



Enhancing the Understanding of climate dynamics: analysis of global warming's influence on Climatic changes across continents

Nimesha Dharmapriya¹ · Sandali Edirisinghe¹ · Vilan Gunawardena¹ · Dithma Methmini¹ · Nilmini Rathnayake² · Ruwan Jayathilaka³

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Abstract

Global warming, primarily due to increased atmospheric carbon dioxide, poses a significant threat to climate stability, yet research on its combined effects across different geographical areas is limited. In order to fill that gap, this study examines how carbon emissions (CE) are impacted by greenhouse gas emissions (GHG), agricultural nitrogen oxide (ANO), urban population (UP), and fossil fuel consumption (FFC) in 185 different nations between 2000 and 2019. With the exception of urban population, which was expressed as a percentage, all variables were standardised to metric tonnes per capita using panel regression analysis. The results draw attention to geographic disparities. Africa has the lowest carbon and greenhouse gas emissions due to its extensive forest cover and minimal industrial production. Although Oceania's greenhouse gas emissions have decreased, the region continues to emit high amounts of agricultural nitrous oxide. Rapid industrialisation is the primary cause of Asia's growing consumption of fossil fuels. Agricultural nitrous oxide and carbon emissions have a negative correlation in Asia, Oceania, and the globe, but a positive correlation in Africa, America, and Europe. Carbon emissions and the use of fossil fuels are strongly positively correlated in every region but Asia. These results highlight the complex, location-specific factors affecting carbon emissions. For policymakers to effectively cut emissions, they must develop customised, geographically specific initiatives. In order to accomplish Sustainable Development Goal 13: Climate Action by 2030, emission controls should be strengthened, and sustainable practices should be encouraged, particularly in the use of fossil fuels and farming.

Keywords Carbon emission · Climate change · Fossil fuel consumption · Global warming · Greenhouse gas · Urban population

1 Introduction

Numerous human activities, including fossil fuel combustion metropolitan expansion, and deforestation for agriculture, have significantly contributed to the atmospheric release of carbon dioxide (CO₂). As stated by the Intergovernmental Panel on Climate Change (2007), *“a change in the state of the climate that can be identified (using statistical tests) by changes in the mean and the variability of its properties and that persists for an extended period, typically decades or longer” makes up climate change.* Since 2008, significant weather related disasters such as wildfires, floods, droughts, and extreme heat have caused an average of 21.8 million people to be internally displaced worldwide (Chatham house, 2021). Moreover, the pace of global warming is unprecedented. The primary causes of global warming are Greenhouse Gas (GHG) emissions particularly CO₂, which result from human activity and industrial production (Duan et al., 2022). The World Health Organization (2023) predicts that between 2030 and 2050, climate change will lead to an additional 250,000 deaths annually from starvation, malaria, diarrhoea, and heat stress. According to the National Aeronautics and Space Administration (2023), sea levels will rise, climate change will continue, hurricanes will intensify, droughts and heatwaves will become more severe, and global temperatures will keep increasing throughout this decade and beyond.

Countries are required by the Paris Agreement to cut their emissions by 45% by 2030 and reach net zero emissions by 2050 (United Nations, 2023). Furthermore, according to the United Nations Framework Convention on Climate Change (2023), given that this would greatly lessen the risks and effects of climate change, the Paris Agreement seeks to “keep the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels.” Hence, immediate action is necessary to mitigate climate change and its severe consequences, safeguard lives and livelihoods and achieve the 2030 Agenda for Sustainable Development.

In Asia, China and India stand out as the largest emitters of CO₂, driven by rapid industrialisation and urbanisation. The region, home to most of the world’s population, has become a focal point in the struggle between economic growth and climate change mitigation. According to the 2021 Climate Risk Index (CRI), six out of ten countries most affected by weather related loss events such as storms, floods, landslides, and heatwaves - from 2000 to 2019 were in developing Asia (Asian Development Bank, 2023). The region’s heavy reliance on fossil fuels exacerbates environmental degradation, deteriorating air quality, and the depletion of clean water resources. Global warming and climate change are greatly exacerbated by Asia’s rising GHG emissions (Lee et al., 2017). Fossil fuel consumption, which is a major contributor to CO₂ emissions, is a central factor in Asia’s growing carbon footprint (Lindsey, 2022). Additionally, the largest per capita CO₂ emitters are oil-producing countries such as Qatar and Kuwait, with emissions of 49 tons and 25 tons per person, respectively. While countries like the United States, Australia, and Canada contribute high total emissions, nations such as China and India, despite their large populations, emit relatively lower per capita GHGs. (Roser & Ritchie, 2023).

As emissions from both developed and developing regions continue to rise, Asia’s efforts in to improve energy efficiency will be critical in mitigating climate change and reducing global warming (Lee et al., 2017; Roser & Ritchie, 2023). The greenhouse effect, driven by increased CO₂ and other GHG emissions, continues to intensify the warming of the Earth’s climate. For instance, the concentration of water vapour in the atmosphere increases as

temperatures rise. Since the 19th century, land use and fossil fuels have increased GHG emissions, which peaked in 2019 (Lamb et al., 2021). Ritchie and Roser (2023) emphasised Agricultural Nitrous Oxide (ANO), which has a high global warming potential, is released through agricultural activities such as synthetic fertiliser use and manure application (Bigai-gnon et al., 2020). According to the World Meteorological Organization (2022a), Nitrous Oxide (N_2O) is released into the atmosphere by both natural (about 57%) and anthropogenic (around 43%) sources, including seas, soils, biomass burning, synthetic fertilisers use, manure application, agricultural residue on farms, and numerous industrial operations.

Urbanization is another important factor influencing climate change. It is predicted that 66% of people on Earth would reside in cities by 2050, up from 54% currently. According to UN forecasts, the world population could expand by 2.5 billion people by 2050 due to urbanisation and population growth, with Asia and Africa accounting for about 90% of the increase (United Nations, 2014b). Rapid urbanisation increases exposure to high heat brought on by the Urban Heat Island (UHI) effect and climate change, which worsens urban warming and jeopardises the sustainability of rapidly growing urban populations (Tuholske et al., 2021). Additionally, UHI has made urban thermal environments less comfortable, and global warming will worsen the UHI effect during heatwaves (Zou et al., 2021).

Fossil Fuel Consumption (FFC) has detrimental social impacts on people's health and quality of life, as well as environmental consequences, including air pollution and global warming (Martins et al., 2018). World Health Organization (2022) estimated that 4.2 million premature deaths occurred globally in 2019 as a result of air pollution in both urban and rural locations. Moreover, the use of fossil fuels results in pollution that increases GHG emissions, contributing to climate change. This creates a domino effect where fossil fuel consumption leads to CO_2 emissions, which in turn drive climate change. (Amaefule et al., 2022).

Taking into account both continental and global dimensions, this study assesses the effect of global emissions on climate change between 2000 and 2019. This research stands out for several reasons. First, it covers 185 nations across all five continents, utilising accurate data from the past two decades, thus providing comprehensive country coverage. Second, it introduces an innovative approach by simultaneously examining the impact of GHG, ANO, UP, and FFC on Carbon emission. This multi-variable approach offers valuable insights into how these factors collectively contribute to global warming. Third, the study offers a thorough comparison of continental impacts and makes a substantial methodological contribution to the literature by using panel regression analysis to investigate correlations across variables. Finally, the research informs policy recommendations aimed at reducing climate change and aligning with the United Nations' Sustainable Development Goal (SDG) 13: "Climate Action" by 2030. The article's remaining content is organised as follows: the literature is reviewed in the next part. The outcomes are presented in the third, which also covers the data and methods. Discussion takes up the fourth section, while the final section wraps up with the key research findings, policy implications, limits, and suggestions for the future.

2 Literature review

This section outlines the contributions of various academics from different nations. Numerous studies have utilised one dependent and one independent variable to examine the impact of global warming on climate change across regions, continents, and the world. The authors of this study consider CE, GHG, ANO, UP, and FFC simultaneously to determine the relationship between each variable on a global and continental scale.

2.1 Global perspective

Rising temperatures endanger humans and other life forms on Earth by changing weather patterns and upsetting the natural order throughout time. National Geographic Partners (2023) explain that if warming continues, the ecosystem will undergo several changes, such as rising sea levels and reduced availability of fresh water. Malnutrition, respiratory disorders, heat-related ailments, and higher death rates are among the health problems that will also surface. However, very few studies have simultaneously considered CE, GHG, ANO, UP and FFC to explore this crisis further. Therefore, research using these variables is necessary.

According to Selahattin (2014), the climate is changing swiftly and the average temperature of the planet is rising rapidly. In order to raise awareness of global warming, the majority of previous academics examined the historical context of climate change (Donatella, 2022). However, it is imperative to examine the correlation between each factor contributing to global warming. JingYun et al. (2011) describe that the spread of GHG emissions is linked to human activities such as transportation, livestock farming, and deforestation. CO₂, methane (CH₄), nitrous oxide (N₂O), and fluorinated gases are the primary components of these emissions. The main causes of climate change during the past century have been changes in the composition of atmospheric aerosols, increases in GHG emissions, and stratospheric ozone depletion, all of which point to human involvement (Stips et al., 2016).

Past researchers, Maraseni and Qu (2016) and Machado et al. (2021), found that ANO makes for around 11% of all anthropogenic emissions and is mostly dispersed by farm crop leftovers, manure applications, and different fertilisers. Moreover, 16–27% of emissions contributing to global warming are produced by agriculture. Many of these emissions are not from CO₂, the well-known cause of climate change. N₂O is a major source, with agricultural soil being the primary contributor, especially given the world's extensive use of synthetic nitrogen fertilisers (British Broadcasting Corporation, 2023).

According to projections by United Nations (2018a), it is predicted that 60% of people on Earth would reside in urban areas, increasing the current percentage of over 50% by 2050. Klein and Anderegg (2021) claim that the urban population makes the problems of growing density and the Urban Heat Island (UHI) effect which is brought on by the combination of rising global temperatures and population growth even worse. Moreover, the growth of the urban population crisis leads to natural disasters like wildfires, rising sea levels, and displacement of communities.

Fossil fuel consumption is one of the main causes of global warming. FFC contains oil, coal, and natural gas, all of which have a major effect on CO₂ increase (Rehman et al., 2019). This dependence has led to the emergence of environmental issues such as air pollution, climate change, and global warming (Poole et al., 2019). Burning fossil fuels increases

in CO₂ emissions, a critical pollutant globally, and directly impacts the rise in global temperatures (Paraschiv & Paraschiv, 2020). These impacts manifest differently across various continents, each facing unique challenges and contributing factors. The following sections highlight findings from each continent based on existing literature.

2.2 Asia

Asia has made substantial contributions to global warming and is among the continents most at risk from climate change. According to South China Morning Post (2019) and Consumer News and Business Channel (2022), human activities in Asia, particularly in China, India, and Japan, are major contributors to global warming. These three countries are among the world's top five polluters. Given its large population and tendency for natural disasters, Asia is expected to be especially impacted by climate change.

Marcotullio et al. (2012) indicate that between 30% and 38% of Asia's total human GHG emissions are produced in urban areas, with regional averages for emissions per capita being lower than national levels. According to Ritchie (2019), China has been Asia's biggest CO₂ emitter in recent years, and as China grows, Asian GHG emissions are likely to rise. Norris et al. (2021) predict that due to rapid economic growth, high energy consumption, and frequent weather-related natural disasters, temperatures are rising across Asia at twice the global average rate (Dharmapriya et al., 2024). Additionally, more than half of global GHG emissions originate from Asia and the Pacific (Sonobe & Pande, 2022).

Raut et al. (2015) and Ito et al. (2018) elucidate that the increase in N₂O due to the use of fertilisers in agricultural activities has become one of the notable GHG contributions in the Asian region. Asia's human activity has a major impact on the world's N₂O budget, particularly in East Asia. As a result of Asia's fast economic growth and population expansion, industrial emissions and fertiliser use have significantly increased, causing serious environmental problems such as air pollution and water body eutrophication (Ito et al., 2018).

Research by the United Nations (2014a) and the Asian Development Bank (2017) demonstrates that the population in urbanised areas is expected to reach 64% of the total population. Asia is projected to have eight more megacities by 2030 than in 2014. Fifty-four per cent (54%) of the world's urban population resides in Asia, despite the continent having a relatively lower rate of urbanisation (United Nations, 2018a). Moreover, Asia is increasingly experiencing deforestation, pollution, and resource degradation, placing the region at risk of natural and human-included disasters, driven by climate change. South Asia, one of the region's most susceptible to climate change, is predicted to see a large increase in average annual temperatures over the next century due to the growth of its metropolitan population (Dimitrova et al., 2021).

The more advanced South Asian economies of Bangladesh, India, Pakistan, and Sri Lanka have traditionally used a mix of imported and domestically produced fossil fuels to generate electricity (Shukla et al., 2017). These countries have historically depended on coal, natural gas, and oil to meet their energy demands, which has significantly contributed to their carbon emissions. However, as Hanif (2018) described, energy consumption in Asian countries is increasing due to growing industrialisation and urbanisation. Most Asian nations continue to rely significantly on non-renewable fossil fuels for sustaining their economies, therefore this rise in energy consumption frequently ignores the detrimental effects on the environment. When these fossil fuels are burned, significant volumes of CO₂ and

other pollutants are released into the atmosphere, raising serious issues for the environment and human health. This is particularly evident in countries like Indonesia, Thailand, Malaysia, Brunei, and Singapore, where the release of toxic smog from burning fossil fuels has caused significant air quality problems and health issues (Hanif, 2018).

The development of suitable renewable energy infrastructure is a major obstacle for Asia as it works to move away from fossil fuels. South Asian nations have not made the full potential of cross-border renewable energy trade to increase their use of renewable energy, despite the promise of renewable energy sources including solar, wind, and hydroelectric power. The implementation of the Renewable Energy Transition (RET) has been hindered by the region's continued dependence on fossil fuels, which has obstructed efforts to achieve environmental sustainability. Enforcing strict environmental legislation and policies may help reduce South Asia's fossil fuel consumption and promote the adoption of renewable energy sources (Murshed et al., 2021). Lessons from past studies suggest that further examination of the Asian region based on CE, GHG, ANO, UP, and FFC is necessary. Future research on the impact of global warming on climate change is urgently needed to achieve the target of reducing CO₂ emissions and mitigating the adverse effects of climate change.

2.3 Africa

Africa is among the continents which are most susceptible to climate variability and change (Brown et al., 2007). Many African countries' growing populations are likely to result in higher CO₂ emissions. A significant portion of CO₂ emissions in Africa is attributed to the burning of fossil fuels (Alaganthiran & Anaba, 2022; Ayompe et al., 2020; Duan et al., 2022). However, CO₂ emissions have fallen by 33% and 38% in Congo and Zimbabwe, respectively (Ayompe et al., 2020). Despite this, Africa currently accounts for only 4% of global CO₂ emissions. According to forecasts, CO₂ emissions in Africa will rise by 30% by 2030.

South Africa is the continent's leading emitter of GHG (Oladunni et al., 2022). Africa produces 4% of the world's GHG emissions and is expected to experience some of the most severe effects of climate change (Dlamini, 2022). According to Hickman et al. (2011), 42% of Africa's overall N₂O emissions are attributable to agriculture. Livestock grazing accounts for most agricultural emissions in Africa, with paddocks, ranges, and pastures contributing 74% of agricultural N₂O emissions, excluding those from biomass burning. Based on projected trends, agricultural N₂O emissions in Africa by 2050 may more than double from 2000 levels (Hickman et al., 2011). In 2019, South Africa's N₂O emissions were recorded at 18,510 thousand metric tonnes of CO₂ equivalent (Knoema, 2019). Furthermore, Lemarpe et al. (2021) discovered that N₂O emissions vary significantly among Sub-Saharan African farming systems. ANO is significantly influenced by environmental, climatic, and soil conditions in the African region.

African cities may become unsuitable for habitation due to frequent extreme temperatures in mid-latitude zones brought on by climate change (Tuholske et al., 2019). The effects of climate change already being felt in African cities may be exacerbated two or threefold with an additional 1.5 °C of warming. Both East and West Africa are among the most threatened and sensitive regions to climate change due to the rising urbanization of their populations and the intense heat (Li et al., 2022). Over the next few decades, as desert regions

become hotter and drier due to climate change, a growing percentage of the population will be African.

Research conducted by Kwakwa et al. (2018) revealed that urbanisation increases FFC in South Africa. Halting the use of FFC is the first step in combating climate change in Africa (Udeh, 2019). Specifically, coal consumption is a significant energy source for many African nations. The continued reliance on fossil fuels, particularly oil, will lead to higher atmospheric CO₂ emissions in Sub-Saharan African countries (Alaganthiran & Anaba, 2022). As a result of the continent's rapid urbanisation, CO₂ emissions from African nations directly contribute to global warming.

2.4 America

A major contributor to global CO₂ emissions and climate change is the American region, which includes the United States, North America, and Latin America. Studies by the U.S. Energy Information Administration (2022) and Raihan and Tuspekova (2022) indicate that America is one of the top emitters of CO₂. Key drivers of CO₂ emissions in the region include urbanisation and energy consumption, while renewable energy use and forest cover have mitigating effects (Panait et al., 2022). Martin and Shaheen (2011) revealed that petroleum use in the US accounts for almost 70% of GHG emissions. Although efforts to lower GHG emissions have led to a significant reduction in natural gas usage for electricity production, coal consumption has paradoxically increased. Additionally, around 20% of US GHG emissions in 2007 were directly attributable to household consumption (Song et al., 2019).

In North America, agricultural lands contribute significantly to N₂O emissions (Cavigelli et al., 2012). America's cities, where 79% of the population lives, are especially susceptible to the consequences of climate change, including heatwaves (Inter-American Development Bank, 2012). In Latin America, Piña (2014) found that pollutants and GHG emissions directly impact air pollution and indirectly affect atmospheric conditions in urban areas. Piña (2014) also analysed urban growth in three Latin American cities; Buenos Aires, Santiago, and Mexico City revealing significant environmental concerns due to the intense demand for urban space. Consequently, pollutants and GHG emissions affecting metropolitan areas are major contributors to air pollution and climate change in America.

FFC continues to be the primary cause of the yearly rise in carbon emissions into the atmosphere in America (Gurney et al., 2012). In 2018, fossil fuel consumption in the US increased, including rises in petroleum and natural gas usage (Inspectioneering, 2019). Despite this increase, FFC in the US reached its lowest level in nearly 30 years (Masterson, 2021). Thus, FFC remains the primary contributor to annual Carbon emission in the American region. To address these problems and lessen the negative effects of climate change in the area, a coordinated effort is needed to switch to renewable energy sources, enforce stronger environmental laws, and encourage sustainable urban growth.

2.5 Europe

Europe's long-term goals include reducing CO₂ emissions and achieving carbon neutrality (Balogh & Leitão, 2022; Bezić et al., 2022). On the other hand, over the last three decades, the average worldwide temperature has risen by more than twice as much as that of Europe

(World Meteorological Organization, 2022b). The US and Europe together account for less than one-third of global CO₂ emissions (Ritchie & Roser, 2020). According to the European Commission (2020), 152 million tonnes of CO₂ equivalent (Mt CO₂eq), or 9.1%, less Carbon emission was produced in 2019 compared to 2018. Moreover, the European Commission (2020) explained that importing agricultural products decreases Carbon emission within Europe.

Over recent years, GHG emissions in 27 European nations have decreased by 3.7% (European Commission, 2020). Additionally, Carozzi et al. (2022) revealed that the regional distribution of GHG emissions in Europe is varied, and by 2050, Europe aims to achieve climate neutrality. The factors driving the increase in GHG emissions may be compared to the combined impact of Europe for Austria and Spain. According to the United Nations (2023), the European Union's GHG mitigation targets, which are in line with the 13th Sustainable Development Goal, include a minimum 55% decrease in emissions by 2030 and the achievement of net-zero GHG emissions by 2050.

European cities are the main contributors to GHG emission (Katavoutas et al., 2022). The coastal and hotspot regions of South Eastern and Southern Europe are anticipated to experience similar impacts to the floodplains in the western regions (Climate-ADAPT, 2023). In the European region, more than 74% of people live in cities, and by 2050, that percentage is anticipated to rise to more than 80% (Climate-ADAPT, 2023). However, Europeans will experience heat stress due to the rapid expansion of urban population.

ANO represents almost 210 MtCO₂eq of agricultural emissions in Europe, primarily from manure management and fertiliser application (De Cara et al., 2005). Moreover, Rees et al. (2013) indicated that nitrogen supplied to agricultural locations causes a significantly higher emission of N₂O. In general, agriculture in Europe substantially increases GHG emissions, with the primary source of N₂O emissions being agricultural soils (Katavoutas et al., 2022; The European Union, 2018).

Many European nations still rely on fossil fuels. However, they have modest fossil fuel reserves, and if they burn all of their fossil fuel reserves, they will soon run out (Martins et al., 2019). In conclusion, CO₂ emissions from GHG, ANO, UP, and FFC directly contributes to the warming of Europe. Policymakers should focus on implementing stringent regulations to limit these emissions and mitigate climate change.

2.6 Oceania

In Oceania, there is limited study on how urbanization and carbon emissions affect global warming. In particular, no thorough research has been done in this area on how GHG, N₂O, and FFC affect global warming. Eugenia (2021) noted that Oceania, including Australia and New Zealand, is experiencing the consequences of global warming, with sea temperatures rising by 1.2 °C above average in 2018 and currently increasing by 3.6 °F in the Pacific region. Both countries have made efforts to reduce their Carbon emission. For instance, New Zealand's per capita CO₂ emissions decreased by 0.08 CO₂ metric tonnes per person in 2015 (Worldometers.info, 2022), and Australia's per capita CO₂ emissions fell by 2.3% in the same year (Worldometers.info, 2023).

Despite efforts to reduce emissions, Bourne et al. (2018) reported a 1.5% increase in GHG emissions in 2017 compared to 2016. Panchasara et al. (2021) emphasised, that the viability and longevity of farming enterprises depend on incorporating environmental con-

siderations into agricultural practices. This approach should also be extended to other industries, including transportation, energy, and manufacturing. Australia must take further action to reduce its emissions and contribute to the global effort to combat climate change.

Agriculture is a significant source of N_2O in Australia, 20% of total emissions (Barker et al., 2005). However, N_2O emissions have declined over the past two decades (Knoema, 2023). Similarly, in New Zealand, agricultural practices significantly impact global warming due to N_2O emissions (New Zealand Agricultural Greenhouse Gas Research Centre, 2023). Therefore, it is crucial to support the agricultural industry in adopting sustainable and resilient practices to reduce emissions.

Oceania covers one-third of the Earth's surface, with 96% of it being the Pacific Ocean, leaving only a small fraction of land for human habitation (Caldwell et al., 2001). Due to limited land availability, people in Oceania predominantly live in coastal areas, and the vulnerability of these communities to rising sea levels and coastal erosion has increased (Seo, 2011). Addressing these challenges requires global cooperation and collaborative efforts to find solutions to the regional problems posed by global warming.

Australia's exports of fossil fuels also add to global emissions, underscoring the necessity of switching to renewable energy sources (Head et al., 2014). In 2019, fossil fuels accounted for 79% of Australia's total electricity generation, a 2% decrease from 2018 (Commonwealth of Australia, 2020). Although New Zealand relies heavily on renewable energy sources, with 40% of its primary energy supply coming from hydro, geothermal, and wind power, 60% still comes from fossil fuels (Energy in New Zealand, 2023). Oceania must find ways to reduce emissions while maintaining a robust energy sector to mitigate global warming and ensure sustainable and resilient energy consumption across the region.

There has been very few research that has examined the effects of GHG, ANO, UP, and FFC on carbon emissions. Most past research has focused on South Asia, South Africa, and the US. In Oceania, there is a need for comprehensive investigations covering the entire region. According to the existing literature, no comprehensive study has covered all continents. Most studies have examined the impact of global warming on climate change in specific continents, regions, or nations. Furthermore, no research has fully investigated the statistical correlation between the independent variables, GHG, ANO, UP, and FFC and the dependent variable carbon emission both globally and by continent. Thus, by offering a more thorough examination of the connection between climate change and global warming on all continents and internationally, this study aims to fill this knowledge gap.

3 Methods

The Sri Lanka Institute of Information Technology (SLIIT) Ethical Review Board and the SLIIT Business School have given their approval to this project. The study made use of Our World in Data's secondary data sources. Appendix 1 makes reference to the data file. This section is split into two sections: the first segment lists the variables and data sources, while the second section describes the study's methodological approach.

3.1 Data

For this study, a panel dataset covering the years 2000 to 2019 was employed for 185 countries. Global and regional data were collected under the variables of CE, GHG, ANO, UP and FFC and the data was presented separately for each continent. Data sources and variables are shown in Table 1. Metric tonnes per capita is used as the unit of measure, and readers can access the data source by clicking the relevant link.

Using the available data in Our World in Data, the study gathered data from 46 Asian countries, 48 African countries, 36 American countries, 43 European countries and 12 Oceanian countries.

3.2 Methodology

To analyse how Greenhouse gas (GHG), Agricultural Nitrous Oxide (ANO), Urban population (UP) and Fossil fuel consumption (FFC) affect Carbon emission (CE) at both global and continental levels, the following equation was developed. The independent variables are GHGE, ANO, UP, and FFC, while the dependent variable is CE as a proxy for global warming.

$$CE_{it} = \beta_0 + \beta_1 GHGE_{it} + \beta_2 ANO_{it} + \beta_3 UP_{it} + \beta_4 FFC_{it} + \epsilon_{it} \quad (1)$$

where i denotes the relevant region and t shows the year taken into consideration, while ϵ_{it} shows the standard error. The dataset combines cross-section and time series data, making the Panel regression model more appropriate. Hence, the results were presented by using panel data regression analysis, including the Pooled Ordinary Least Square (POLS), Fixed Effect (FE) model and Random Effect (RE) model. The FE model provides two estimation methods: within-effect estimation and between-effect estimation. These methods produce different parameter estimates even though they both provide identical slope estimates for non-dummy independent variables, emphasizing the significance of choosing the proper

Table 1 Data sources and variables

Variable	Definition and Measure	Source
CE	Carbon Emission (Metric ton Per Capita)	Our World in Data https://ourworldindata.org/grapher/co-emissions-percapita
GHG	Greenhouse Gas Emission (Metric ton Per Capita)	Our World in Data https://ourworldindata.org/grapher/per-capita-ghg-emissions
ANO	Agricultural Nitrous Oxide (Metric ton Per Capita)	Our World in Data https://ourworldindata.org/grapher/per-capita-nitrous-oxide-agriculture
UP	Urban Population (Percentage)	Our World in Data https://ourworldindata.org/Urbanisation
FFC	Fossil Fuel Consumption (Metric ton Per Capita kWh)	Our World in Data https://ourworldindata.org/grapher/fossil-fuel-s-percapita

estimation method for precise results (Wooldridge, 2015). The RE model provides a more profound knowledge of the underlying causes of variation in the data, which is created to explore the impact of cross-section and time series on the error variance (Fitrianto & Musakkal, 2016). Both FE and RE models were employed to obtain a comprehensive understanding of the phenomenon under study. Each model offers the option of one-way and two-way analysis, providing flexibility in study design and interpretation.

3.2.1 Overview of the analytical framework

As per the Fig. 1, this study deployed panel regressions as the main statistical analysis to find the statistical insights for the study. The study used data for CE, GHG, ANO, UP and FFC covering worldwide countries including Asian countries, African countries, American countries, European countries and Oceanian countries. After classifying the dataset, converted them to the natural logarithm to run the panel regression analysis. In the panel regression analysis, the study conducted F test, LM test and Hausman test to get the major findings for the study.

3.3 Addressing multicollinearity and variable selection

As per referenced research papers, all selected independent variables have a direct impact on Carbon emission. Transportation, deforestation, industrial activities, and energy production are key contributors to GHG emissions across all continents (Le Quéré et al., 2018). The use of nitrogen-based fertilisers in agriculture directly contributes to Carbon emis-

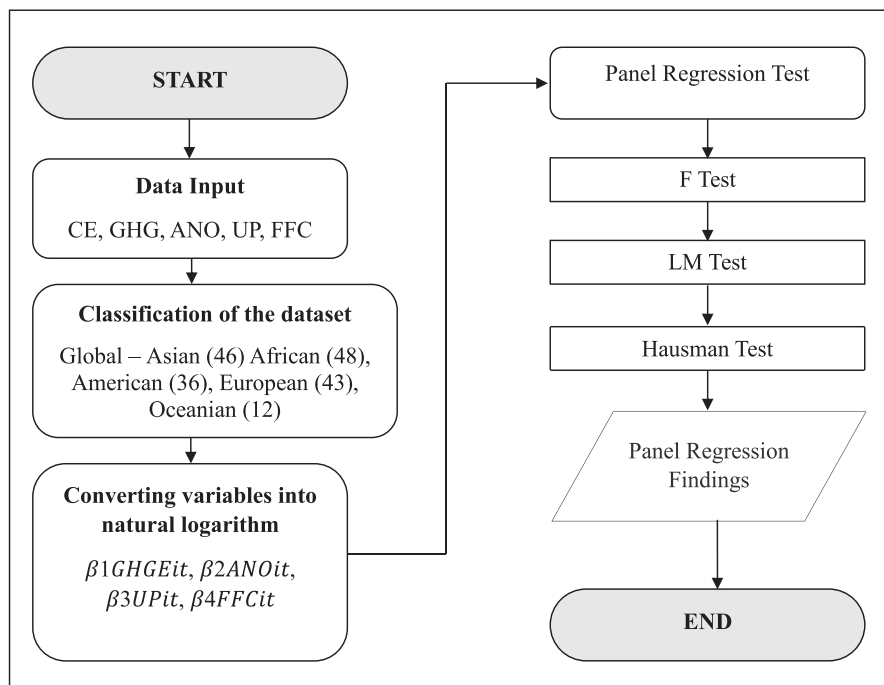


Fig. 1 Workflow of the statistical analysis

sion in all regions. Additionally, higher N_2O emissions from these fertilisers exacerbate carbon releases indirectly by altering natural carbon sinks such as soils and forests, which store CO_2 (Reay et al., 2012). Urban regions tend to have higher carbon emissions due to increased energy use, manufacturing activity, and transportation. As urban populations grow, demand for amenities increases, leading to higher carbon emissions. Urbanisation also tends to reduce green spaces, limiting CO_2 absorption (Hong et al., 2022). Fossil fuel use, particularly in power plants, automobiles, and industries, remains a major source of CO_2 emissions, particularly in manufacturing, transportation, and energy generation sector (Huang et al., 2023).

To address potential multicollinearity among these variables, we employed several strategies. First, variables were carefully selected based on their established relevance in climate change literature, ensuring each variable contributed uniquely to the analysis. While some correlation among variables was expected, each represents distinct dimensions of climate change drivers. Second, our analysis demonstrated that the fixed effects model was more suitable than the random effects model for our dataset. By employing the fixed effects model, we controlled for unobserved heterogeneity across countries and regions, effectively accounting for potential confounding effects of correlated variables. This method allows for isolating the impact of each variable on climate effects, enhancing the robustness of results.

Using the fixed effects model strategically mitigates multicollinearity in this study. By controlling for unobserved heterogeneity and focusing on changes within units over time, this approach strengthens the reliability of findings regarding the impact of GHG, ANO, UP, and FFC on climate effects. This method also allows for clearer interpretations of the relationships between variables, ultimately contributing to a more robust analysis of climate change dynamics. Therefore, it is evident that the selected independent variables have a direct impact on Carbon emission globally.

4 Results and discussion

An outline of the research findings is given in the following section, and then a commentary follows. The results of this study were calculated using the statistical software STATA. The descriptive statistics of the variables for the chosen period are shown in Appendix 2. Using the gathered data, descriptive statistics were analysed. To provide a graphical representation of the descriptive statistics, boxplots were used. To enhance clarity, the authors removed the upper and lower whiskers from the boxplots. Variable-wise boxplots, including whiskers, are shown in Appendix 3.

In Fig. 2, boxplots illustrate the contribution of independent variables both globally and by continent. This emphasizes how urgently all areas must work together to confront the problem of climate change.

Figure 2(A) shows regional variations in the global CO_2 emissions, with Asia and Oceania exhibiting greater variation than the centre. The Asia-Pacific region, with its populous economies, emits over half of the global CO_2 , largely due to China. Oceania, comprising nineteen nations, accounts for 97% of the regional total. Africa has the smallest deviation (Department of Energy, 2018).

Figure 2(B) depicts negative global and Asian GHG values due to forest coverage, which helps reduce GHG emission (TheGlobalEconomy.com, 2024). Carbon emission levels are

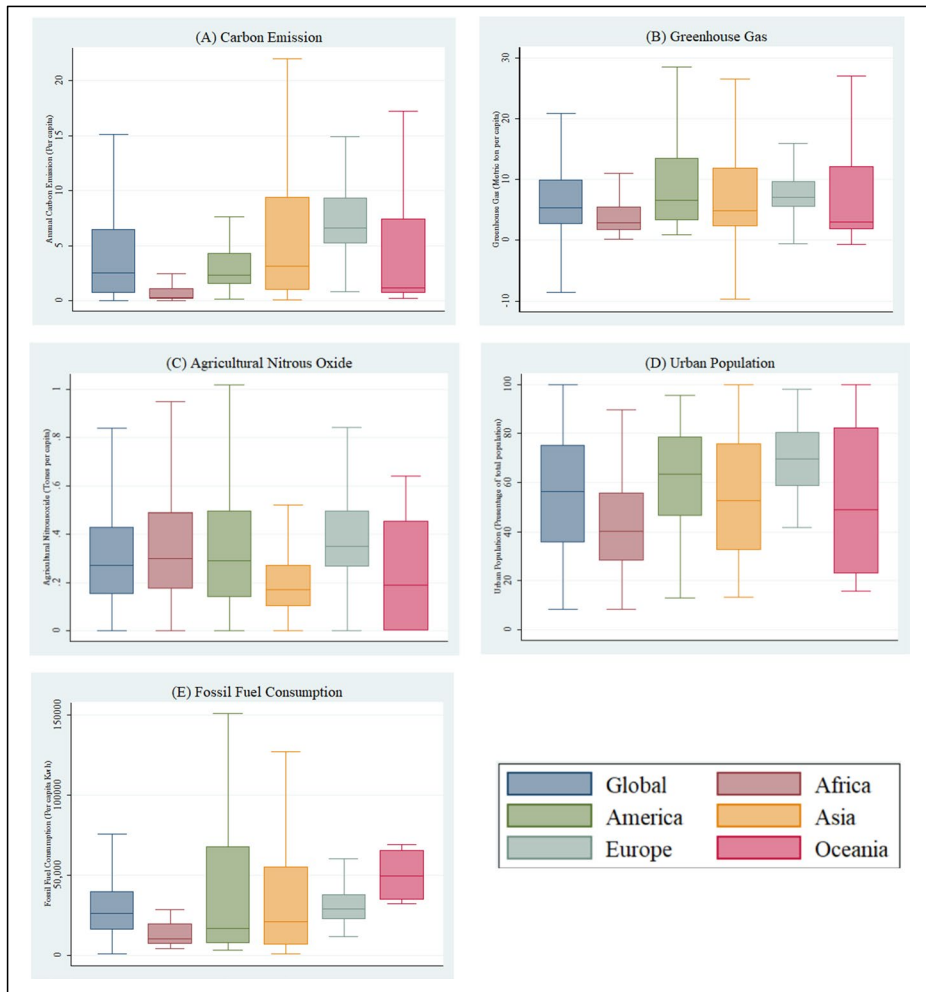


Fig. 2 Variable-wise descriptive statistics for each continent. Source: Authors' illustration based on Our World in Data (2023)

higher in Asia (Dharmapriya et al., 2024). Regional disparities in ANO emissions are evident, with Europe displaying the highest median value. Soil contributes more N_2O to the atmosphere, resulting in higher upper variance across continents.

Figure 2(C) further illustrates these regional disparities in ANO emissions, with Europe demonstrating the highest median value compared to other continents. The contribution of soil to N_2O emissions is a key factor, leading to greater upper variance at both the continental and global levels.

Moreover, Fig. 2(D) demonstrated the variation of UP in different regions and the global level. The large urban population in Europe is a result of historical circumstances, ongoing urbanisation trends, and economic growth. Over the past 200 years, Europe has experienced a significant increase in urbanisation, with industrialisation in the 19th and 20th centuries accelerating the transition from rural to urban living. By 2020, 72% of EU citizens resided in

cities, with urbanisation rates reaching as high as 80% in several nations, including the UK, the Netherlands, and Italy (Our World in Data, 2024). Due to a variety of factors, including geographic diversity, differing rates of urbanisation, and varying levels of development across the region, Oceania's urban population exhibits the greatest variance. Some Pacific Island nations, such as Papua New Guinea and the Solomon Islands, have sizable rural populations and are urbanising considerably more slowly than countries like Australia and New Zealand, which have highly urbanised populations and substantial infrastructure. The economic growth, migratory trends, and infrastructure disparities between larger, developed countries and smaller, less developed island states all influence Oceania's urbanisation rates (Neumann et al., 2015; United Nations, 2018b).

Finally, Fig. 2(E) reveals that at the global level, Europe and Oceania exhibit a normal distribution for FFC, while all other continents show a positive skew. As emphasised in the study, FFC presents a higher maximum value due to the heavy reliance of fossil fuels in Asia and America for energy and electricity production (REN21, 2021).

Figure 3. presents a comprehensive examination of the average trends in CE, GHG, ANO, UP and FFC across five continents: Africa, America, Asia, Europe, and Oceania. The authors examined the period from 2000 to 2019 to provide valuable insights into the regional dynamics of these variables.

In Fig. 3(A), Africa records the lowest consumption for Carbon emission. This is attributed to lower Carbon emission levels across the African region compared to other continents. According to predictions of The United Nations for UN Climate Change Conference Nairobi (2006), only two 2–3% of CO₂ emissions originates from energy and industrial sources in Africa. Similarly, Fig. 3(B) shows that the African continent has lower GHG emissions. In terms of GHG emissions, Africa is not a significant contributor. Researchers highlight that CO₂ can be quantified and used to predict its potential impact on climate change. Additionally, they emphasise the challenges of predicting climate variations over decades with any degree of reliability. However, the current study successfully presents the variation in CO₂ emissions over the past two decades using graphical outputs and advanced statistical models. By referring to this study, readers can clearly observe the variation in the dependent variable, CO₂ emissions, over time (Cracknell & Varotsos, 2021; Li et al., 2024; Qiu et al., 2024).

Moreover, Oceania significantly reduced GHG emissions between 2015 and 2016. According to Australian Government Clean Energy Regulator (2017), Australia saw emissions reductions from its top ten emitters, primarily from electricity generators. As the largest country in Oceania, Australia's contribution to GHG emissions directly influences the region's overall carbon emissions. As shown in Fig. 3(C), the Oceania region has the highest contribution to ANO among the continents. Australian agriculture releases more than eighty per cent (80%) of N₂O into the atmosphere (Sudmeyer et al., 2014), which significantly contributes to the region's emissions.

In Fig. 3(D) urban population growth is increasing globally, with Africa experiencing the highest growth rate. Numerous reasons, such as rapid population increase, large-scale rural-to-urban migration, and economic changes, are contributing to this rapid urbanisation. According to Statista, Africa's urban population is projected to more than triple by 2050, reaching 1.5 billion residents (Statista, 2024). Despite the challenges in promoting structural transformation and contributing to national economic progress, the continent's urban areas are expanding rapidly, highlighting the need for sustainable urban development policies.

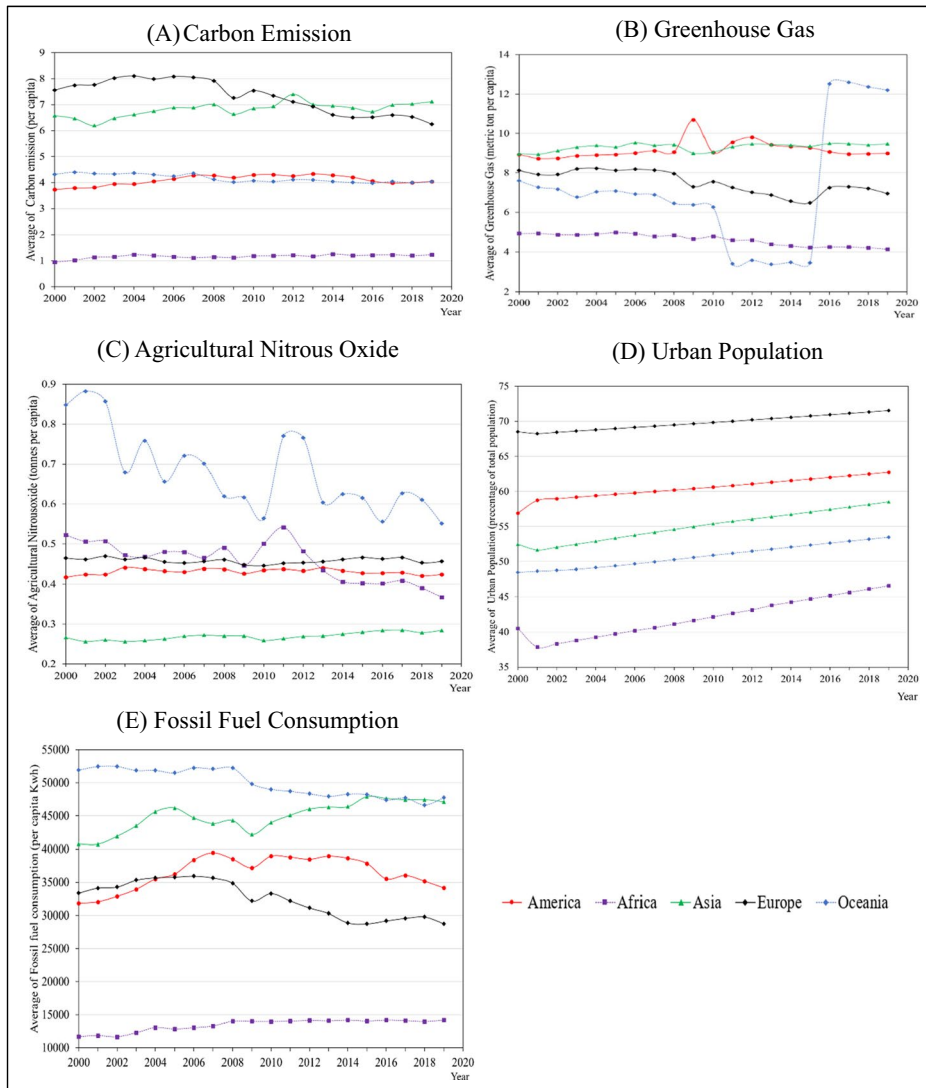


Fig. 3 Continent-wise averaged variables from 2000 to 2019. Source: Authors' illustration based on Our World in Data (2023)

Studies have emphasised the importance of understanding urban population to assess the impact of population growth on climate change (Blinova & Blinova, 2023; Urban et al., 2024; Yang et al., 2024). According to these studies, factors such as climate, hydrology, and soil composition are primary determinants of rising temperatures. In contrast, the current study explores population variation across continents by incorporating urban population as a variable, providing readers with insights into how population growth impacts climate change across regions. Figure 3(E) shows lower usage of FFC in Africa compared to other regions. This is due to the abundance of renewable energy sources such as hydro, solar, and wind throughout Africa (International Renewable Energy Agency, 2023). The figure also

indicates a decreasing trend in FFC consumption in Europe, America, and Oceania compared to previous levels. However, Asia has shown an increasing trend in FFC consumption compared to other regions, driven by rapid economic growth and industrialisation (Lee et al., 2024; Taghizadeh-Hesary & Rasoulnejad, 2020). Additionally, food delivery systems consume higher levels of fuel when transporting goods across long distances compared to local deliveries (Abbas et al., 2022; Bacon & Gliessman, 2024; Gülmez et al., 2024). This presents a new avenue for future research, particularly as many countries engage in cross-border and intercontinental food transportation. Governments should explore ways to reduce fuel consumption and mitigate FFC by utilising available domestic resources.

The data reveals a counterintuitive trend in Oceania, where GHG emissions are rising sharply, while FFC is gradually decreasing. This paradox can be attributed to several factors. Firstly, the region, particularly Australia, has experienced significant economic growth and industrial expansion, notably in mining and agriculture, which are major sources of emissions. Secondly, while there has been a shift towards renewable energy sources such as solar and wind, this transition has not yet fully offset emissions from other sectors. Additionally, Oceania is a major exporter of fossil fuels, meaning that while domestic consumption decreases, production and export processes continue to contribute significantly to GHG emissions. Furthermore, environmental policies may have successfully reduced fossil fuel consumption but have not had a substantial impact on overall emissions. Lastly, population growth in the region leads to higher energy demand and increased emissions from transportation and other activities. These factors collectively explain the seemingly contradictory trends observed in the data.

As shown in Figs. 2 and 3, results of this study emphasise that the findings are not specific to individual countries but reflect broader continental trends. This is a key contribution, as it highlights the importance of considering the entire continents when assessing the impacts of climate change. Understanding the collective situation across countries within a continent allows for a more accurate measurement of regional effects and provides a holistic perspective on the challenges and responses needed at the continental level. The outcome of this study clearly explains the results are not for one country but for the entire continent. It is crucial to have an overall understanding of the entire continent to measure what kind of impact is there across the continent while understanding the situation in each country.

Table 2 displays the outcomes of the equation's panel data model specification tests. The findings of the probability F test and the Breusch-Pagan test for all countries and continents rejected the null hypothesis. This led to the rejection of the POLS approach, which is unsuitable for the current analysis. The LM test results also showed that the value for the African and Oceanian continents was defined as 0.00, which is insignificant to reject the null hypothesis. Therefore, the Hausman test was conducted to select between the RE and FE models. The findings of the Hausman test for all nations, as well as for the continents of Asia, Africa, Oceania, and America, rejected the null hypothesis, showing that the FE model's estimation results are more effective than the RE model's. Thus, it is suggested to use the FE model for all countries, as well as for the Asian, African, Oceanian, and American continents, while for Europe the null hypothesis is neither accepted nor rejected.

As illustrated in Table 3, the effects of GHG, ANO, UP, and FFC on a global and continental level are presented, using a statistical summary that includes coefficients, standard errors, and significance levels. The R^2 values show that over 40% of the variation in Carbon emission can be explained for all countries, as well as for the European and American

Table 2 Specification Test for Panel Data Models

	Region	F test	LM test	Hausman test
		H ₀ : POLS	H ₀ : POLS	H ₀ : Random effect
		H ₁ : Fixed effect	H ₁ : Random effect	H ₁ : Fixed effect
The symbols *, ** and *** represent 10%, 5% and 1% significance levels, respectively. Σ represents the model fitted to these data that fails to meet the asymmetry assumptions of the Hausman test	All countries	60.43*	7678.89***	3.77**
	Asia	20.69*	865.65***	4.33**
	Africa	18.20**	0.00	63.98***
	America	116.15*	1411.96***	0.18*
	Europe	140.48*	4336.87***	Σ
	Oceania	7.95*	0.00	7.98*

regions, while over 20% of the variation in Carbon emission can be explained for the Asian, African, and Oceanian continents. However, the FFC had scientific errors due to the higher number of decimals. Thus, the authors adjusted the unit of measurement to 1,000 kg instead of using metric tonnes (1,000 kg = 1 metric tonne).

The research found that only the Oceanian region is positively significant for the RE model in GHG emission, while it is negatively significant for the FE model. However, a study by Alaganthiran and Anaba (2022) found significant associations between energy consumption and population growth with CO₂ emissions using the robust FE model. In Oceania, Australia has become the highest emitter of GHG. The primary sources of Australia's emissions are energy generation followed by transportation, agriculture, and industrial processes (Commonwealth Scientific and Industrial Research Organisation, 2023). According to Hanna (2023), the Australian government has implemented several measures to reduce emissions across all industries. They established the Emission Reduction Fund (ERF) as a current policy to reduce GHG emissions. The objectives of these laws are to stimulate the use of renewable energy sources, reduce emissions, and improve energy efficiency. These regulations are anticipated to help lower global GHG emissions because Australia is the largest nation in Oceania.

Asia and Oceania have negative significance levels for ANO, while Africa, Europe, and America show positive levels due to their agriculture-dependent economies. Human land use change and agricultural management techniques contribute to over ninety per cent (90%) of soil N₂O emissions (Lu et al., 2022). However, the negative significance of ANO in Asian and Oceanian regions, as well as the underestimation of agricultural N₂O emissions requires further analysis (Xu et al., 2021).

Henderson et al. (2017) discovered that, in some cases, there is a considerable correlation between climatic factors and urbanisation. Similarly, all countries, as well as the Asian and American regions, show positive significance levels for urban population, while Africa, Europe, and Oceania are negatively significant. According to predictions by the United Nations (2013), Asia continues to show urban population growth, as it is home to thirteen of the world's twenty-two megacities. On the other hand, the population of urban and suburban areas in the US has increased since 2000 by at least as much as in the previous decade, according to the Pew Research Centre's analysis of census data (Parker et al., 2018). Due to these factors, urban population growth is at a high level in the Asian and American regions. However, as many African countries suffer from poverty and struggling economies,

Table 3 Fixed effect and random effect estimates

Variables	All countries			Asia			Africa			America			Europe			Oceania		
	CE	FE	RE	CE	FE	RE	CE	FE	RE	CE	FE	RE	CE	FE	RE	CE	FE	RE
GHG	0.396 (-0.164)	0.404 (-0.16)		0.746 (-0.126)	0.766 (-0.112)	0.766 (-0.112)	0.298 (-0.072)	0.298 (-0.072)	0.312 (-0.152)	0.109 (-0.04)	0.109 (-0.038)	0.109 (-0.038)	0.316 (-0.0259)	0.316 (-0.0259)	0.034 (-0.027)	-0.009* (-0.075)	0.056* (-0.032)	
ANO	-0.525** (-0.504)	-0.479*** (-0.484)		-3.515*** (-4.646)	-2.252* (-4.374)	-2.252* (-4.374)	0.876* (-1.379)	0.876* (-1.379)	8.128 (-1.511)	0.969* (-1.49)	0.969* (-1.49)	0.808* (-1.097)	0.275* (-0.619)	0.275* (-0.619)	0.295*** (-0.453)	-0.033* (-0.14)	-0.129* (-0.041)	
UP	0.003* (-0.009)	0.003* (-0.008)		0.040** (-0.027)	0.028** (-0.017)	0.028** (-0.017)	-0.005* (-0.017)	-0.005* (-0.017)	0.010*** (-0.009)	0.000* (-0.004)	0.000* (-0.004)	0.000* (-0.004)	-0.020*** (-0.015)	-0.020*** (-0.015)	-0.025 (-0.01)	-0.550** (-0.348)	-0.120* (-0.345)	
FFC	0.0906 (-0.0451)	0.0947 (-0.0416)		-0.00067** (-0.03)	0.00073* (0.0259)	0.00073* (0.0259)	0.2089 (0.038)	0.2089 (0.038)	0.1884 (0.0637)	0.1776 (0.011)	0.1776 (0.011)	0.1875 (0.011)	0.2315 (0.0152)	0.2315 (0.0152)	0.2283 (0.0144)	0.2247 (0.0263)	0.2979 (0.0007)	
Constant	1.144* (-0.942)	0.864*** (-0.589)		-0.826** (-1.91)	-1.166* (-1.037)	-1.166* (-1.037)	-0.386* (-1.004)	-0.386* (-1.004)	-2.492 (-0.301)	-0.103* (-1.013)	-0.103* (-1.013)	-0.052* (-0.636)	1.528** (-1.283)	1.528** (-1.283)	1.956 (-0.795)	49.340** (-32.296)	7.806* (-30.363)	
N	1500	1500		480	480	480	80	80	80	220	220	220	680	680	680	40	40	
No of countries	185	185		46	46	46	48	48	48	36	36	36	43	43	43	12	12	
No of years	20	20		20	20	20	20	20	20	20	20	20	20	20	20	20	20	
R ² within	0.57	0.57		0.615	0.612	0.612	0.858	0.858	0.78	0.935	0.935	0.935	0.887	0.887	0.887	0.828	0.809	
R ² between	0.929	0.929		0.969	0.974	0.974	0.982	0.982	1	0.986	0.986	0.987	0.892	0.892	0.892	1	1	
R ² overall	0.912	0.912		0.952	0.957	0.957	0.979	0.979	0.994	0.985	0.985	0.985	0.89	0.89	0.891	0.993	0.995	

The symbols *, **, and *** represent 10%, 5% and 1% significance levels respectively

CE– Carbon Emission, GHG– Greenhouse Gas, ANO, UP– Urban Population, FFC– Fossil Fuel Consumption

their urban population growth remains low, as they fail to provide adequate benefits in urban areas.

Furthermore, Africa has poorer megacities compared to other regions. According to predictions Europe and Oceania show lower population growth than other continents (United Nations, 2019). As a result, there is a decline in urban population, as a lower population allows these continents to provide better services to rural areas, thereby controlling rural-urban migration.

For FFC, only the Asian region is significantly positive for the RE model, while it shows negative significance for the FE model. As many Asian countries aim to reduce Carbon emission, they are focusing on renewable energy rather than FFC. Consequently, the FE model indicates a negative significance level. In addition, Glaeser and Kahn (2010) discovered a robust inverse relationship between land use restrictions and Carbon emission. Furthermore, the increasing severity of climate change is heightening the risk of extreme weather events and rising sea levels (Zulinski, 2018). Addressing emissions from various sources, such as reforestation, new construction, ANO emissions, and the impact of urbanisation on local climates, is necessary for effective climate change mitigation. It is essential to continue reducing fossil fuel emissions while ensuring sustainable farming and urban planning are implemented.

According to the findings of this study, the use of panel regression analysis provides a comprehensive view of both global trends and regional variations across continents. This approach sets the current study apart from existing research, as it offers a detailed analysis of data from the past two decades. By examining these trends, the study equips governments and policymakers with critical insights into the specific challenges faced by each continent, thereby enhancing their understanding and informing more effective, region-specific climate policies moving forward.

5 Policy implications

Different regional patterns in the drivers of carbon emissions are revealed by the results of the descriptive statistics and panel regression analysis. In order to effectively reduce emissions and promote sustainable development, these insights highlight the necessity of evidence-based, region-specific policy solutions. These empirical findings are used to provide the following policy implications to direct focused climate action at the regional and global levels.

5.1 Specific policy recommendations based on descriptive statistics

The study's descriptive statistical results show notable geographical variations and trends in carbon emissions and the variables that contribute to them. This research shows distinct environmental advantages and drawbacks around the world, with carbon emissions as the dependent variable and greenhouse gas emissions, agricultural nitrous oxide, urban population, and fossil fuel usage as the main independent variables. For example, Europe has high amounts of agricultural nitrous oxide, Asia has high CO₂ emissions and a dependency on fossil fuels, and forest cover lowers greenhouse gas emissions in both Asia and the world.

The following policy suggestions are put forth in accordance with these findings with the aim to direct efficient climate action that is adapted to regional and global dynamics.

The adverse impacts of greenhouse gases, particularly in regions with dense forests, indicate that forests are essential for absorbing carbon. This carbon sink effect can be further enhanced by preventing deforestation and boosting global reforestation. One of the strongest greenhouse gases is agricultural nitrous oxide. While preserving food production, emissions can be greatly decreased by encouraging composting, organic farming practices, and the efficient use of fertilisers worldwide. The usage of fossil fuels is still widespread, particularly in America and Asia. Cooperation among nations to provide access to renewable infrastructure and technology will lessen reliance on carbon and produce cleaner energy systems. Growth in the urban population increases emissions from housing, transportation, and energy use, especially in the European region. To reduce carbon footprints, international policy should support sustainable urban development, such as mass transit and green buildings. Also, the European region can move forward with the circular economic principles in city planning to reduce the carbon footprint.

5.2 Specific policy recommendations based on the findings of panel regression analysis

The findings of the panel regression offer a more thorough comprehension of how regional dynamics impact carbon emissions through considered variables. Africa, Europe, and America show a positive significance between ANO and carbon emissions, showing that agriculture is a major source of carbon emissions, but Asia and Oceania show a negative significance, suggesting potential mitigation strategies or improved land-use efficiency. Also, urbanisation has a favourable impact on emissions across the world, especially in Asia and America, while it has a negative impact in Africa, Europe, and Oceania. In order to match emission drivers with sustainable development strategies, these findings highlight the necessity of regionally specific policy actions.

Given that ANO has a negative significance with carbon emissions in Asia and Oceania and it suggests that agricultural methods are comparatively effective in lowering emissions. Precision farming, low nitrogen cropping systems, and organic farming are examples of sustainable farming techniques that these regions ought to expand and disseminate to other regions. A positive significance with emissions in Africa, Europe and America indicates that carbon intensity is influenced by the excessive use or inefficiency of nitrogen-based fertilisers. Governments ought to provide training for climate-smart farming methods, encourage crop rotation and biofertilisers, and enforce fertiliser application limitations. Urban expansion is energy-intensive and probably dependent on fossil fuels, as indicated by the beneficial effect of population density on emissions. Public transport and non-motorized transportation should be encouraged by governments. Invest in waste-to-energy initiatives and green building regulations. Decentralise urban design to prevent high-density emission clusters. The negative significance implies that more condensed and effective urban structures might be advantageous for certain areas. Policies should keep rewarding homes that use less energy. To lessen the demand for travel, strengthen mixed-use urban zoning. To absorb CO₂, promote urban agriculture and green spaces.

In conclusion, the study emphasises how crucial it is to adjust climate policies to local conditions because the variables affecting carbon emissions differ greatly between conti-

nents. Countries can implement more efficient, data-driven strategies to lower their carbon footprint and further global climate goals by coordinating policy actions with the particular emission patterns identified in the study. Promoting sustainable development and attaining long-term environmental resilience will need the implementation of these focused measures.

6 Conclusion

By examining the combined effects of GHG, ANO, UP, and FFC on carbon emissions globally and across various locations, researchers sought to comprehend how global warming affects climate change. Limited studies have explored the impact of CE, GHG, ANO, UP and FFC both globally and continentally, and none have used these variables simultaneously. Our study reveals that each variable has a distinct positive or negative impact on Carbon emission.

Additionally, current research indicates that the FE model is more appropriate than the RE model, as many variables show a positive impact in the FE model. Previous studies, blogs and available data have not adequately presented the significance of CE, GHG, ANO, UP and FFC within statistical models simultaneously. This research helps to fill the gap regarding the impact of global warming on climate change across all continents and globally.

The results of this study show that, at the global level, GHG, UP, and FFC have a significant positive relationship with Carbon emission, while ANO has a negative relationship. In Asia, GHG and urban population have a positive relationship with Carbon emission. Furthermore, the Asian region is negatively associated with FFC, whereas, at the global level and across all other continents, FFC is positively significant. All the variables show a positive significance towards the Carbon emission in the African and American continents. In Europe, GHG, ANO and FFC have a positive relationship with Carbon emission, while urban population shows a negative significance. In Oceania, only FFC has a positive relationship with Carbon emission.

GHG negatively impacts Oceania, whereas all other continents show a positive impact. Africa, America, and Europe exhibit a positive relationship between Carbon emission and ANO, while other different continents, including the global level, show a negative impact. Carbon emission has a positive relationship with the urban population worldwide, but in Asia, America and other continents, the, relationship is negative. Moreover, the study's findings conclude that carbon emissions positively impact all continents, including the global level, although some variables show negative impacts in certain regions.

This study has limitations, such as missing data for three countries, which were excluded from the analysis. Data for the years 2020 to 2022 were not considered as they were not accessible during the study period, and only the available data in the databases were retrieved. The study employed GHG, ANO, UP, and FFC as independent variables due to the lack of accessible, trustworthy data sources. Therefore, other relevant variables that might impact climate change could not be considered. Future research can incorporate important variables such as rising in sea levels, ocean acidification, deforestation, and wildfires, which directly influence climate change. Hence, future studies can improve upon this research by addressing these limitations. Additionally, the selected variables cannot be considered proxy variables. Future research may also explore different units of measurement to further enhance the quality of research output.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10668-025-06558-w>.

Data availability All data generated or analysed during this study are included in this published article and its supplementary information files.

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Authors and Affiliations

Nimesha Dharmapriya¹  · Sandali Edirisinghe¹  · Vilan Gunawardena¹  ·
Dithma Methmini¹  · Nilmini Rathnayake²  · Ruwan Jayathilaka³ 

✉ Ruwan Jayathilaka
ruwan.j@slit.lk; ruwanips@gmail.com

Nimesha Dharmapriya
nimeshamadushani156@gmail.com

Sandali Edirisinghe
sandaliedirisinghe0005@gmail.com

Vilan Gunawardena
vilangeesilu@outlook.com

Dithma Methmini
dithma.vidyarupa@gmail.com

Nilmini Rathnayake
nilmini.r@slit.lk; rathnayaken94@gmail.com

- ¹ SLIIT Business School, Sri Lanka Institute of Information Technology, New Kandy Road, Malabe,, Sri Lanka
- ² Department of Business Management, SLIIT Business School, Sri Lanka Institute of Information Technology, New Kandy Road, Malabe, Sri Lanka
- ³ Department of Information Management, SLIIT Business School, Sri Lanka Institute of Information Technology, New Kandy Road, Malabe, Sri Lanka