Unveiling the Carbon Footprint: Investigating the Influence of Socio-Economic Factors on Carbon Emissions through FMOLS Analysis

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Abstract. This study investigates the relationship between carbon emissions and several socio-economic factors in E7 countries, employing the Fully Modified Ordinary Least Squares (FMOLS) method. The examined factors include population, renewable energy consumption, net trade, and greenhouse gases. We employ the FMOLS technique to estimate the long-term relationship between carbon emissions and these variables. The results reveal significant findings. Specifically, renewable energy consumption exhibits substantial impacts on carbon emissions. Additionally, population, net trade, and greenhouse gases also demonstrate significant associations with carbon emissions. These findings provide valuable insights into the dynamics of carbon emissions in E7 countries, suggesting policy implications for sustainable development and environmental conservation efforts.

Keywords: Carbon emissions, Socio-economic factors, E7 countries, FMOLS

1 Introduction

Climate change, primarily driven by carbon emissions, is a critical global challenge that demands immediate attention. Efforts to combat climate change require maintaining global CO2 emissions below a specific threshold over time [1]. The healthcare sector, responsible for 4-5% of global greenhouse gas emissions, is essential in addressing the impacts of climate change [2]. Insights from psychology are valuable in comprehending and addressing the complexities of global climate change [3]. Nations are increasingly prioritizing the decarbonization of their economies to reduce greenhouse gas emissions in alignment with international agreements like the Paris Agreement [4].

The issue of carbon emissions and climate change involves various sectors such as business, agriculture, and energy. Blockchain technology is being explored for the sustainable management of carbon credits in supply chains [5]. Studies on plant communities and drought tolerance emphasize the impact of climate change on biodiversity, highlighting the necessity for comprehensive strategies to tackle global warming [6].

K. B. Abiprayu and A. B. Setiawan (eds.), *Proceedings of the International conference of Economics Business and Economics Education Science (ICE-BEES-24)*, Advances in Economics, Business and Management Research 298,
https://doi.org/10.2991/978-94-6463-522-5_7

Greenhouse gas emissions are a significant concern due to their contribution to global warming, underscoring the urgency of taking immediate action to mitigate climate change [7], [8].

Global cooperation is crucial to address the collective action problem of climate change and ensure equitable burden-sharing in implementing carbon pricing mechanisms [9]. The potential for carbon leakage under international agreements like the Paris Agreement emphasizes the importance of cohesive policies and enforcement mechanisms [10]. Research on embodied carbon flows in trade and network evolution is vital for a unified global response to the challenges posed by climate change [11]. The significant contribution of Asian countries to global emissions highlights the need for collaborative efforts to combat climate change [12]. The global challenge of carbon emissions and climate change necessitates a coordinated, interdisciplinary approach involving various sectors and nations. Addressing this challenge requires prompt action, innovative solutions, and international collaboration to mitigate the impacts of global warming and secure a sustainable future for all.

Socio-economic factors play a crucial role in influencing carbon emissions, with various studies highlighting the complex interplay between economic activities, population dynamics, urbanization, and technological advancements. Wang et al. [13] emphasized that industrial emissions, extensive capital investment, and urban land expansion are key drivers of the increase in carbon intensity, underscoring the impact of economic activities on emission levels. Similarly, Sapkota et al. [14] pointed out that socio-economic factors such as gender, education levels, and access to information significantly influence the adoption of technologies that contribute to low-emission pathways in agriculture, highlighting the importance of social factors in shaping emission trajectories. Shen [15] and Zhang et al. [16] have shown that economic growth, urban expansion, and population dynamics are major contributors to carbon emissions, indicating the significant influence of socio-economic factors on emission patterns. Additionally, Long & Tang [17] emphasized that economic growth acts as a primary driving factor for agricultural carbon dioxide emissions, further illustrating the pivotal role of economic activities in shaping emission trends.

Furthermore, the impact of socio-economic factors on carbon emissions extends beyond economic growth to include factors such as urbanization, energy consumption patterns, and industrial structures. Zhou et al. [18] highlighted that economic output and population size are major contributors to the increase in electricity-related carbon emissions, emphasizing the role of urbanization and demographic factors in emission dynamics. Tu & Ma [19] noted that factors like industrial structure, energy composition, and technological advancements significantly influence the convergence of carbon emissions performance, showcasing the multifaceted nature of socio-economic influences on emission trends. The intricate relationship between socio-economic factors and carbon emissions underscores the need for comprehensive strategies that address not only technological advancements but also societal behaviors, economic policies, and urban planning to effectively mitigate emissions and combat climate change.

The E7 countries, comprising Brazil, India, Indonesia, Mexico, China, Russia, and Turkey, are significant players in global carbon emissions and socio-economic factors.

These nations are recognized for their rapid economic growth and substantial contributions to worldwide carbon emissions [20]. Research indicates that economic expansion, energy consumption, and industrial operations in the E7 countries have resulted in notable carbon emissions, solidifying their importance in the global carbon emission landscape [21]. The commitment of these countries to enhancing energy efficiency, decreasing coal usage, and reducing carbon dioxide emissions highlights their efforts to tackle environmental challenges [22].

Studies have also emphasized the influence of financial development, renewable energy consumption, and foreign direct investment on carbon emissions in the E7 countries [23], [24]. Strategies such as promoting financial inclusivity, globalization, and investing in renewable energy generation are recommended to reduce carbon dioxide emissions in these nations [24]. Additionally, research has explored the correlation between energy investment, economic growth, and tourism in the E7 countries, suggesting that investing in energy and economic growth can aid in lowering carbon emissions, although energy consumption remains a contributing factor to emissions [25].

The E7 countries are actively investigating the roles of technological innovation, renewables, and environmental taxes in advancing environmental quality and striving for carbon-free economies [25], [26]. These nations are pursuing sustainable environments by prioritizing energy security, renewable energy, and economic complexity to address pollution metrics and promote sustainable development [20]. The commitment of the E7 countries to energy transition and aiming for carbon neutrality by 2050 demonstrates their acknowledgment of the necessity to transition to cleaner energy sources and reduce carbon emissions. The E7 countries are pivotal in the global carbon emission landscape due to their economic growth, energy consumption patterns, and industrial activities. By implementing sustainable practices, investing in renewable energy, and fostering green economic growth, these nations can significantly contribute to mitigating carbon emissions and fostering a more sustainable future.

There is a research gap in the literature regarding comprehensive studies that thoroughly investigate the long-term relationship between carbon emissions and socio-economic factors in E7 countries. While existing studies touch on various aspects related to carbon emissions, economic growth, energy consumption, and environmental sustainability in these countries, a holistic and in-depth analysis specifically focusing on the intricate and long-term interplay between carbon emissions and socio-economic factors within the E7 nations is lacking. Studies such as those by Qin [22], Salahuddin [27], Tong [28], and Chen & Hao [20] have explored the relationship between economic growth, energy consumption, renewable energy, and carbon emissions in E7 countries. However, these studies do not comprehensively delve into the long-term dynamics and causality between carbon emissions and a wide array of socio-economic factors within the E7 nations.

Furthermore, while research by Gyamfi et al. [23] and Onifade & Alola [25] touches on renewable energy, globalization, and environmental quality in E7 economies, the focus is not solely on the long-term relationship between carbon emissions and socio-economic factors. Similarly, studies by Uche et al. [29] and Husnain et al. [30] examine pollution metrics and geopolitical risks in E7 countries but do not extensively cover the long-term carbon emissions and socio-economic factors relationship. The existing literature provides valuable insights into various aspects related to carbon emissions and socio-economic factors in E7 countries. However, a comprehensive study dedicated to thoroughly examining the long-term relationship between carbon emissions and a wide range of socio-economic factors within the E7 nations is notably absent, highlighting a significant research gap that warrants further investigation.

The study conducted a comprehensive analysis of the relationship between carbon emissions and various socio-economic factors within the E7 countries. The factors examined include population dynamics, renewable energy consumption, net trade, and greenhouse gas emissions. While previous studies have explored the impact of renewable energy consumption and economic globalization on carbon emissions [20], [23], there is a research gap regarding the specific focus on population dynamics, net trade, and greenhouse gas emissions within the E7 countries. Research by Omri & Nguyen [31] provides insights into the determinants of renewable energy consumption, including net trade, which is essential for understanding the dynamics of carbon emissions. By integrating these factors into the analysis, the study aims to offer a holistic understanding of the long-term relationship between carbon emissions and socio-economic factors in the E7 countries, contributing to filling the existing research gap and providing valuable insights for policymakers and stakeholders aiming to address environmental sustainability and carbon emission reduction in these nations. The main goal of investigating the relationship between carbon emissions and socio-economic factors in E7 countries is to understand how population, renewable energy consumption, net trade, and greenhouse gases influence carbon emissions over the long term. This analysis aims to provide insights that can inform policy decisions aimed at promoting sustainable development and environmental conservation in these rapidly developing economies.

The Fully Modified Ordinary Least Squares (FMOLS) method is a statistical technique designed to provide reliable estimates in the presence of cointegration among non-stationary variables. It adjusts for serial correlation and endogeneity, making it particularly effective for estimating long-term relationships in economic data. FMOLS corrects for both the bias and inefficiency typically associated with ordinary least squares (OLS) in such contexts.

FMOLS is chosen for this study due to its robustness in handling non-stationary data, which is common in time-series analyses involving socio-economic and environmental variables. By addressing issues like serial correlation and endogeneity, FMOLS provides more accurate and reliable estimates of the long-term relationships between carbon emissions and factors such as population, renewable energy consumption, net trade, and greenhouse gases in E7 countries. This accuracy is crucial for formulating effective policies aimed at sustainable development and environmental conservation.

Renewable energy consumption has been a focal point in research examining its impact on carbon emissions. Several significant findings have emerged from studies investigating the relationship between renewable energy consumption and carbon emissions. Firstly, research by Qin et al. [22] revealed that the impact of renewable energy consumption on reducing carbon emissions varies across income-based subgroups of countries. While fossil fuel energy consumption tends to grow faster than renewable energy consumption in general, the effectiveness of renewable energy in reducing carbon emissions differs among countries.

Additionally, Robalino-López et al. [32] found that renewable electricity consumption plays a more significant role than non-renewable electricity consumption in promoting economic growth in both the short and long term. This highlights the dual benefit of renewable energy in fostering economic development while reducing carbon emissions. Moreover, studies such as Alharthi et al. [33] and Roy & Rej [34] indicated that renewable energy consumption significantly reduces carbon emissions. The impact of renewable energy consumption on emissions was found to increase with higher quantiles, suggesting a positive correlation between renewable energy use and emission reduction.

Liu et al. [35], Khan et al. [36], and Gyimah et al. [37] highlighted that in the long run, green energy investment and renewable energy consumption lead to decreased carbon emissions. Conversely, non-renewable energy consumption and economic growth were associated with increased carbon emissions, emphasizing the importance of transitioning to renewable sources for sustainable environmental outcomes. Shen et al. [38] demonstrated that renewable energy consumption could reduce the growth of carbon emission intensity, with the most significant effects observed in certain regions. This decoupling of economic growth from carbon emissions through renewable energy consumption is crucial for achieving sustainable development goals.

Several studies have investigated the relationships between population, net trade, greenhouse gases, and carbon emissions, shedding light on the complex interplay among these factors. Research by Shi [39] explored the impact of population pressure on global carbon dioxide emissions. The study utilized pooled cross-country data from 1975 to 1996 and found evidence of a relationship between population growth and carbon emissions, highlighting the influence of demographic factors on emissions. Saka [40] examined the net impacts of international trade on carbon dioxide emissions in African countries. The study revealed that carbon dioxide emissions have a statistically significant impact on net trade, population size, the manufacturing sector, and the services sector, emphasizing the role of trade dynamics in carbon emissions.

Moreover, Zhuo et al. [41] conducted a comparative analysis of carbon reduction potential for different types of wind turbines. The study quantified greenhouse gas emissions from directly driven permanent magnet and doubly fed asynchronous wind turbines, providing insights into the emissions associated with renewable energy technologies. Ganda [42] investigated the influence of green energy investments on environmental quality in OECD countries. The study demonstrated negative and significant relationships between renewable energy investments, primary energy supply, economic growth, and the growth of carbon emissions, highlighting the importance of sustainable energy investments for environmental sustainability.

These studies collectively emphasize the intricate relationships between population dynamics, net trade, greenhouse gases, and carbon emissions. Understanding these associations is crucial for developing effective policies and strategies to mitigate carbon emissions, promote sustainable development, and address environmental challenges. The research findings underscore the pivotal role of renewable energy consumption in mitigating carbon emissions. The evidence suggests that increasing the share of renewable energy in the energy mix not only contributes to environmental sustainability by reducing emissions but also promotes economic growth and long-term sustainability.

The study's contribution to understanding the dynamics of carbon emissions in E7 countries is significant. By investigating the relationship between carbon emissions and various socio-economic factors such as population, renewable energy consumption, net trade, and greenhouse gases, using the Fully Modified Ordinary Least Squares (FMOLS) method, this research sheds light on crucial aspects of carbon emissions dynamics. Through the application of the FMOLS technique, the study estimates the long-term relationship between carbon emissions and these variables. The results unveil noteworthy findings. Notably, renewable energy consumption emerges as a key factor with substantial impacts on carbon emissions. Additionally, population size, net trade, and greenhouse gases also demonstrate significant associations with carbon emissions. These findings provide valuable insights into the complex interplay of socio-economic factors influencing carbon emissions in E7 countries. Such insights are crucial for policymakers and stakeholders in formulating effective strategies for sustainable development and environmental conservation efforts in these nations.

The paper is structured as follows: Firstly, the introduction sets the stage by outlining the study's objectives, emphasizing the importance of investigating the relationship between carbon emissions and socio-economic factors in E7 countries, and introducing the Fully Modified Ordinary Least Squares (FMOLS) method as the analytical approach. Following this, the literature review provides a comprehensive overview of existing research concerning carbon emissions, socio-economic factors, and FMOLS methodology, identifying gaps and establishing the study's relevance. Subsequently, the methodology section offers a detailed explanation of the data sources, variables, and the FMOLS technique employed for analysis, elucidating the rationale behind the choice of FMOLS for estimating long-term relationships. The results section presents the key findings derived from the FMOLS analysis, highlighting the impacts of population, renewable energy consumption, net trade, and greenhouse gases on carbon emissions in E7 countries. These results are then discussed in detail, drawing comparisons with prior research and exploring their implications for policy-making and sustainable development efforts. Finally, the conclusion summarizes the main findings, underscores their significance, offers recommendations for future research, and outlines policy implications based on the study's results, thus providing a cohesive overview of the research journey from inception to conclusion.

2 Result and Analysis

Descriptive statistical analysis highlights the characteristics of each variable observed in the context of the analysis. The variable CO2E (carbon dioxide emissions) shows an overall mean of 4.16, with significant variation ranging from 0.82 to 12.22. The high average across groups indicates consistency in emission levels among different categories, while within-group variation suggests significant differences in emissions among observations within the same category. The variable POP (population) has an overall mean of 1.07, with a minimum value of 0.14 and a maximum of 1.89. Although there is substantial between-group variation, within-group variation indicates significant differences in population among observations within the same category.

The variable REC (renewable energy consumption) shows an overall mean of 23.47, with a minimum value of 0.69 and a maximum of 50.05. Between-group variation indicates considerable differences in renewable energy consumption among different categories, while within-group variation suggests significant differences in consumption among observations within the same category. Similarly, the variable NET_TRD (net trade) has an overall mean of 0.54, with a minimum value of -7.32 and a maximum of 10.58. Between-group variation indicates significant differences in net trade among different categories, while within-group variation suggests significant differences in net trade among observations within the same category. The variables Ln_URBN (log of urban population) and Ln_GHG (log of greenhouse gases) also show similar patterns in terms of between-group and within-group variability. The variable Ln_INDS (log of industrialization) shows lower variation both between groups and within groups compared to the other variables.

Variable		Mean	Std. dev.	Min	Max	Observations
CO2E	overall	4.156622	3.172149	.818721	12.21646	N = 161
	between		3.272364	1.274749	10.73588	n = 7
	within		.9091556	1.190192	6.42891	T = 23
POP	overall	1.067174	.4006966	.1378693	1.887558	N = 161
	between		.3698647	.5237293	1.441547	n = 7
	within		.2063197	.4826691	1.513772	T = 23
REC	overall	23.46708	16.07689	.69	50.05	N = 161
	between		16.49663	1.644348	45.19261	n = 7
	within		4.873054	7.754472	36.83447	T = 23
NET_TRD	overall	.5439377	3.455641	-7.316773	10.57589	N = 161
	between		2.771828	-2.92062	3.421439	n = 7
	within		2.305394	-4.909405	7.707491	T = 23
Ln_URBN	overall	4.082346	.3603312	3.304686	4.466747	N = 161
	between		.3760665	3.422313	4.429488	n = 7
	within		.0886489	3.756553	4.351978	T = 23
Ln_GHG	overall	3.154863	.3639288	2.241569	3.95563	N = 161
	between		.3326102	2.547978	3.59608	n = 7
	within		.192422	2.645682	3.723896	T = 23
Ln_INDS	overall	3.466137	.2487907	2.90079	3.872466	N = 161
	between		.2586143	3.071732	3.783724	n = 7
	within		.0648975	3.295195	3.613078	T = 23

2.1 Correlation Matrix Test

The correlation results indicate several relationships between carbon dioxide emissions (CO2E) and various other variables in the dataset. A moderately strong negative correlation between population and CO2E emissions suggests that regions with larger populations tend to have lower CO2E emissions. Similarly, there is a strong negative correlation between Renewable Energy Consumption (REC) and CO2E emissions, indicating that regions with higher renewable energy consumption tend to have lower CO2E emissions.

However, a moderate positive correlation is observed between net trade (NET_TRD) and CO2E emissions, suggesting a more complex relationship between trade and CO2E emissions. Additionally, urbanization (Ln_URBN) and greenhouse gas levels (Ln_GHG) show a strong positive correlation with CO2E emissions, indicating that higher urbanization and increased greenhouse gases contribute to higher CO2E emissions. Finally, there is a moderate positive correlation between industry (Ln_INDS) and CO2E emissions, indicating that larger industrial sectors correlate with higher CO2E emissions. Thus, these correlation results provide insights into the factors related to CO2E emissions and can aid in planning policies to reduce carbon dioxide emissions.

	CO2E	POP	REC	NET_TRD	Ln_URBN	Ln_GHG	Ln_INDS
CO2E	1.0000						
POP	-0.6958	1.0000					
REC	-0.8079	0.4363	1.0000				
NET_TRD	0.3293	-0.4331	-0.0823	1.0000			
Ln_URBN	0.4709	-0.3189	-0.4541	0.0338	1.0000		
Ln_GHG	0.5520	-0.1788	-0.6858	0.1297	0.1175	1.0000	
Ln_INDS	0.2188	-0.2363	-0.2933	0.5330	-0.3357	0.4207	1.0000

2.2 Test of Relationships Between Variables

The initial statistical summary shows the mean, standard deviation, minimum, and maximum values of each variable, along with the number of observations (N), number of groups (n), and number of time periods (T). From these results, we can observe the distribution and variation of the data for each variable. The correlation matrix displays the relationships between variables. Correlation values range from -1 to 1, where positive values indicate a positive relationship, negative values indicate a negative relationship, and zero indicates no relationship. Correlations closer to 1 or -1 indicate stronger relationships.

The regression results provide further information about the relationships between the independent variables (POP, REC, NET_TRD, Ln_URBN, Ln_GHG, Ln_INDS) and the dependent variable (CO2E). The regression coefficients indicate how much the independent variables affect the dependent variable. Additionally, the p-value indicates the statistical significance of each coefficient, with lower values indicating higher significance. In this regression model, it is evident that the variables POP, REC, NET_TRD, Ln_GHG, and Ln_INDS have a significant influence on CO2E emissions, as they have p-values lower than the common significance level (typically 0.05). The variable Ln_URBN does not appear to have a significant influence based on its p-value being higher than 0.05.

Source	SS	df	MS			
				Number of obs	=	161
				F(6, 154)	=	135.27
Model	1353.2436	6	225.5406	Prob > F	=	0.0000
Residual	256.761164	154	1.66728029	R-squared	=	0.8405
				Adj R-squared	=	0.8343
Total	1610.00476	160	10.0625298	Root MSE	=	1.2912

CO2E	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
POP	-2.914991	.3284249	-8.88	0.000	-3.56379	-2.266191
REC	-.1226053	.0118902	-10.31	0.000	-.1460943	-.0991163
NET_TRD	.2123957	.0417636	5.09	0.000	.1298923	.2948992
Ln_URBN	-.297359	.422806	-0.70	0.483	-1.132607	.5378892
Ln_GHG	1.184624	.4211568	2.81	0.006	.3526335	2.016614
Ln_INDS	-3.088856	.675764	-4.57	0.000	-4.42382	-1.753892
_cons	18.21208	4.013306	4.54	0.000	10.28384	26.14032

2.3 Linearity corrected model

The linear regression results show the model used to predict carbon dioxide emissions (CO2E) based on the included independent variables. This analysis aims to evaluate the significant influence of the independent variables on CO2E emissions. The results indicate that the overall model is highly statistically significant, as evidenced by the high F-statistic value and very low p-value. Additionally, the model has good quality, with an R-squared value of 0.8405, indicating that approximately 84.05% of the variability in CO2E emissions can be explained by the independent variables in the model.

The analysis of regression coefficients shows the relationship between the independent variables and CO2E emissions. The population (POP) and renewable energy consumption (REC) variables show a significant negative relationship with CO2E emissions, meaning that as the population of an area increases or its renewable energy consumption rises, CO2E emissions tend to be lower. Conversely, the net trade balance (NET_TRD) variable shows a significant positive relationship with CO2E emissions, indicating that the larger the trade surplus of an area, the higher its CO2E emissions. However, the variables Ln_URBN (urbanization), Ln_GHG (greenhouse gases), and Ln_INDS (industry) do not have a significant impact on CO2E emissions, as their coefficients and p-values are not significant. The intercept (_cons) has a significant value in the model, indicating the estimated value of CO2E emissions when all independent variables in the model are zero.

```
Linear regression                               Number of obs     =        161
                                                F(6, 154)         =     154.04
                                                Prob > F          =     0.0000
                                                R-squared         =     0.8405
                                                Root MSE          =     1.2912
```

CO2E	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
POP	-2.914991	.3139955	-9.28	0.000	-3.535285	-2.294696
REC	-.1226053	.0108387	-11.31	0.000	-.144017	-.1011936
NET_TRD	.2123957	.0457386	4.64	0.000	.1220396	.3027518
Ln_URBN	-.297359	.448017	-0.66	0.508	-1.182411	.5876933
Ln_GHG	1.184624	.5053424	2.34	0.020	.1863259	2.182921
Ln_INDS	-3.088856	.6834864	-4.52	0.000	-4.439075	-1.738637
_cons	18.21208	4.370328	4.17	0.000	9.578547	26.84561

2.4 Cross-Country Variable Relationship Analysis

The regression analysis results demonstrate a robust model for predicting carbon dioxide emissions (CO2E) based on a set of independent variables included in the model. The overall model is highly statistically significant, with a high F-statistic value and a very low p-value, indicating that at least one independent variable in the model has a significant effect on CO2E emissions. Additionally, the model explains a very high proportion of the variability in CO2E emissions, with about 97.54% of the variability accounted for by the independent variables.

The relative effects of different countries are reflected through the coefficients of the dummy variables representing various countries, such as China, India, Indonesia, Korea, Mexico, and Turkey. Significant positive coefficients for these countries suggest that they have higher CO2E emissions compared to the reference country, Brazil, in this context.

The analysis of regression coefficients reveals that variables like population (POP), renewable energy consumption (REC), and greenhouse gas levels (Ln_GHG) have a significant positive impact on CO2E emissions. This indicates that as a country's population, income, or greenhouse gas levels increase, its CO2E emissions tend to be higher. Furthermore, the variables urbanization (Ln_URBN) and the countries coded as "China," "India," "Indonesia," "Korea, Rep.," "Mexico," and "Turkey" also show a significant positive relationship with CO2E emissions, suggesting that higher urbanization levels or being from these countries correlates with higher CO2E emissions. However, variables such as net trade balance (NET_TRD) and the logarithm of industry (Ln_INDS) do not have a significant impact on CO2E emissions, as their coefficients and p-values are not significant.

In the regression analysis examining the factors influencing CO2 emissions (CO2E), Brazil serves as the reference category for the "country_code" variable. This means that Brazil's coefficient is implicitly included in the intercept term (_cons), which is -57.36117. The coefficients for other countries, such as China (11.24343), India (10.46778), Indonesia (5.397405), Korea (10.48837), Mexico (3.328238), and Turkey

(4.627202), represent the difference in CO2 emissions relative to Brazil. These values indicate how much higher or lower the CO2 emissions are for these countries compared to Brazil when all other variables (POP, REC, NET_TRD, Ln_URBN, Ln_GHG, Ln_INDS) are held constant.

For instance, the positive coefficient for China suggests that China's CO2 emissions are significantly higher than those of Brazil. Similarly, the coefficients for India, Indonesia, Korea, Mexico, and Turkey also indicate higher emissions compared to Brazil. This comparative framework helps highlight Brazil's position in the context of global CO2 emissions and underscores the relative impact of various factors across different countries. Understanding Brazil as the baseline in this analysis is crucial for interpreting the results and drawing meaningful conclusions about its CO2 emission dynamics relative to other major economies.

Source	SS	df	MS			
				Number of obs	=	161
				F(12, 148)	=	489.52
Model	1570.43774	12	130.869811	Prob > F	=	0.0000
Residual	39.5670281	148	.267344785	R-squared	=	0.9754
				Adj R-squared	=	0.9734
Total	1610.00476	160	10.0625298	Root MSE	=	.51705

CO2E	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
POP	.9470994	.2773666	3.41	0.001	.3989891	1.49521
REC	.0500851	.015577	3.22	0.002	.0193031	.0808671
NET_TRD	.0181424	.0202269	0.90	0.371	-.0218283	.0581132
Ln_URBN	11.76586	.877934	13.40	0.000	10.03095	13.50076
Ln_GHG	.9845343	.2487039	3.96	0.000	.493065	1.476004
Ln_INDS	.4835328	.7932821	0.61	0.543	-1.08409	2.051155
country_code						
China	11.24343	.9830713	11.44	0.000	9.300757	13.1861
India	10.46778	.9135639	11.46	0.000	8.662471	12.2731
Indonesia	5.397405	.698206	7.73	0.000	4.017665	6.777146
Korea, Rep.	10.48837	.784479	13.37	0.000	8.938143	12.0386
Mexico	3.328238	.6528859	5.10	0.000	2.038056	4.618421
Turkiye	4.627202	.6244941	7.41	0.000	3.393125	5.861279
_cons	-57.36117	5.417233	-10.59	0.000	-68.06629	-46.65606

2.5 Mode of Estimation

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Method of estimation: fmols
Number

Tab[22,6]
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	POP	REC	NET_TRD	Ln_URBN	Ln_GHG	Ln_INDS
r1	.	.	.	.	.	.
beta_1	-1.75	-0.07	-0.03	-4.56	-0.35	0.10
Se._1	0.06	0.00	0.00	0.65	0.02	0.03
t-stat_1	-27.04	-99.86	-33.49	-6.97	-23.08	3.12
beta_2	1.01	0.03	-0.02	14.38	-0.78	10.17
Se._2	0.11	0.01	0.01	0.56	0.09	0.64
t-stat_2	8.76	2.51	-2.40	25.71	-8.75	16.01
beta_3	-0.12	-0.05	0.00	0.05	0.14	-1.11
Se._3	0.04	0.00	0.00	0.18	0.01	0.04
t-stat_3	-2.97	-73.32	1.66	0.30	10.58	-27.34
beta_4	0.15	-0.04	0.00	0.12	-0.02	0.78
Se._4	0.11	0.00	0.01	0.38	0.07	0.16
t-stat_4	1.41	-11.09	0.91	0.30	-0.33	4.91
beta_5	0.47	0.65	-0.01	44.79	1.34	10.51
Se._5	0.17	0.03	0.01	5.02	0.24	1.04
t-stat_5	2.72	22.66	-0.54	8.93	5.52	10.05
beta_6	0.12	-0.25	0.03	-10.06	0.76	2.18
Se._6	0.10	0.02	0.02	2.57	0.25	0.26
t-stat_6	1.17	-15.27	1.37	-3.91	3.08	8.31
beta_7	-0.02	-0.08	0.01	8.62	-0.35	2.39
Se._7	0.06	0.01	0.00	0.43	0.15	0.19
t-stat_7	-0.36	-9.93	1.52	19.90	-2.41	12.54

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Cave[6,2]
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	beta	t-stat
POP	-0.02	-6.17
REC	0.03	-69.66
NET_TRD	-0.00	-11.71
Ln_URBN	7.62	16.73
Ln_GHG	0.10	-5.82
Ln_INDS	3.57	10.44

The analysis using the Fully Modified Ordinary Least Squares (FMOLS) method reveals significant relationships between carbon emissions (CO2E) and various socio-economic factors, including population (POP), renewable energy consumption (REC), net trade (NET_TRD), urbanization (Ln_URBN), greenhouse gases (Ln_GHG), and industrialization (Ln_INDS). First, the results indicate a negative and significant relationship between population (POP) and carbon emissions, with a beta value of -0.02 and a t-statistic of -6.17. This suggests that, although the effect is small, an increase in population is associated with a reduction in carbon emissions. This counterintuitive finding highlights the complexity of population dynamics and their environmental impacts, possibly pointing to efficiency gains or demographic shifts that offset emissions.

In terms of renewable energy consumption (REC), there is a significant negative impact on carbon emissions. Despite the positive beta value of 0.03, the t-statistic of -69.66 indicates a strong inverse relationship. This aligns with expectations that increased use of renewable energy sources substantially reduces carbon emissions by decreasing reliance on fossil fuels. Net trade (NET_TRD) shows a negligible yet significant negative relationship with carbon emissions, with a beta of -0.00 and a t-statistic of -11.71. This suggests that higher net trade, indicative of economic activities, might be linked to greater efficiency and lower carbon emissions per unit of trade. Urbanization (Ln_URBN) is positively and significantly associated with carbon emissions. The beta value of 7.62 and t-statistic of 16.73 imply that as urbanization increases, so do carbon emissions. This relationship likely reflects the higher energy consumption and industrial activities in urban areas, contributing to increased emissions.

For greenhouse gases (Ln_GHG), there is a significant negative relationship with carbon emissions, indicated by a beta of 0.10 and a t-statistic of -5.82. This finding suggests that higher emissions of greenhouse gases correlate with reduced carbon emissions, potentially reflecting improvements in emission control technologies or a shift towards cleaner energy sources. Lastly, industrialization (Ln_INDS) shows a strong positive relationship with carbon emissions, with a beta value of 3.57 and a t-statistic of 10.44. This indicates that increased industrial activity is significantly associated with higher carbon emissions, consistent with the notion that the industrial sector is a major source of carbon emissions due to its energy-intensive processes. these results highlight the intricate interplay between socio-economic factors and carbon emissions in E7 countries. Urbanization and industrialization significantly drive up carbon emissions, while renewable energy consumption plays a crucial role in mitigating them. The findings provide valuable insights for policymakers aiming to design effective strategies for reducing carbon emissions and promoting sustainable development.

Cointegration regression (FMOLS):

VAR lag(user)	=	0	Number of obs	=	160
Kernel	=	bartlett	R2	=	.3002282
Bandwidth(neweywest)	=	72.1589	Adjusted R2	=	.2727862
			S.e.	=	4.728572
			Long run S.e.	=	1.829585

CO2E	Coefficient	Std. err.	z	P>|z|	[95% conf.	interval]
POP	-2.911935	.4665334	-6.24	0.000	-3.826324	-1.997547
REC	-.1261463	.01685	-7.49	0.000	-.1591716	-.093121
NET_TRD	.2318873	.059194	3.92	0.000	.1158693	.3479053
Ln_URBN	-.5848875	.6014016	-0.97	0.331	-1.763613	.593838
Ln_GHG	1.034718	.6046132	1.71	0.087	-.1503023	2.219738
Ln_INDS	-3.289124	.9580793	-3.43	0.001	-5.166925	-1.411323
_cons	20.55566	5.686709	3.61	0.000	9.409916	31.70141

2.6 Fully Modified Ordinary Least Square (FMOLS)

The Fully Modified Ordinary Least Squares (FMOLS) regression results provide insights into the long-run relationship between CO2 emissions (CO2E) and several explanatory variables using a dataset of 160 observations. The model explains approximately 30% of the variability in CO2 emissions, as indicated by the R-squared value of 0.3002. This suggests a moderate fit, implying that while the included variables are significant, other factors not captured in this model may also influence CO2 emissions.

Key findings indicate that population (POP) has a significant negative impact on CO2 emissions. Specifically, for every unit increase in population, CO2 emissions decrease by approximately 2.91 units, holding other factors constant. This result is highly statistically significant ($p < 0.01$). Similarly, renewable energy consumption (REC) also negatively impacts CO2 emissions, with each unit increase in renewable energy consumption leading to a reduction of about 0.126 units in emissions, which is also statistically significant ($p < 0.01$). These findings highlight the potential of population management and renewable energy in mitigating CO2 emissions.

On the other hand, net trade (NET_TRD) shows a significant positive relationship with CO2 emissions. An increase of one unit in net trade is associated with an increase of approximately 0.232 units in CO2 emissions, indicating that higher trade activities might contribute to higher emissions levels. This result is significant at the 1% level ($p < 0.01$). Industrialization, measured by the log of industrialization (Ln_INDS), surprisingly shows a significant negative impact on CO2 emissions, with an increase in industrialization leading to a reduction of about 3.29 units in emissions. This counterintuitive finding could suggest that modern industrial practices may incorporate more efficient and less polluting technologies.

However, not all variables show significant impacts. The log of urbanization (Ln_URBN) does not significantly affect CO2 emissions ($p > 0.05$), suggesting that urbanization alone might not be a determinant factor in emissions levels in the context of this study. The log of greenhouse gases (Ln_GHG) has a positive impact on CO2 emissions, but this result is only marginally significant ($p < 0.10$), indicating that while greenhouse gases are relevant, their impact might be less pronounced or more complex.

The constant term is significant and indicates the baseline level of CO2 emissions when all predictor variables are zero, emphasizing the inherent emissions levels present irrespective of the included factors. In summary, the study underscores the importance of renewable energy and industrialization in reducing CO2 emissions while pointing out the complex role of trade and population dynamics in shaping emissions profiles. These findings have critical implications for policymakers aiming to design effective strategies for sustainable development and emissions reduction.

2.7 Discussion

CO2 emissions decrease by approximately 2.91 units for every unit increase in population and the result is highly significant ($p < 0.01$). To explore the reasons behind the negative relationship that might reduce per capita emissions, several factors can be considered based on the provided references. One key factor is economic growth. Initially, per capita CO2 emissions tend to increase with per capita GDP, but as the economy grows, there is a point where per capita emissions start to decrease [31]. This reduction in emissions with economic growth can be attributed to technological progress and adjustments in industrial structures [43]. Additionally, the level of per capita CO2 emissions is influenced by factors such as real GDP per capita and real imports per capita, both of which have been found to have a negative impact on per capita emissions [44].

The Environmental Kuznets Curve (EKC) theory suggests an inverted U-shaped relationship between economic development, typically measured as income per capita, and environmental degradation. Initially, as economies grow, environmental degradation worsens, but after reaching a certain income threshold, environmental quality begins to improve [45], [46], [47]. This relationship has been observed in various studies across different countries and pollutants, including CO2 emissions [48], [49], [50]. Factors such as labor productivity growth have been shown to influence carbon emissions, with emissions initially increasing with productivity but later decreasing after a certain threshold [43].

Technological advancements and shifts in demographic patterns can also play a role in reducing per capita emissions. For instance, urban household food waste has been linked to demographic factors such as household size, with studies showing a negative relationship between per capita food waste and household size [51]. Additionally, the impact of clean energy consumption has been found to reduce CO2 emissions, indicating that shifts towards cleaner energy sources can contribute to lowering emissions [52]. The relationship between economic growth and carbon emissions is complex and can be influenced by various factors. Some studies have highlighted the importance of considering the impact of energy consumption, population growth, and industrial activities on carbon emissions [53], [54]. Furthermore, the relationship between economic growth and environmental quality is not always straightforward, as growth in the scale of the economy can lead to increased environmental impacts [55].

Furthermore, technological advancements and shifts in energy consumption patterns can impact per capita emissions. For instance, an increase in renewable energy consumption has been linked to lower per capita CO2 emissions [56]. Additionally, the development of clean energy sources has been shown to reduce per capita CO2 emissions and electricity consumption in the long run [57]. The effectiveness of abatement technology is crucial, as a low level of effectiveness combined with high pollution emission rates can lead to stable but low-income economies with high per capita emissions [58]. The negative relationship observed can be attributed to a combination of factors such as increased efficiency, technological advancements, and shifts in demographic patterns that influence per capita emissions. While economic development initially leads to higher environmental degradation, various mechanisms, including changes in productivity, energy consumption patterns, and waste management practices, can contribute to a decline in per capita emissions as economies progress along the EKC trajectory.

Renewable energy policies have been crucial in reducing emissions and mitigating the impacts of climate change. Research has demonstrated that an increase in the share of renewable energy in the energy mix can lead to a decrease in vulnerability to climate change Ding et al. [59]. The incorporation of renewable energy sources in the electricity generation sectors not only facilitates significant reductions in greenhouse gas emissions but also offers a cost-effective approach to achieving this goal [60]. Additionally, renewable energy policies are vital in reducing greenhouse gas emissions by diversifying energy supplies and granting access to modern energy, thereby enhancing energy security [61].

It is essential to consider the balance between economic growth through trade and its environmental impact. While trade expansion can lead to economic benefits, it can also result in environmental degradation, such as depletion of natural resources and increased pollution emissions [62]. The costs of spreading trade to international markets can have adverse effects on the environment, ultimately deteriorating environmental quality [62]. However, it is crucial to note that trade expansion can also generate income that could be utilized to fund poverty reduction programs, highlighting the complex interplay between trade, economic growth, and environmental sustainability [63].

Technological innovation and regulatory frameworks are crucial in reducing emissions from industrial activities. Studies have shown that advancements in technology, such as energy-efficient processes and cleaner production technologies, can lead to significant reductions in carbon emissions [64], [65], [66]. By investing in research and development to enhance industrial processes and promote energy efficiency, industries can achieve substantial emission reductions while maintaining productivity and competitiveness [67], [68], [69].

Urbanization alone may not be a sole determinant factor in emissions within a study due to the multifaceted nature of urban development and the various factors that influence emissions in urban areas. While urbanization can lead to increased energy consumption and emissions, the role of urban planning, green spaces, public transportation, and other urban policies can significantly influence emissions in different contexts. Urban planning plays a crucial role in shaping the environmental impact of urban areas. Effective urban planning strategies can promote sustainable development, reduce emissions, and enhance overall environmental quality [70], [71]. By incorporating green spaces, such as parks and urban forests, into urban design, cities can improve air quality, reduce the urban heat island effect, and enhance biodiversity, ultimately contributing to lower emissions [70], [72]. The availability and efficiency of public transportation systems also play a key role in influencing emissions in urban areas. Well-designed public transportation networks can reduce the reliance on private vehicles, leading to lower emissions from the transportation sector [71], [72]. Additionally, policies that promote active transportation modes, such as walking and cycling, can further contribute to emission reductions and improve urban air quality [71].

The interactions between different greenhouse gases, such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), are intricate and interconnected. While CO2 is a major contributor to global warming, other gases like CH4 and N2O also significantly impact the greenhouse effect due to their varying global warming potentials and atmospheric lifetimes Inoue et al. (2016). Understanding the relationship between different greenhouse gases and CO2 emissions is crucial for assessing their combined effects on the environment. Although CO2 is the dominant greenhouse gas, comprehensive studies are needed to analyze the interactions and feedback mechanisms between CO2 and other gases to accurately evaluate their cumulative impact on climate change [73].

3 Conclusions

One key approach is to incentivize the development and adoption of renewable energy technologies. This can be achieved through subsidies and tax incentives for solar, wind, and hydroelectric power projects, as well as increased funding for research and development to innovate and improve the efficiency of renewable energy sources. Additionally, implementing renewable energy standards, such as mandatory production targets for both public and private sectors and policies to enhance grid integration, can ensure a steady increase in renewable energy adoption. Supporting small-scale renewable projects in communities and residences through grants and low-interest loans can further encourage local energy production and consumption.

Enhancing industrial efficiency is another critical area for reducing CO2 emissions. Promoting clean industrial technologies by offering grants and incentives for industries to upgrade to more energy-efficient and less polluting technologies is essential. Implementing emissions trading schemes can also incentivize industries to reduce emissions through market-based mechanisms. Strengthening regulations and standards, such as enforcing strict emission limits and setting energy efficiency benchmarks for industrial machinery and processes, can significantly reduce energy consumption and emissions. Encouraging green manufacturing practices, including circular economy models and sustainable supply chains, can minimize environmental impact and promote sustainability.

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