic growth, especially in developing countries (Rahman & Majumder, 2022). As a result, the negative effects of human activity, such as the widespread use of fossil fuels, extend beyond the present climate and represent a critical gamble for our future generations (Polcyn et al., 2023). It has become increasingly difficult to keep up with the rapid rate of climate change caused by global warming. It is important to examine these issues from a political and economic perspective to develop effective methodologies for moderation and transformation (Zhang et al., 2023).

In response to the urgent need for action, international agreements such as the Kyoto Protocol, signed in Japan in 1997, have been established to address greenhouse gas emissions. Hence, the transition from non-renewable to renewable energy sources is a key strategy in this effort, as it offers a pathway to reduce carbon dioxide emissions and mitigate the adverse impacts of climate change (Zafar et al., 2019). Consequently, reducing CO2 emissions emerges as a pivotal measure to combat global warming and foster sustainable economic development worldwide (Wang et al., 2020).

1.2 Exports of Goods and Services and CO2 Emissions

Exports of goods and services are important for economic growth, but they also have important environmental consequences, i.e., in terms of emissions. When examining trade dynamics across some Asian countries, differences between exports and imports indicate varying levels of CO2 emissions, particularly in some countries (Raihan et al., 2023). This difference is significant because it shows that distinct trade activities have different environmental impacts. Through extensive research into the intricate relationships between exports and emissions, researchers have shed light on various ways exports can contribute to environmental degradation. The increased energy consumption associated with export-oriented industries is a crucial link between products and increased emissions. Higher export levels often coincide with increased energy use, which eventually leads to higher CO2 emissions (Leitão & Lorente, 2020).

Because of their energy-concentrated nature, these ventures leave a huge carbon footprint. Besides, the consumption of oil produces a ton of carbon dioxide (CO2) into the atmosphere, further exacerbating the issue in numerous product-driven economies. One more stressful aspect of goal-driven development is the consumption of non-renewable resources, which can compound the byproducts of fossil fuels. As demonstrated, the advancement of itemized ventures regularly results in an expansion in the extraction and use of common resources such as minerals and non-renewable energy sources. This accelerates asset exhaustion and increases the production of fossil fuel byproducts from mining and drilling. When petroleum derivatives extracted for trade are burned, carbon dioxide (CO2) is released into the atmosphere, contributing to climate change and environmental degradation. In this manner, pursuing exchange-driven development could unfavorably affect the overall climate and natural systems. The negative environmental effects of products are not limited to specific areas, as research across several countries and over various time periods indicates.

Contended that export growth has driven increased carbon emissions across a wide range of nations over the past several years. Between 1990 and 2011, data from 189 countries were analyzed, revealing a worrying pattern of rising emissions driven by export-oriented economic policies. Besides, recognized bidirectional causality between exports and carbon emissions across nations, suggesting a complex relationship between economic activity and ecological degradation.

Despite these alarming patterns, a few researchers have proposed alternative perspectives on the association between commodities and fossil fuel byproducts. found a correlation between lower carbon emissions and higher exports of manufactured goods in a sample of industrialized and developing nations. Their examination, which ran from 1981 to 2012, highlighted the acknowledged insight that some commodity-based businesses could adopt more environmentally friendly methods and reduce their environmental impact. However, these findings should be interpreted with caution, as they may not apply to all export sectors or regions.

Through a variety of channels, imports and exports also play a significant role in shaping environmental outcomes. One essential concern is the environmental impact of transporting imported goods. Imported goods often require extensive transportation networks to reach global markets (Sadorsky, 2012). These transportation exercises consume a lot of fuel, adding to the production of fossil fuel byproducts and worsening ecological degradation. Additionally, the longer distances involved in transportation because of supply chain globalization have increased the carbon footprint of imported goods.

Moreover, the energy intensity of imported items can also affect carbon emissions. It has been found that certain imported goods, such as coolers, climate control systems, and cars, are energy-intensive and can significantly contribute to overall energy use and emissions. This is especially pertinent for non-industrial nations, where the adoption of energy-intensive innovations and lifestyles is on the rise.

As these countries continue to bring in such goods to meet developing consumer needs, their ecological impact is likely to grow, fueling global environmental change (Ohlan, 2015). Another important aspect of the environmental impact of imports is how free trade agreements affect economic growth and consumption patterns. argued that different countries may experience increased energy consumption and carbon emissions because of higher import levels. Countries that sign free trade agreements can gain access to a broader range of goods and services, which in turn can increase consumer demand and economic activity. Emissions and energy use may rise as a result. By pointing out that both imports and exports significantly contribute to emissions based on consumption, Liddle (2018) also emphasized the interconnectedness of global trade and environmental degradation.

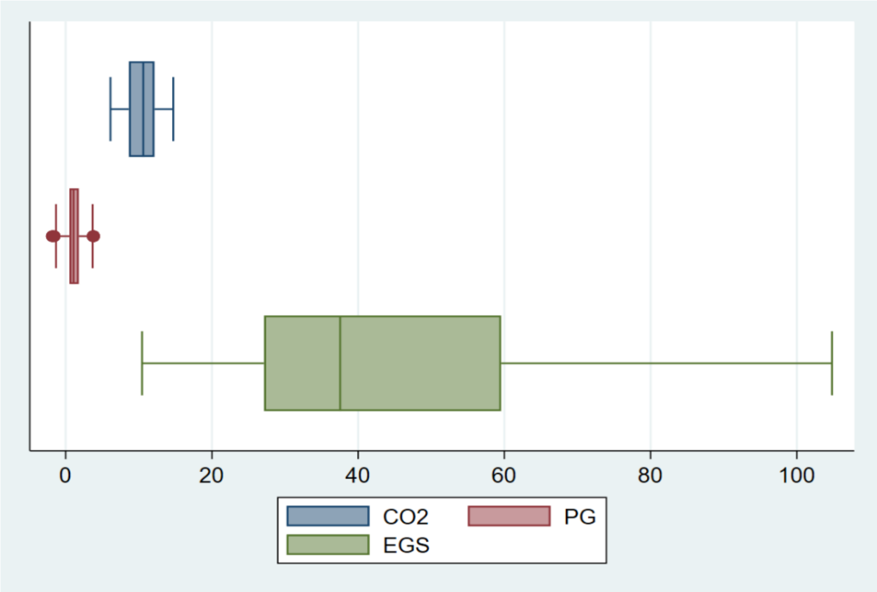
1.3 Population Growth and CO2 Emissions

Different assessments have examined the complex relationship between population size and growth, and carbon emissions across various countries, uncovering insights into the perplexing association between human socio-economic and environmental effects (Esquivias et al., 2022). It has been noted that population growth affects environmental quality by increasing demand for energy, a scarce resource.

Population growth reduces ecological quality by increasing energy demand for industry, transport, and power (Ohlan, 2015). also examined the relationships among population, carbon emissions, and other macroeconomic indicators. The study found that population growth over time worsens environmental pollution. investigated how population growth and other environmental factors affect environmental quality and reported similar findings. In 11 Asian nations, the findings indicate that population growth worsens environmental quality. The period from 1990 to 2019 is the focal point of this review, and they found, using panel quantile regression, a convincing result: districts with higher population density typically exhibit activities that undermine ecological sustainability.

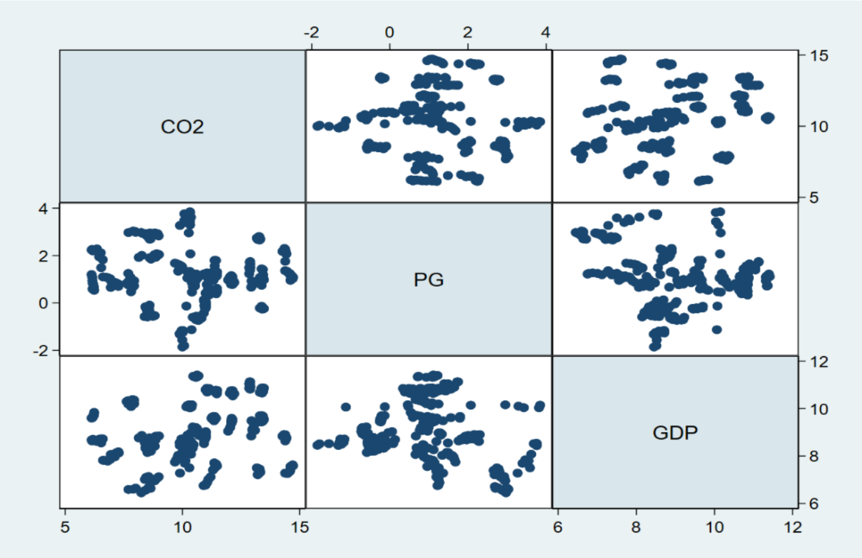
While assessing the climate consequences, this tracking highlights the importance of considering the entire population's size, distribution, and density (Esquivias et al., 2022). looked at data for a group of nations known as the N11 from 1980 to 2018. Their investigation revealed a clear link between population components and CO2 emissions. Computation based on long-term data analysis found that utilization-based CO2 emissions increased by 0.197% for each 1% increase in population. This suggests that, especially when viewed through utilization patterns, population growth can affect carbon emissions (Rahman & Majumder, 2022).

Figure 1 depicts boxplots for CO2, PG, and EGS. The CO2 boxplot is compact, suggesting minimal variability in its data distribution. The range between the quartiles and whiskers is narrow, indicating consistent CO2 levels across the dataset. This stability could signify that CO2 levels are less sensitive to fluctuations in the explanatory variables (PG and EGS). PG exhibits a narrow distribution with two visible outliers. The concentration of data points near zero suggests that PG values are clustered in a specific range. However, the outliers might influence CO2 variability. These outliers need further examination to determine whether they significantly impact CO2 levels. EGS shows wide variability, as evidenced by its larger interquartile range and long whiskers. This indicates a wide range of EGS values. The variability in EGS could provide a more substantial explanation for variations in CO2 levels compared to PG.



(Source: Author's Derivation
Figure 1 : CO2, ESG, and PG (2011-2020)

The graph shows that EGS may have a broader influence on CO2 levels due to its greater variability. PG, on the other hand, shows limited variability but may still contribute to CO2 fluctuations through outlier effects. Analyzing these relationships using statistical methods could clarify the strength and significance of the explanatory variables on CO2.



(Source: Author's Derivation)
Figure 2: CO2, PG, and GDP (2011-2020)

Figure 2 illustrates the relationship between CO_2 emissions, population growth, and GDP over the period from 2011 to 2020. The results indicate a positive relationship among these variables. Evidence from a 41-year-long study in Pakistan shows that population growth significantly increases CO_2 emissions(Ahmed et al., 2017). Similar findings have been reported for South Asian countries, where population growth contributes to higher CO_2 emissions (Al Mamun et al., 2014). Research on Malaysia found that urbanization plays a significant role in increasing CO_2 emissions by interacting with financial development, economic growth, and energy consumption (Amin et al., 2022). Further analysis of the relationship between population growth and CO_2 emissions from 1980 to 2016, using the CCEMG technique, revealed a strong positive association (Anser, 2019). As a result, climate change mitigation efforts must incorporate population growth dynamics.

This implies that as a region's population increases, its carbon emissions are likely to rise correspondingly. An additional study using the ARDL approach to examine population growth and environmental pollution from 1980 to 2016 confirmed earlier findings, showing that population growth contributes to increased fossil fuel emissions (Bekhet & Othman, 2017). These results underscore the importance of integrating population dynamics into environmental policies to achieve sustainable development globally.

Conversely, an analysis of twelve developed countries using the CS-ARDL approach found a negative relationship between population size and ecological footprint (Chang et al., 2018). This suggests that ecological footprints on a per capita basis may decline, highlighting the importance of considering both total population growth and per capita consumption patterns when evaluating environmental impacts. Moreover, a panel study of BRICS economies spanning 1972 to 2021 examined the relationship between population growth and environmental degradation. Although population size was found to increase CO_2 emissions, the relationship was not statistically significant, indicating the need for further research to clarify the complex interaction between population dynamics and environmental outcomes (De Silva et al., 2016).

1.4 Research Gap

Despite broad exploration of the natural effects of transportation and the connection between population dynamics and CO2 emissions, a critical gap remains in understanding this relationship. Even though previous research has examined the effects of transportation on CO2 emissions and the influence of population growth on environmental sustainability separately, there is a dearth of research that specifically examines how population dynamics moderate the relationship between transportation activities and CO2 emissions.

Given the export-oriented nature of many industries and the energy-intensive nature of transportation networks, the existing literature has highlighted the significant contribution of transportation to CO2 emissions. Moreover, studies have shown a positive relationship between population size and ecological degradation, as well as the impact of population growth on CO2 emissions.

However, the specific mechanisms by which transportation's environmental impact is influenced by population dynamics remain poorly understood. Understanding the moderating role of population growth in the relationship between transportation activities and CO2 emissions is essential for devising effective methodologies and strategies to advance sustainable transportation systems and mitigate ecological change. The proposed study aims to fill this research gap and provide valuable insights into the intricate interactions that exist among demographic trends, transportation structure, and environmental sustainability.

2. Research Methodology

In this research, we aim to explore how trade indicators influence climate change (Table 1). Trade is the independent variable, while climate change is the dependent variable. Health, specifically population growth, is also considered a moderate variable for this study. Exports of goods and services include the total amount of goods and various services traded with other countries. It includes merchandise amounts, transportation costs, travel expenses, royalties and license fees, and an array of services, such as financial, information, business, personal, and government services. Carbon dioxide emissions stem from burning fossil fuels and cement manufacturing. These emissions include carbon dioxide generated from solid, liquid, and gas fuels, as well as from flaring activities.

The annual population growth rate, defined for year "t," is the exponential growth rate of the population from year "t-1" to year "t," expressed as a percentage. The population calculation is based on the de facto definition, which identifies all residents regardless of their legal citizenship. Investment in transport projects involving private involvement involves commitments made to infrastructure projects in the transport sector that have achieved financial closure and provide directly or indirectly to public needs.

Table 1: Variable Description

Variable	Symbol	Proxy	Measurement	Sources
Trade	EGS	Exports of Goods and Services	% of GDP	WDI
Climate Change	CO_2	CO_2 Emission	kt	WDI
Health	PG	Population Growth	annual %	WDI
Infrastructure	ATW	Investment in transport	Current US $	WDI
Economy and Growth	GDP	Gross Domestic Product	Per Capita	WDI

Sample Selection, Data Collection, and Limitations. The data for this study were obtained from the World Bank indicators, and a sample of 30 countries around the world was taken for the period of 10 years, from 2011 to 2020.

2.1 Theoretical Model of the Study

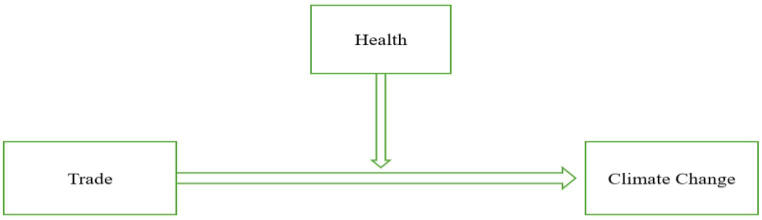


Figure 3: Study framework

3. Research Hypothesis

3.1 Trade has a positive impact on Climate Change.

Trade activities, which involve the exchange of goods and services across borders, often involve moving goods over long distances, resulting in substantial carbon emissions from transportation. Additionally, trade-oriented industries might emphasize cost-effectiveness over environmental sustainability, thereby increasing the use of fossil fuels and the production of more greenhouse gases, such as CO2. Besides, the effect of trade on climate change extends beyond emissions to include deforestation, habitat destruction, and pollution associated with the production and transportation of traded goods. Enterprises like agriculture, forestry, and manufacturing may engage in practices that degrade natural ecosystems and contribute to global warming.

This hypothesis suggests that the negative effects of trade on climate change can significantly exacerbate environmental degradation because of the interconnected relationship between trade dynamics and climate change. The concept is based on the belief that increasing trade activities, particularly in regions with high carbon emissions and environmental footprints, can contribute to climate change.

3.2 Health moderates the relationship between trade and climate change

Trade and climate change are heavily influenced by population-driven interactions. In rapidly developing populations, natural resources and ecosystems are under increased pressure, leading to greater deforestation, habitat destruction, and trade-related pollution. Trade has a huge effect on climate change due to rapid population growth. In the same way, trade may be less beneficial if there is no way to manage or slow population growth. Small populations are considerably less inclined to consume large amounts of assets or create waste that contributes to climate change and fossil fuel byproducts from a trade program.

The complex relationship between trade and climate change is influenced by population growth, which serves as a critical moderating factor in mitigating the ecological impacts of trade activities and alleviating the effects of climate change worldwide. The relationship between climate change and trade is largely influenced by population growth. As population growth decreases, demand for services and goods increases, prompting greater trade activity. This expanded trade can contribute to environmental change through various channels, including increased emissions from transportation or trade activities.

4. Empirical Study of Model

For H1

$$CO2it = \beta0 + \beta1 \cdot EGSit + \mu i + \epsilon it \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 1)}$$

The concept is that trade has a direct impact on climate change. When trade increases, it speeds up climate change. To test this, we'll use a statistical model to examine how changes in trade are associated with climate change.

In equation (1), CO2it represents the carbon dioxide emissions in country i at time t. TDSit represents a trade dependence score in country i at time t. β0 is the intercept, β1 is the coefficient representing the effect of trade dependence on carbon dioxide emissions, μi is the country-specific effect, and ϵit is the error term.

For H2

$$CO2it = \beta0 + \beta1 \cdot EGSit + \beta2 \cdot PGit + \beta3 \cdot (EGSit \times PGit) + \mu i + \epsilon it \ldots\ldots\ldots\ldots \text{(Eq. 2)}$$

In equation (2), CO2it represents the carbon dioxide emissions in country i at time t. TDSit represents the trade dependence score in country i at time t. PGit represents the population growth rate in country i at time t. β0 is an intercept, β1, β2, and β3 are coefficients representing the effects of trade dependence, population growth, and the interaction between trade dependence and population growth on carbon dioxide emissions, respectively. μi is the country-specific effect, and ϵit is the error term. The concept is that the effect of trade on climate change depends on the health factor. This means that the connection between trade and climate change can change based on whether the population is growing or shrinking.

4.1 Analysis Tools and Techniques

Stata is widely used by researchers, financial experts, and social scientists for data analysis. It provides a wide range of measurable techniques, including modeling, long-term data analysis, and regression analysis. Microsoft Excel is a spreadsheet that is used to organize and analyze data.

It is useful for simple tasks because it provides fundamental functionality, such as finding midpoints, medians, and standard deviations. It uses various statistical tools and techniques to examine relationships among trade, climate change, and health. Moderation analysis is also used to find the relationship between trade and climate change. Regression analysis is then used to estimate the direct effect of trade on climate change, while examining the moderating role of health. The analysis consists of two main components: determining the factors that influence climate change and examining how health affects the relationship between trade and climate change. This approach provides insights into the complex relationships among variables through rigorous statistical analysis.

5. Data Analysis

Table 2: Data analysis

Variables	N	Mean	Std. Dev.	Min	Max
Code	300	15.5	8.67	1	30
Year	300	2015.5	2.877	2011	2020
CO_2	300	10.571	2.251	6.123	14.715
EGS	300	43.249	22.054	10.443	104.805
PG	300	1.119	1.163	-1.854	3.845
ATW	300	10.78	2.295	2.303	14.285
GDP	300	9.026	1.275	6.449	11.413

The dataset provides descriptive statistics for five variables across 300 observations, providing insights into central tendencies, dispersion, and ranges (Table 2). The "CO2" variable has an average of 10.571 and a standard deviation of 2.251, indicating some variation and values ranging from 6.123 to 14.715. The "EGS" shows a high level of variability, with a mean of 43.249 and a standard deviation of 22.054, spanning 10.443 to 104.805. For the "PG" variable, the mean is 1.119, and the standard deviation is 1.163, which suggests moderate variability and a range of values from -1.854 to 3.845, which indicates both negative and positive values. The "ATW" variable has an average of 10.78, a standard deviation of 2.295, and values ranging from 2.303 to 14.285, indicating a moderate spread around the mean. The "GDP" variable shows a mean of 9.026 with a relatively low standard deviation of 1.275, with values ranging from 6.449 to 11.413, showing less variability around the mean.

Table 3: Matrix of Correlations

Variables	VIF	(1)	(2)	(3)	(4)	(5)
(1) CO_2	–	1.000				
(2) EGS	1.38	−0.095	1.000			
(3) PG	1.23	−0.012	−0.149	1.000		
(4) ATW	1.47	0.698	0.069	0.158	1.000	
(5) GDP	2.01	0.200	0.493	−0.287	0.450	1.000

Table 3 presents the variance inflation factor (VIF) analysis and the correlation matrix for five variables: CO2, EGS, PG, ATW, and GDP. The VIF values indicate the degree of multicollinearity present in the regression model. With VIF values of 1.38 for EGS, 1.23 for PG, 1.47 for ATW, and 2.01 for GDP, multicollinearity is low across these variables, as all values are well below the threshold of concern (typically 5-10). The correlation matrix shows the relationships among these variables, with coefficients ranging from -1 to 1. A coefficient close to 1 or -1 signifies a strong positive or negative correlation, respectively, while values near 0 indicate weak or no correlation. Specifically, CO2 shows a weak negative correlation with EGS (-0.095) and PG (-0.012), but a strong positive correlation with ATW (0.698), and a weak positive correlation with GDP (0.200). EGS is weakly negatively correlated with PG (-0.149) and weakly positively correlated with ATW (0.069), and it shows a moderate positive correlation with GDP (0.493). PG shows a weak positive correlation with ATW (0.158) and a weak-to-moderate negative correlation with GDP (-0.287). Lastly, ATW and GDP are moderately positively correlated (r = 0.450).

Table 4: Linear Regression

CO_2	Coef.	St. Err.	t-value	p-value	[95% Conf	Interval]	Sig
EGS	-.009	.005	-1.99	.047	-.019	0	**
PG	-.401	.084	-4.76	0	-.567	-.235	***
ATW	.803	.047	17.21	0	.712	.895	***
GDP	-.322	.098	-3.28	.001	-.515	-.129	***
Constant	5.67	.706	8.03	0	4.28	7.059	***

Mean dependent var	10.571	SD dependent var	2.251
R-squared	0.547	Number of obs	300
F-test	88.928	Prob > F	0.000
Akaike crit. (AIC)	1109.836	Bayesian crit. (BIC)	1128.354

**** p<.01, ** p<.05, * p<.1*

The linear regression results provide an analysis of the relationships between the dependent variable CO2 and the independent variables EGS, PG, ATW, and GDP. Table 4 summarizes the coefficients, standard errors, t-values, p-values, and 95% confidence intervals for each predictor.

EGS has a coefficient of -0.009 with a standard error of 0.005. The T-value is -1.99, and the p-value is 0.047, which is significant at the 0.05 level. This shows a small but significant negative relationship between EGS and CO2: a one-unit increase in EGS is associated with a 0.009 decrease in CO2. PG has a coefficient of -0.401 with a standard error of 0.084. The t-value is -4.76, and the p-value is 0.000, which is significant at a 0.01 level.

This indicates a substantial negative relationship between PG and CO2, with a one-unit increase in PG leading to a 0.401 decrease in CO2 emissions. ATW has a coefficient of 0.803 with a standard error of 0.047. The t-value is 17.21, and the p-value is 0.000, indicating significance at the 0.01 level. This strong positive relationship suggests that a one-unit increase in ATW is associated with a 0.803 increase in CO2. GDP presents a coefficient of -0.322 with a standard error of 0.098.

The t-value is -3.28, and the p-value is 0.001, which is significant at the 0.01 level. This indicates a negative relationship between GDP and CO2, where a one-unit increase in GDP results in a 0.322 decrease in CO2. The constant term is 5.67 with a standard error of 0.706, a t-value of 8.03, and a p-value of 0.000, which is highly significant. This represents the expected CO2 value when all predictors are zero.

Table 5: Testing for slope heterogeneity

H0: Slope coefficients are homogeneous	
Delta	P-value
6.266	0.000
Adj. 7.489	0.000
Variables partially out: Constant	

The analysis, as outlined by Pesaran and Yamagata (2008) in the Journal of Econometrics, tests for slope heterogeneity to assess whether the slope coefficients in a regression model are uniform across groups or observations. The null hypothesis posits that these coefficients are homogeneous, while the alternative hypothesis suggests heterogeneity.

The results of the test reveal a Delta statistic of 6.266 with a corresponding p-value of 0.000, indicating strong evidence against the null hypothesis. Additionally, an adjusted Delta statistic of 7.489 is reported, also yielding a p-value of 0.000 (Table 5). These highly significant p-values lead to the rejection of the null hypothesis, signifying significant heterogeneity in the slope coefficients. Consequently, it is inferred that the relationship between the dependent variable and the independent variables varies substantially across different subsets or observations within the dataset. In particular, a constant term is adjusted for in the analysis to separate the variability in the slope coefficient.

Based on these findings, it is appropriate to account for slope heterogeneity in analyses, potentially necessitating the use of models capable of capturing fluctuating slopes, such as random-coefficients models or models including interaction terms to account for differences observed across observations.

Table 6: Cross-Sectional Dependency

Variables	Statistics	P-value	Abs (Corr)
CO_2	9357***	0.000	0.46
EGS	9.042***	0.000	0.44
PG	20.147***	0.000	0.55
The***represents a significant level			

The analysis aims to evaluate cross-sectional dependencies among the variables CO2 emissions (CO2), exports of goods and services (EGS), and population growth (PG) (Table 6). Statistical tests show highly significant results (p-value = 0.000), indicating strong evidence of cross-sectional dependency. The absolute correlation coefficients, that is, range from 0.44 to 0.55, further highlight the associations between the variables. This indicates that changes in one variable are likely correlated with changes in the others within this dataset. Therefore, it is crucial for any further analyses involving CO2, EGS, and PG to take these inter-relationships into account to maintain the accuracy and validity of the findings.

Table 7: Unit Root Tests

Variables	CIPS		Variable	CADF	
	Level	First Difference		Level	First Difference
CO_2	-2.344	-2.675	**CO_2**	-2.344	-2.675
EGS	-2.168	-3.108		-1.845	-3.108

The data presented offer insights from two-unit root tests, namely the Cross-sectional Implied Pesaran-Shin (CIPS) and Cross-sectional Augmented Dickey-Fuller (CADF) tests, applied to the variables CO2 and EGS at both levels and first differences (Table 7). In the CIPS test, at the level, the test statistics indicate values of -2.344 for CO2 and -2.168 for EGS, respectively. Following the first difference, these statistics shift to -2.675 for CO2 and -3.108 for EGS. Similarly, the CADF test produces identical results at the level, with CO2 and EGS displaying test statistics of -2.344 and -2.168, respectively. Upon differencing, the values for CO2 and EGS remain consistent with those of the CIPS test, at -2.675 and -3.108, respectively. These statistics help determine whether the time series exhibits stationary behavior or a unit root, indicating non-stationarity.

Table 8: Pedroni Test for Cointegration

Ho: No cointegration Number of panels = 30
Ha: All panels are cointegrated Number of periods = 9
Cointegrating vector: Panel-specific
Panel means: Included Kernel: Bartlett
Time trend: Not included Lags: 2.00 (Newey-West)
AR parameter: Panel specific Augmented lags: 1

	Statistic	p-value
Modified Phillips-Perron t	3.3152	0.0005
Phillips-Perron t	-2.2259	0.0130
Augmented Dickey-Fuller t	-3.1828	0.0007

The Pedroni test for cointegration is utilized to examine whether a long-term relationship, or cointegration, exists among variables across multiple panels (Table 8). With the null hypothesis (Ho) positing no cointegration and the alternative hypothesis (Ha) suggesting cointegration across all panels, the test uses various statistics to test for cointegration. In this analysis, conducted across 30 panels over 9 periods, the cointegrating vector is specified as panel-specific, and panel means are included in the assessment (Shahbaz et al., 2017).

The Bartlett kernel is employed, with no time trend included, and lag specifications of 2.00 (Newey-West) and 1. augmented lags. The test statistics provide strong evidence against the null hypothesis of no cointegration. Specifically, the Modified Phillips-Perron t statistic yields a value of 3.3152 with a corresponding p-value of 0.0005, the Phillips-Perron t statistic shows -2.2259 with a p-value of 0.0130, and the Augmented Dickey-Fuller t statistic registers -3.1828 with a p-value of 0.0007. These results collectively suggest strong support for the alternative hypothesis, signifying that all panels are co-integrated.

Table 9: Kao Test for Cointegration

Ho: No cointegration	Number of panels = 30	
Ha: All panels are cointegrated	Number of periods = 8	
Cointegrating vector: Same		
Panel means: Included	Kernel: Bartlett	
Time trend: Not included	Lags: 1.33 (Newey-West)	
AR parameter: Same	Augmented lags: 1	
	Statistic	p-value
Modified Dickey-Fuller t	0.0709	0.4718
Dickey-Fuller t	-2.2034	0.0138
Augmented Dickey-Fuller t	-1.8674	0.0309
Unadjusted modified Dickey-Fuller t	-0.5179	0.3022
Unadjusted Dickey-Fuller t	-2.6013	0.0046

The Kao test for cointegration is a robust tool for assessing whether a long-term relationship, or cointegration, exists among variables across multiple panels (Table 9). In this analysis, the null hypothesis (Ho) posits no cointegration, whereas the alternative hypothesis (H1) posits that all panels are cointegrated. The examination incorporates various statistics to scrutinize this relationship (Usman et al., 2022).

Applying the test to a dataset featuring 30 panels over 8 periods, the cointegrating vector is specified as the same across panels, and panel means are included in the assessment. The Bartlett kernel is utilized, and a time trend is omitted from the analysis. Lag specifications are set at 1.33 (Newey-West), with an augmented lag of 1. The test statistics yield insightful results: the Modified Dickey-Fuller t statistic is 0.0709 with a p-value of 0.4718, indicating relatively weak evidence against the null hypothesis.

In contrast, the Dickey-Fuller t and Unadjusted Dickey-Fuller t statistics present more compelling evidence against the null hypothesis, with p-values of 0.0138 and 0.0046, respectively, suggesting stronger indications of cointegration. The Augmented Dickey-Fuller t statistic also provides evidence against the null hypothesis, albeit less significantly, with a p-value of 0.0309.

Table 10: Regression results (GMM)

CO_2	**Coef.**	**St.Err.**	**t-value**	**p-value**	**[95% Conf**	**Interval]**	**Sig**
L	.658	.08	8.27	0.000	.502	.813	***
EGS	.005	.001	4.65	0.000	.003	.007	***
Mean dependent Var	10.592			SD dependent var	2.237		
Number of obs	240			Chi-square			

**** p<.01, ** p<.05, * p<.1*

	(1)	(2)	(3)	(4)	(5)
Variables	CO_2	CO_2	CO_2	CO_2	CO_2
EGS	-0.00966	-0.00966	-0.0101*	-0.0101*	0.00512***
	(0.00589)	(0.00589)	(0.00596)	(0.00596)	(0.00110)
PG			-0.0507	-0.0507	
			(0.113)	(0.113)	
L.CO_2					0.658***
					(0.0796)
Constant	10.99***	10.99***	11.06***	11.06***	

	(0.286)	(0.286)	(0.330)	(0.330)	
Observations	300	300	300	300	240
	0.009	0.009	300	0.010	
Number of Code					30

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The regression analyses conducted using the Generalized Method of Moments (GMM) and the Autoregressive Generalized Method of Moments (AGM) techniques yield insightful findings regarding the relationships between the dependent variable CO2 and the independent variables EGS and PG. In the GMM regression (Table 10), a coefficient for a lagged CO2 variable (L.CO2) is estimated at 0.658 with a standard error of 0.08, which indicates a highly significant positive relationship with CO2 levels.

Likewise, the coefficient for an EGS is 0.005 with a standard error of 0.001, indicating a statistically significant positive association between an EGS and CO2. The AGM regression provides a more detailed examination of these relationships by including additional variables. In a different model specification, the coefficient for EGS ranges from -0.00966 to 0.00512, all of which are statistically significant and reinforce the positive relationship between EGS and CO2.

In contrast, a coefficient for PG, which could influence CO2 levels, is not statistically significant in some models, suggesting it may play a less substantial role in predicting CO2 levels (Voumik et al., 2023). And the inclusion of a lagged CO2 variable (L.CO2) in some models shows it has a strong positive effect on current CO2 levels, with highly significant coefficients. The constant term represents a baseline CO2 level when all the independent variables are at zero and remains highly significant across all the models.

5.1 Summary of the Result

In summary, an extensive examination of a dataset provides useful insights into an intricate dynamic that is influencing CO2 emissions (Wang et al., 2020). Descriptive statistics provide a fundamental understanding of variables' characteristics, highlighting their variability and interconnections. Subsequent analyses, including correlation matrices, variance inflation factor assessments, and linear regression models, reveal substantial relationships between CO2 emissions and a key predictor (Zafar et al., 2019).

The findings underscore the importance of considering multiple determinants when addressing CO2 emissions, highlighting the impactful roles of various variables. Slope heterogeneity and cointegration suggest complex dynamics among these relationships, and policymakers and stakeholders are advised to adopt approaches to mitigate CO2 emissions (Zhang et al., 2023).

6. Conclusion

This study examines the relationship between carbon emissions (CO2) and the export of goods and services, population growth as a moderate variable, and gross domestic product (GDP) as a control variable. Robust analysis and various statistical methods, such as correlation matrices, linear regressions, and tests for slope heterogeneity and cross-sectional dependence, provide insights into the complex dynamics that govern CO2 emissions. It shed light on the relationships among economic activities, demographic trends, and environmental sustainability, and stressed the need to adopt holistic approaches to effectively address carbon emissions. Finally, it underscores the importance of considering various determinants when formulating strategies to reduce CO2 emissions, recognizing that policymakers can develop sustainable solutions to tackle climate change and promote global environmental sustainability.

7. Recommendations

The research provides several recommendations to policymakers and stakeholders in formulating effective strategies to reduce CO2 emissions and promote sustainable development. They can devise integrated policy approaches that prioritize investments in clean energy technologies and renewable energy sources, and that encourage sustainable economic development.

Population management strategies can support sustainable urbanization, and reducing per capita energy consumption can help alleviate environmental impacts. Further advancing cross-sector collaboration between government, academia, and industry is essential for the implementation and scaling up of efforts to reduce effectively.

8. Limitations

The study encounters several limitations in interpreting findings and their implications. The data constraints present a huge challenge as the analysis relies on the availability, quality, and comprehensiveness of a dataset and its sample size, with 10-year data, is also concerning, ranging from 2012 to 2021.

The study on CO2 emissions and its predictors faces several limitations, including missing or incomplete data, variations in data reliability across regions or countries, and reliance solely on the World Bank data. Endogeneity concerns, such as bidirectional causality, present a methodological challenge. Its context-specific and interdisciplinary nature may limit its generalizability across settings, and it may not fully capture the long-term dynamics of CO2 emissions relationships, suggesting a need for further research.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent

Not applicable. This study uses publicly available, de-identified secondary data and does not involve human participants or personal information.

Competing interests

The authors declare no competing interests.

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