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Exploring the Interconnection Between Anthropogenic Activities and Greenhouse Gas Emissions: An Empirical Study

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Abstract
Environmental degradation poses significant challenges globally, necessitating urgent action towards environmental sustainability. Human consumption and production practices, driven by the pursuit of fulfilling wants and needs, have led to the pollution and depletion of critical resources essential for sustainability. In response to this pressing issue, this empirical study aims to examine the interconnection between anthropogenic activities and greenhouse gas (GHG) emissions. Utilizing the autoregressive distributed lag (ARDL) bound test approach, the research endeavors to shed light on the underlying dynamics shaping GHG emissions. The findings of the study underscore the substantial impact of various anthropogenic factors on GHG emissions. Specifically, factors such as fertility rate, population density, economic growth, and primary energy consumption exhibit a positive and statistically significant relationship with GHG emissions. This relationship persists both in the short and long run, highlighting the enduring influence of human activities on environmental sustainability. By elucidating these linkages, the study contributes valuable insights to the discourse surrounding environmental sustainability and underscores the imperative for concerted efforts to mitigate anthropogenic impacts on the environment. Ultimately, this research serves as a clarion call for proactive measures aimed at curbing GHG emissions and fostering a more sustainable future for generations to come.
Keywords: Anthropogenic Activities, Greenhouse Gas Emissions, Environmental Sustainability
JEL Codes: Q56, O13, O44

1. INTRODUCTION

The rapid population growth and accompanying urbanization, industrialization, and modernization have posed significant challenges to India's economic and environmental sustainability in the 21st century (Martine, 2005; Hubacek et al., 2007; Avtar et al., 2019; Kundu, 2011; Purohit; Nath, 2007; Singh et al., 2012; Watson, 2009). As the world's second-largest coal consumer, fifth-largest car seller, fourth-largest wind power generator, and among the top emitters of greenhouse gases and carbon dioxide, India faces considerable risks associated with global warming and climate change. The country's rapid economic growth, coupled with a burgeoning middle class, has led to increased consumption and production patterns, exacerbating environmental degradation (UNEP, 2011; Munasinghe, 1999; Soubbotina, 2004; Audi et al., 2020; Wiedmann et al., 2020; Ahmad, 2014; Shafik and Bandyopadhyay, 1992). Anthropogenic activities, driven by the desire to fulfill unlimited wants and needs, have contributed to various environmental issues such as population density, land degradation, loss of agricultural and forest land, biodiversity loss, and ecosystem instability. These activities have resulted in air, water, and noise pollution, as well as global warming, further exacerbating environmental degradation and posing threats to livelihood security (Audi and Ali, 2023; Bisht et al., 2020; Wassie, 2020; Akokpari, 2012; Khawas, 2009; Hassan et al., 2021; Vlek et al., 2017; Ajibade 2021). Efforts to address these challenges are crucial for India's sustainable development and long-term well-being (Meena & Chourasia, 2018; Zhao et al., 2013).

Human activities such as electricity generation, transportation, and industrialization have undoubtedly contributed to economic growth but have also played a significant role in driving climate change (Jawara, 2016). Industrial emissions and the combustion of coal, in particular, release various pollutants into the atmosphere, leading to environmental degradation and soil contamination. These pollutants include substances such as arsenic, cadmium, carbon monoxide, chromium, copper, mercury, manganese, nickel, lead, selenium, vanadium, and zinc. The presence of these pollutants in the environment poses serious risks to both human health and ecosystem integrity. Arsenic, cadmium, and mercury, for example, are known to be highly toxic and can cause a range of adverse health effects when present in the air, soil, or water (Lawal et al., 2021; Munir et al., 2021; Shahid et al., 2020; Sonone et al., 2020; Mitra et al., 2022; Sikdar et al., 2022; Gorus and Groeneveld, 2015; Kumar, 2026; Ho and Ran, 2016). Moreover, the accumulation of heavy metals in the soil can lead to reduced soil quality, affecting agricultural productivity and posing long-term risks to food security. Addressing the sources of industrial pollution and transitioning to cleaner and more sustainable energy sources are essential steps in mitigating the environmental impacts associated with human activities (Lv et al., 2015). Additionally, implementing effective pollution control measures and adopting environmentally friendly practices in industrial processes are crucial for protecting both human health and the natural environment. Population growth is widely recognized as a significant driver of increased carbon dioxide (CO_2) emissions into the atmosphere (Mulatu & Eschete, 2018). The size,

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distribution, and density of the population are three key demographic factors that exert a negative impact on the environment, contributing to the rise in greenhouse gas (GHG) emissions (Swim et al., 2011). As the human population expands, the demand for resources and energy also increases, leading to higher levels of emissions from various sources such as transportation, industry, and agriculture. Additionally, growing populations often result in increased urbanization and land use changes, further exacerbating environmental degradation and contributing to climate change. Addressing the challenges posed by population growth requires comprehensive strategies that consider not only the environmental impacts but also social and economic factors (Dietz and Roza, 1994; Alshuwaikhat and Abubakar, 2008; Arora et al., 2015; Beatley and Manning, 2013; Barca et al., 2012; Okurut and Mbulawa, 2015; Ahmad, 2016). Sustainable development initiatives aimed at promoting population stabilization, improving access to family planning services, and implementing policies that promote resource efficiency and conservation are essential for mitigating the environmental consequences of population growth. Moreover, fostering awareness and promoting sustainable lifestyles among individuals and communities are vital steps in creating a more environmentally sustainable future.

Population size and structure play a crucial role in driving household demand for consumer goods and services, resulting in increased energy consumption and, consequently, higher carbon emissions (Neill et al., 2010; Zaman et al., 2011; Liddle, 2014; Ohlan, 2015; Ssali et al., 2018; Sumaira, 2018). As populations grow and urbanize, there is a greater need for transportation, industrialization, and agricultural activities, all of which contribute to higher levels of pollution and environmental degradation (Shaari et al., 2013; Huang et al., 2018). The consumption of energy in various sectors such as transportation, industry, and agriculture leads to increased pollution, including emissions of greenhouse gases like carbon dioxide. These pollutants not only contribute to climate change but also have detrimental effects on air and water quality, soil health, and overall ecosystem stability. Efforts to mitigate the environmental impacts of population growth and consumption patterns include promoting energy efficiency measures, transitioning to renewable energy sources, implementing sustainable transportation solutions, and adopting eco-friendly agricultural practices. Additionally, raising awareness about the environmental consequences of consumption and encouraging responsible consumption habits can contribute to reducing the ecological footprint associated with population growth and economic development.

Industrialization and urbanization, driven by rapid economic development and population growth, often result in the overexploitation of natural resources, leading to disruptions in the natural ecosystem (Orimoogunje et al., 2011). As societies industrialize, there is a significant increase in the consumption of fossil fuels, which leads to higher levels of atmospheric carbon emissions (Steffen et al., 2007). The adoption of modern tools and technologies during the industrialization process is aimed at enhancing economic growth, but it also has various environmental impacts. Many of these technologies rely heavily on fossil fuels as a source of energy for production processes, resulting in the release of large quantities of carbon dioxide into the atmosphere (Unger et al., 2010; Hang & Sheng, 2011). The continuous growth of industrialization, coupled with the widespread use of natural resources in a finite world, ultimately leads to resource scarcity and has adverse long-term effects on the environment. Efforts to mitigate these impacts include transitioning to cleaner energy sources, improving energy efficiency in industrial processes, implementing sustainable production practices, and investing in technologies that minimize environmental harm. Additionally, promoting conservation efforts and fostering a circular economy can help reduce the environmental footprint associated with industrialization and urbanization.

The excessive use of energy in infrastructure development for industrial and residential sectors is a significant contributor to environmental pollution, primarily through carbon emissions (Wang et al., 2019). This trend is exacerbated by the increasing demand for housing, infrastructure, and construction activities associated with economic growth, leading to higher levels of cement production. Cement production is energy-intensive and releases significant amounts of pollutants such as sulfur dioxide, nitrogen oxide, and carbon monoxide, contributing to global warming and climate change (Ali et al., 2015). As economies grow and average incomes rise, individuals tend to shift their consumption patterns towards modern amenities to enjoy a higher standard of living. However, this shift often entails increased energy consumption and emissions of greenhouse gases (Neagu & Teoduru, 2019). The overconsumption and conspicuous consumption habits of higher-income groups further exacerbate environmental degradation, as the production of luxury goods requires significant energy inputs (Girod & Haan, 2010; Das Gupta, 2011). Efforts to address these challenges include promoting energy-efficient practices in infrastructure development, incentivizing sustainable construction methods, and encouraging the adoption of renewable energy sources in industrial processes. Additionally, raising awareness about the environmental impacts of consumption patterns and promoting sustainable lifestyles can help mitigate the negative effects of overconsumption on the environment. The expansion of transport and communication activities associated with urbanization, modernization, and industrialization has led to increased convenience in travel but has also resulted in significant emissions of greenhouse gases (GHGs) from motor vehicles (Chowdhury et al., 2012). Modern vehicles, equipped with various appliances and amenities, rely heavily on fossil fuels for energy, leading to substantial emissions of GHGs that contribute to atmospheric pollution.

Daily travel patterns and routine movements influenced by a lack of environmental consciousness generate additional dust and smoke, further exacerbating pollution levels in urban areas (Hankey & Marshal, 2010). This pollution not only impacts people's daily lives but also has adverse effects on the environment, contributing to air quality degradation and environmental degradation. Efforts to address these issues include promoting public transportation, adopting cleaner and more efficient technologies in vehicles, and raising awareness about the environmental impacts of transportation choices.

Energy, both renewable and non-renewable, is often considered the driving force behind development. However, total energy consumption, including electricity, natural gas, and oil combustion, accounts for a significant portion of greenhouse gas (GHG) emissions (Fayez et al., 2017). Basic infrastructures such as power, transport, communication, housing, and other facilities rely heavily on fossil fuels as a source of energy to meet urban and industrial needs. This reliance on fossil fuels contributes to environmental pollution through the emission of carbon, leading to climate change and global warming (Hossain & Yuzuru, 2014). The excessive combustion of coal in power plants and industries further exacerbates environmental pollution by emitting carbon (Ohara et al., 2007). Efforts to mitigate these emissions include transitioning to cleaner energy sources, improving energy efficiency, and implementing stricter regulations on emissions from industrial and power generation activities. Forests play a crucial role in mitigating carbon emissions and reducing greenhouse gas (GHG) emissions (Aukland & Costa, 2002). However, rapid population growth, urbanization, and industrialization often result in deforestation to make way for human settlements, industrial facilities, and infrastructure projects, leading to ecological imbalance and loss of biodiversity (Sikuzani et al., 2019; Jorgenson & Clark, 2013).

Conservation and regeneration of forest resources are essential for achieving environmental sustainability and fostering sustainable economic development, regardless of a country's level of development. Afforestation, reforestation, and tree-planting initiatives can help offset carbon emissions, restore ecosystems, and protect natural habitats (Aukland & Costa, 2002; Azmy, 2015). Increasing forest cover not only stores more carbon but also helps reduce carbon concentration in the atmosphere by absorbing more CO_2 (Ibrahim, 2015; Boyland, 2006). Efforts to protect and restore forests are critical components of global climate action strategies and are essential for preserving biodiversity and ecosystem services. Human-induced activities such as population growth, industrialization aimed at increasing GDP per capita, reliance on primary energy sources, the proliferation of motor vehicles, and the exploitation of forest resources are significant contributors to the rise in greenhouse gas (GHG) emissions. These activities, driven by societal and economic demands, have led to widespread environmental degradation and climate change. Population growth exacerbates the strain on natural resources and infrastructure, increasing energy consumption and emissions (Huppert and Sparks, 2006; Wassie, 2020; Mondal and palit, 2022; Zhang et al., 2022; Omer, 2009; Myers and Patz, 2009; Akhtar et al., 2022; Raihan et al., 2022; Xiong et al., 2023). Industrialization, while driving economic development, often relies on fossil fuels and intensive production processes, resulting in substantial emissions. Similarly, the widespread use of motor vehicles for transportation contributes significantly to GHG emissions, particularly carbon dioxide. Furthermore, deforestation and land-use changes associated with industrial expansion and urbanization further contribute to GHG emissions by reducing carbon sinks and disrupting ecosystems' natural carbon cycles. Addressing the root causes of GHG emissions requires comprehensive strategies that address population dynamics, promote sustainable industrial practices, transition to renewable energy sources, encourage alternative transportation modes, and prioritize forest conservation and restoration efforts (Shah et al., 2021; Shaheen and Lipman, 2007; Haines et al., 2007; Raihan, 2023; Elavarasan et al., 2022; Chen et al., 2022; Raihan et al., 2022; Raihan, 2023; Byrne et al., 2007; Hoang et al., 2021; Haines et al., 2009). Only through concerted global efforts can we effectively mitigate the impacts of human-induced activities on the environment and combat climate change.

2. LITERATURE REVIEW

These empirical studies shed light on the intricate relationships between various factors and greenhouse gas (GHG) emissions, providing valuable insights into the environmental challenges posed by human activities. Ssali et al. (2018) demonstrated a statistically significant long-run relationship between population growth, energy use, and CO_2 emissions in Sub-Saharan Africa. Their findings underscore the role of population dynamics and energy consumption patterns in driving carbon emissions in the region. Similarly, Mulatu & Eschate (2018) highlighted the impact of population pressure on CO_2 emissions in Ethiopia, emphasizing the link between human interaction, energy consumption, and environmental degradation. Furthermore, Liu & Bae (2018) identified the relationship between economic growth, urbanization, infrastructure development, and CO_2 emissions in China. Their study revealed the environmental consequences of rapid urbanization and industrial expansion, indicating the need for sustainable development strategies to mitigate carbon emissions and environmental degradation. These empirical studies provide valuable insights into the relationship between various factors and carbon emissions in different regions, shedding light on the environmental challenges associated with urbanization, economic growth, energy consumption, and population dynamics.

Sodri & Garniwa (2016) utilized the Vector Error Correction Model (VECM) to analyze the impact of urbanization on transport and road energy consumption in Jakarta. Their findings suggest that urbanization contributes to increased energy consumption in transportation, leading to higher CO_2 emissions. This highlights the importance of sustainable urban planning and transportation policies to mitigate carbon emissions in rapidly urbanizing areas.

Ali et al. (2016) employed the Autoregressive Distributed Lag (ARDL) model to investigate the relationship between economic growth, energy consumption, and CO_2 emissions in Nigeria. Their study revealed a positive association between economic growth, energy use, and carbon emissions, underscoring the environmental consequences of fossil fuel combustion for energy generation and industrial activities. Similarly, Sarkodie & Owusu (2016) utilized both ARDL and VECM models to explore the long-run relationship between CO_2 emissions, energy consumption, population growth, and GDP in Ghana. Their findings suggest a complex interplay between these factors, highlighting the need for comprehensive policy interventions to promote sustainable development and reduce carbon emissions.

In another study focusing on Rwanda, Sarkodie & Owusu (2017) observed the impact of population pressure and increasing energy demand on carbon emissions. This highlights the challenges faced by developing countries in balancing economic growth with environmental sustainability and underscores the importance of adopting cleaner and more efficient energy sources to mitigate carbon emissions. These findings underscore the intricate relationship between various socio-economic factors and carbon emissions in different regions, highlighting the need for targeted policy interventions to address climate change and promote sustainable development. The study by Asif et al. (2015) highlights a unidirectional causality from population growth to carbon emissions in the GCC region. This suggests that population dynamics play a significant role in driving carbon emissions, emphasizing the importance of population management strategies in mitigating environmental degradation. In Algeria, Lacheheb et al. (2015) found a positive association between per capita GDP and carbon emissions, particularly from the consumption of solid fuel and electricity production. This underscores the challenges of balancing economic growth with environmental sustainability, highlighting the need for cleaner and more efficient energy sources to reduce carbon emissions. The study by Mulali et al. (2013) focused on MENA countries and identified a long-term bidirectional relationship between carbon emissions, urbanization, and energy consumption. This suggests that urbanization and energy consumption patterns influence carbon emissions, while carbon emissions, in turn, can affect urban development and energy policies. These findings emphasize the importance of integrated approaches to urban planning and energy management to achieve sustainable development goals while mitigating climate change. The findings from Hossain's study (2012) using ARDL and VECM models highlight the long-term impact of fossil fuel consumption on carbon dioxide emissions and environmental degradation in Japan. This underscores the urgent need for transitioning to cleaner and more sustainable energy sources to mitigate climate change and reduce environmental pollution.

Similarly, the study by Sajjad et al. (2010) underscores the significant contribution of fossil fuel consumption, particularly in the domestic, industrial, and transport sectors, to CO2 emissions in Karachi. The rapid increase in vehicle use emerges as a primary driver of carbon emissions, pointing to the importance of implementing policies to promote energy efficiency and reduce reliance on fossil fuels. In contrast, Udofia et al. (2011) offer insights into potential solutions to environmental degradation in Nigeria through sustainable afforestation practices. By sequestering carbon through afforestation and tree planting initiatives, Nigeria can offset atmospheric CO2 emissions and contribute to greenhouse gas mitigation efforts. This highlights the importance of nature-based solutions in combating climate change and preserving ecosystems. The debate surrounding the balance between emission-reducing factors, such as afforestation, and emission-enhancing factors, including population growth, economic growth, and deforestation, is a critical issue for academicians, researchers, planners, and policymakers. At the heart of this debate lies the question of environmental sustainability and whether the benefits of emission-reducing actions outweigh the consequences of emission-enhancing activities. On one hand, emission-reducing factors like afforestation have the potential to sequester carbon dioxide from the atmosphere, mitigate climate change, and promote ecosystem health. Afforestation efforts can enhance carbon sinks, improve biodiversity, and contribute to overall environmental sustainability. These actions align with global initiatives aimed at reducing greenhouse gas emissions and achieving climate targets. On the other hand, emission-enhancing factors such as population growth, economic growth, and deforestation can lead to increased carbon emissions, environmental degradation, and biodiversity loss. Rapid population growth and economic development often drive higher energy consumption, industrial activities, and land-use changes, resulting in elevated emissions of greenhouse gases. Deforestation, in particular, contributes to the release of stored carbon from forest ecosystems into the atmosphere, exacerbating climate change. The ongoing debate revolves around assessing the net impact of these opposing forces on environmental sustainability. Researchers and policymakers seek to quantify the trade-offs between emission-reducing and emission-enhancing factors and identify strategies that prioritize emission reduction while supporting economic development and human well-being. Integrated approaches that promote sustainable development, conservation, and renewable energy adoption are increasingly advocated to address these complex challenges (Dernbach, 2003; Munasinghe, 2002; Olawuyi, 2020). Ultimately, achieving a balance between emission-reducing and emission-enhancing factors requires holistic and interdisciplinary efforts that consider social, economic, and environmental dimensions. By fostering dialogue, collaboration, and evidence-based decision-making, stakeholders can work towards solutions that advance environmental sustainability and mitigate the impacts of climate change.

3. DATA AND METHODOLOGY

The main objective of this paper is to analyze the relationship between anthropogenic activities and greenhouse gas (GHG) emissions in India, with a focus on promoting environmental sustainability. GHG emissions are considered a key indicator of environmental health, and reducing these emissions is crucial for sustainable development. Conversely, factors that contribute to higher GHG emissions are associated with environmental degradation. To explore this relationship, the study examines several anthropogenic variables, including fertility rate, population density, the total number of registered motor vehicles, primary energy consumption, and forest area. These variables represent the human-induced activities that are known to influence GHG emissions and environmental sustainability in India. By analyzing the interplay between these anthropogenic factors and GHG emissions, the study aims to identify patterns, trends, and potential drivers of environmental degradation. Understanding these relationships can inform policy interventions, mitigation strategies, and sustainable development initiatives aimed at reducing GHG emissions and promoting environmental sustainability in India. The model estimated in this study aims to examine the relationship between anthropogenic variables and environmental sustainability, particularly focusing on greenhouse gas (GHG) emissions in India. It considers several key factors that are hypothesized to influence GHG emissions. Firstly, fertility rate (FER) is included as a proxy for population growth dynamics, acknowledging the potential impact of population changes on environmental pressures. Population density (DEN) is also considered, reflecting the concentration of human activities and its potential contribution to environmental degradation.

Moreover, the model incorporates gross domestic product per capita (GDPC) as an indicator of economic development, recognizing the potential trade-off between economic growth and environmental sustainability. The total number of registered motor vehicles (MV) is included to capture the emissions associated with transportation activities, reflecting the impact of vehicular emissions on GHG levels. Additionally, primary energy consumption (EC) is considered as a measure of overall energy usage, acknowledging the role of energy consumption in driving GHG emissions. Furthermore, forest area (FAG) is included in the model to represent the impact of land use and forestry on GHG emissions. Forests play a crucial role in sequestering carbon and mitigating GHG emissions, and changes in forest area can have significant implications for overall GHG levels. By considering these anthropogenic variables collectively, the model aims to provide insights into the factors driving GHG emissions in India and their implications for environmental sustainability.

4. RESULTS AND DISCUSSION

The table 1 showcases the long-run results of a regression analysis with the dependent variable being GHG (presumably greenhouse gas emissions) and several independent variables. Each row in the table represents a different variable, displaying its coefficient, t-statistic, and corresponding p-value, which helps assess the significance and impact of each variable on GHG emissions. Starting with the coefficients, which represent the magnitude and direction of the relationship between each independent variable and GHG emissions, several noteworthy findings emerge.

Table 1: Long-Run Results

Dependent: GHG

Variables	Coefficient	t-Statistic	p-value
Ln(FER)	1.217149*	4.031017	0.0003
Ln(DEN)	1.274392*	4.259668	0.0002
Ln(GDPC)	0.172550**	2.171483	0.0372
Ln(MV)	0.039415	0.777763	0.4422
Ln(EC)	1.177473*	11.419115	0.0000
Ln(FAG)	-0.267021	-0.841912	0.4059
Constant	-2.600137	-1.176177	0.2479

The coefficients associated with Ln(FER), Ln(DEN), and Ln(EC) are marked with asterisks, indicating statistical significance. This suggests that changes in these variables have a meaningful impact on GHG emissions. Specifically, increases in Ln(FER) and Ln(DEN) are associated with substantial increases in GHG emissions, as indicated by their positive coefficients. Conversely, increases in Ln(EC) are associated with significant decreases in GHG emissions, given its negative coefficient. These results imply that factors such as energy consumption (Ln(FER)), population density (Ln(DEN)), and economic development (Ln(EC)) play crucial roles in shaping long-term GHG emissions. Moreover, the t-statistics provide insights into the reliability and significance of the coefficients. Higher t-statistics indicate greater reliability and stronger evidence for the significance of the corresponding coefficients. In this regard, Ln(FER), Ln(DEN), and Ln(EC) exhibit notably high t-statistics, reinforcing their significance in explaining variations in GHG emissions. Conversely, Ln(MV) and Ln(FAG) have lower t-statistics, suggesting weaker evidence for their impact on GHG emissions. Regarding the p-values, which indicate the probability of observing the t-statistic or a more extreme value if the null hypothesis (no effect) is true, all variables except Ln(MV) and Ln(FAG) have p-values below the conventional threshold of 0.05. This signifies that Ln(FER), Ln(DEN), Ln(GDPC), Ln(EC), and even the constant term are statistically significant predictors of GHG emissions. However, Ln(MV) and Ln(FAG) fail to reach statistical significance, suggesting that they may not be robust determinants of GHG emissions in the long run. Overall the results of the long-run regression analysis shed light on the factors influencing GHG emissions. Energy consumption, population density, and economic development appear to be key drivers, while variables related to motor vehicle ownership and agricultural activity exhibit less pronounced effects. These findings provide valuable insights for policymakers and researchers aiming to develop effective strategies for mitigating GHG emissions and addressing climate change.

Table 2 presents the short-run results of a regression analysis with greenhouse gas (GHG) emissions as the dependent variable and various independent variables. Each row represents a different variable, displaying its coefficient, t-statistic, and corresponding p-value, which indicate the significance and impact of each variable on GHG emissions in the short term. Examining the coefficients, we observe that changes in variables are denoted as Δ (delta), representing the first difference or change in the natural logarithm of each variable. Several variables exhibit statistically significant coefficients. Notably, Δ Ln(FER), Δ Ln(DEN), Δ Ln(GDPC), Δ Ln(EC), and ECTt-1 are marked with asterisks, indicating significance. These variables play crucial roles in influencing short-term fluctuations in GHG emissions. Specifically, positive coefficients for Δ Ln(FER), Δ Ln(DEN), and Δ Ln(EC) suggest that increases in energy consumption, population density, and economic activity lead to higher GHG emissions in the short run. Conversely, the negative coefficient for Δ Ln(MV) implies that an increase in motor vehicle ownership may lead to a slight decrease in GHG emissions, although this effect is not statistically significant. Moreover, the coefficient for ECTt-1 (the error correction term lagged by one period) is negative and statistically significant, indicating the presence of a significant short-run relationship between changes in GHG emissions and their deviations from the long-run equilibrium. This suggests that GHG emissions tend to adjust towards their long-run equilibrium in response to short-term shocks. Considering the t-statistics, which assess the reliability and significance of the coefficients, we find that Δ Ln(FER), Δ

Ln(DEN), Δ Ln(EC), and ECTt-1 have notably high t-statistics, reinforcing their significance in explaining short-term variations in GHG emissions. On the other hand, Δ Ln(MV) and Δ Ln(FAG) have lower t-statistics, indicating weaker evidence for their impact on GHG emissions in the short run. Regarding the p-values, which indicate the probability of observing the t-statistic or a more extreme value if the null hypothesis (no effect) is true, all variables except Δ Ln(MV) and Δ Ln(FAG) have p-values below the conventional threshold of 0.05, indicating statistical significance. The short-run regression analysis provides valuable insights into the immediate drivers of GHG emissions. Energy consumption, population density, economic activity, and the error correction mechanism play significant roles, while variables related to motor vehicle ownership and agricultural activity exhibit weaker effects. These findings offer valuable guidance for policymakers and researchers seeking to develop strategies to manage and mitigate short-term fluctuations in GHG emissions.

Table 2: Short-run Results

Dependent: GHG

Variable	Coefficients	t-Stat	p-value
Δ Ln(FER)	1.444425*	3.843861	0.0005
Δ Ln(DEN)	1.512356*	3.636885	0.0009
Δ Ln(GDPC)	0.204770**	2.194477	0.0353
Δ Ln(MV)	-0.140848	-1.532236	0.1350
Δ Ln(EC)	1.026466*	6.402363	0.0000
Δ Ln(FAG)	-0.316882	-0.822081	0.4169
ECTt-1	-1.186728*	-7.157032	0.0000

The analysis presented in Tables 1 and 2 reveals several notable findings regarding the relationship between anthropogenic variables and greenhouse gas (GHG) emissions in India. Firstly, there is a positive and statistically significant relationship between fertility rate and GHG emissions, both in the long and short run. This finding aligns with prior research conducted by Wynes and Nicholas (2017), indicating that population growth dynamics, as represented by fertility rate, contribute to increased GHG emissions. Similarly, the analysis demonstrates a positive and statistically significant relationship between population density and GHG emissions, both in the long and short run. This result is consistent with studies by Dodman (2009), Swim et al. (2011), Jones and Kameen (2014), and Yanghong et al. (2017), highlighting the role of population concentration in driving GHG emissions. Moreover, the findings indicate a positive and statistically significant relationship between gross domestic product (GDP) per capita and GHG emissions, both in the long and short run. This corroborates with research by Neagu and Teoduru (2019), Sterpu et al. (2018), Khan and Siddique (2017), Lu (2017), Li et al. (2016), Vavrek and Chovancoa (2016), Barido and Marshall (2014), Sadorsky (2014), and Hamit Haggar (2012), underscoring the association between economic development and increased GHG emissions. Furthermore, the analysis reveals a positive and statistically significant relationship between primary energy consumption and GHG emissions, both in the long and short run. This finding is consistent with prior studies by Neagu and Teoduru (2019), Lizbetin et al. (2018), Fayez et al. (2017), Khan and Siddique (2017), Lu (2017), Barido and Marshall (2014), Sadorsky (2014), and Ren et al. (2013), highlighting the role of energy consumption in driving GHG emissions. However, the analysis also identifies statistically insignificant relationships between the use of motor vehicles and GHG emissions, as well as between forest coverage and GHG emissions, both in the long and short run. These findings suggest the need for further in-depth studies specific to India, as prior research has supported a positive and significant relationship between the use of motor vehicles and GHG emissions, while indicating a negative and significant relationship between forest coverage and GHG emissions. Therefore, further investigation is warranted to understand the nuanced dynamics of these relationships within the Indian context (Khan & Siddique, 2017; Zheng et al., 2015; Chowdhury et al., 2012; Hankey & Marshall, 2010; Aukland & Costa, 2002; Fearnside & Laurance, 2004; Laurence et al., 1998).

5. CONCLUSION

The findings of the study underscore the significant role that anthropogenic factors play in contributing to greenhouse gas (GHG) emissions in India. As a densely populated and rapidly developing nation, India ranks among the top emitters of GHGs globally, highlighting the urgency of addressing emissions within the country. The analysis reveals that key demographic and economic indicators, including fertility rate, population density, gross domestic product (GDP) per capita, and primary energy consumption, exert a statistically significant positive influence on GHG emissions both in the short and long run. However, it is noteworthy that the impact of motor vehicle usage and forest coverage on GHG emissions was deemed statistically insignificant. While these factors have been identified in previous research as contributors to emissions, the findings suggest that their influence may vary within the context of India. This highlights the importance of further research to better understand the nuanced dynamics of these relationships and their implications for emissions reduction strategies. Additionally, the presence of a negative and statistically significant error correction term indicates the presence of short-run adjustments to deviations from the long-run equilibrium in GHG emissions. This suggests that while there may be short-term fluctuations in emissions levels, there is a tendency for the system to revert back to its long-term equilibrium over time. Understanding these dynamics is crucial for designing effective policies aimed at mitigating GHG emissions and promoting environmental sustainability in India.

Based on the findings of the study, several policy recommendations emerge to address the drivers of greenhouse gas emissions in India. Firstly, there is a pressing need to reorient population policies towards reducing fertility rates and curbing rapid population growth. This could involve initiatives aimed at raising awareness about the benefits of smaller family sizes for environmental sustainability and promoting family planning measures. Additionally, efforts should be made to promote the widespread adoption of renewable energy sources such as solar, wind, and nuclear power across various sectors including domestic, industrial, and transportation. Public awareness campaigns can play a crucial role in encouraging individuals and businesses to transition towards renewable energy alternatives, thereby reducing reliance on fossil fuels and mitigating emissions. Furthermore, there is a need to incentivize the use of energy-efficient products and practices among consumers and businesses. This could involve programs aimed at promoting energy-efficient lighting solutions such as LED bulbs and encouraging the adoption of energy-efficient appliances and equipment.

Urban authorities should also prioritize energy efficiency measures, particularly in areas such as street lighting and public transportation infrastructure. Implementing initiatives like the Bus Rapid Transit System (BRTS) can help reduce emissions associated with urban transport while improving overall energy efficiency. Imposing pollution charges on entities with significant carbon emissions can serve as a powerful economic incentive to reduce greenhouse gas emissions. By holding these entities financially accountable for their environmental impact, such measures encourage investment in cleaner technologies and practices. Moreover, establishing thresholds for GHG emissions and requiring entities that exceed these limits to pay into funds dedicated to renewable energy generation and forest protection can further incentivize emissions reduction efforts. While India has made commitments under the COP21 protocol and has ambitious plans for investing in clean energy and transitioning to low-carbon sources, there is still considerable work to be done. Continued efforts are needed to meet these targets and accelerate progress towards a cleaner and more sustainable environment. This may involve implementing additional policy measures, fostering innovation in renewable energy technologies, and enhancing collaboration between government, industry, and civil society stakeholders. By remaining committed to its climate goals and implementing effective strategies, India can play a significant role in addressing global climate change and achieving a cleaner and more sustainable future.

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