
Does population growth affect carbon emissions? Selected West African studies, 1980–2022

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Abstract: Some theories, like Malthus's, predict that population growth will outpace resources, while others disagree. This study investigated the impact of population growth on carbon emissions in Nigeria, Ghana, Senegal, and Niger from 1980 to 2022. The research, using secondary data from the World Bank Group and tested at a 0.05 confidence level, found that a 1% rise in population results in a 1.75% (or 174.966 units) increases in carbon emissions. A key finding was that while population growth positively impacts carbon emissions, it was insignificant to proxies of wealth creation, such as per capita GDP. Additionally, poverty and inequality were found to have a positive and significant relationship with emissions. The study recommends that West African governments implement measures to reduce fossil fuel use, such as carbon taxes on firms, and adopt deliberate population control strategies to mitigate climate change.

Keywords: carbon emission; greenhouse gas; population growth; West Africa.

JEL codes: Q54, Q56, Q57, R22.

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1 Introduction

The common notion that a growing human population inherently equates to detrimental increases in atmospheric carbon dioxide (CO₂) often overshadows the more significant drivers of environmental degradation. While it is true that human respiration releases CO₂, framing population growth as the primary culprit overlooks the overwhelming impact of high mass consumption, industrial activities, and reliance on damaging energy sources (Dietz and Rosa, 1997). The critical disruption to the delicate balance of the atmospheric environment is not merely the act of breathing by an increasing population, but rather the increased energy consumption and unsustainable practices associated with certain modes of development and consumption patterns (York et al., 2003). The large buildup of human-generated greenhouse gases, which undeniably threatens ecosystems and global climate patterns, is overwhelmingly attributed to the burning of fossil fuels for energy, industrial emissions, deforestation driven by agricultural expansion and resource extraction, and the production and consumption of goods with high embodied energy (IPCC, 2014). Therefore, while population size plays a role, the per capita environmental impact, heavily influenced by consumption patterns and technological choices, is a far more significant determinant of greenhouse gas emissions and overall environmental damage. Addressing the urgent need to reduce atmospheric CO₂ to the suggested 350 ppm necessitates a focus on transforming energy systems, promoting sustainable industrial practices, and encouraging less resource-intensive consumption patterns, rather than solely focusing on population numbers. Arguably, population growth leads to increased human activity, which can significantly influence climate change. Studies in West Africa reveal a rise in total regional greenhouse gas emissions (USAID, 2019). This research also found that using energy-efficient facilities can reduce greenhouse gas emissions, while the carbon footprint per child has increased 20-fold. Consequently, the study advocates for population reduction mechanisms (United Nations, 2013).

Sulaiman and Abdul-Rahim (2018) further support this link, arguing that population growth increases greenhouse gas emissions, particularly CO₂, through activities such as deforestation, cattle grazing, bush burning, industrialisation, and transportation. However, this study seeks to empirically examine the direct effect of population growth on carbon emissions in specific West African countries (Nigeria, Ghana, Senegal and Niger).

Despite some family planning initiatives and public education on family development practices in the modern world, population growth in West Africa continues to rise. This aligns with Thomas Malthus's (1798) predictions and has resulted in increased carbon emissions (Sulaiman and Abdul-Rahim, 2018).

This paper aims to validate this theory within the West African context by examining the impact of population changes on carbon emissions. The research will be of great value to policymakers, informing them about the key factors affecting CO₂ emissions in the region. It will also provide policy recommendations for potential measures to curb population growth in the West African sub-region.

1.1 Main objective and specific objectives

The main objective of this study is to determine whether population changes affect carbon dioxide (CO₂) emissions in West Africa. The specific objectives are:

- to determine if population growth affects carbon emissions in the short run, using selected West African countries as samples: Nigeria, Ghana, Senegal and Niger
- to examine whether population growth affects carbon emissions in the long run, using the same sample countries.

1.2 Hypotheses

The study will test two corresponding hypotheses:

H₀₁ There is no significant effect of population growth on carbon emission in the short run in the selected sample countries.

H₀₂ There is no significant effect of population growth on carbon emission in the long run in the selected sample countries.

The structure of the study shall comprise of:

- 1 introduction
- 2 literature review
- 3 materials and methods
- 4 data and analysis
- 5 conclusions.

2 Review of related literature

This section provides a conceptual, theoretical and empirical review relevant to understanding the relationship between population growth and carbon emissions, particularly within the context of West Africa.

2.1 Conceptual review

2.1.1 Carbon emission and their contexts

2.1.1.1 Carbon and greenhouse gas emissions

Carbon, the fundamental building block of life on Earth, is also a key component of greenhouse gases emitted through various natural and human activities. Carbon emission refers to the release of carbon dioxide (CO₂) into the atmosphere. Naturally, CO₂ exchange occurs between oceans and the atmosphere. However, human activities, including mineral extraction, refining, transportation, and the combustion of fossil fuels (coal, natural gas and oil), significantly elevate carbon and other gas concentrations in the air. Deforestation and the burning or decomposition of natural vegetation further contribute to CO₂ emissions, as these processes release stored carbon.

Hannah and Max (2019) define greenhouse gases (including CO₂, methane, and water vapor) as atmospheric gases capable of trapping heat energy and radiating it back towards the Earth's surface, thus contributing to the greenhouse effect. Carbon dioxide (CO₂) is a primary greenhouse gas that absorbs heat-inducing radiation in the atmosphere. Elevated

levels of atmospheric heat disrupt climate patterns, deplete the ozone layer, and contribute to global warming and climate change (Hannah and Max, 2019). Climate change, driven by the increased emission of gases like CO₂, nitrous oxide, and methane, poses a significant challenge to both developed and developing nations, having already raised global average temperatures by over 1°C since pre-industrial times (Hannah and Max, 2019).

The Fifth Intergovernmental Panel on Climate Change (IPCC) (2015) highlighted critical points: global average temperatures have increased by more than 1°C since the pre-industrial era; CO₂ concentrations have surpassed 400 parts per million (ppm), the highest level in over 800,000 years; and globally, over 36 billion tons of CO₂ are emitted annually, with per capita emissions varying significantly across countries, and China being the largest global emitter (Hannah and Max, 2019).

Addressing this challenge requires a multifaceted approach aimed at reducing carbon footprints. Klasen and Lawson (2007) define population growth as the increase in population per 1,000 people, calculated as the birth rate minus the death rate minus net emigration. Strategies to mitigate carbon emissions include population control, reducing energy consumption rates, and reforestation efforts. Ohlan's (2015) research indicated a positive and significant long-run and short-run impact of changes in population, GDP, and energy consumption on carbon emissions.

2.1.1.2 Carbon emission vs. poverty vs. inequality

The interplay between carbon emissions, poverty, and inequality is complex and multifaceted:

- 1 Energy consumption:
 - a Energy ladder hypothesis: as individuals and societies escape poverty, they often adopt more energy-intensive lifestyles, leading to increased carbon emissions. This is particularly relevant in developing countries transitioning from traditional fuels to modern energy sources.
 - b Energy access: poverty can restrict access to cleaner, modern energy, forcing reliance on traditional and often more polluting energy sources.
- 2 Economic development:
 - a Kuznets curve hypothesis: this hypothesis suggests that environmental degradation, including carbon emissions, initially increases with economic growth but may decline at higher income levels as countries adopt cleaner technologies and prioritise environmental quality. However, the applicability of this curve may vary, especially in highly unequal societies.
- 3 Environmental degradation: poverty can drive environmental degradation, such as deforestation and land degradation, which in turn can release stored carbon and reduce carbon sequestration capacity.
- 4 Consumption patterns:
 - a Inequality in consumption: disparities in wealth often translate to unequal consumption patterns, with wealthier individuals having significantly larger carbon footprints due to higher consumption of goods, services, transportation, and larger housing.

- b Inequality in access to clean technologies: affluent populations often have greater access to and can afford cleaner technologies and energy-efficient products, while poorer populations may be limited to more polluting alternatives.
- 5 Political economy:
 - a Inequality and policy: highly unequal societies may exhibit weaker environmental policies and governance due to the influence of powerful elites who may prioritise economic growth over environmental protection.
 - b Distributional impacts of climate change: the adverse effects of climate change disproportionately impact the poor, potentially exacerbating poverty and inequality, creating a feedback loop that can further contribute to emissions.
- 6 Social justice:
 - a Environmental justice: the relationship between inequality and emissions is often viewed through the lens of environmental justice, highlighting how marginalised communities often bear a disproportionate burden of pollution and environmental degradation.
- 7 Industrial emissions and population growth: while direct human respiration contributes minimally to overall CO₂ emissions, population growth indirectly impacts industrial carbon footprints, particularly in sectors like cement and refining. Increased populations drive demand for infrastructure, housing, transportation, and industrial activity, leading to greater production in these energy-intensive industries.

2.1.1.3 Carbon emissions and energy industries

The energy sector, is known to emitted large proportion of carbon through various mediums, such medium includes:

1 Link to the cement industry and carbon emissions:

Population growth fuels urbanisation and the expansion of infrastructure (Schneider, 2019), driving demand for cement, a crucial component of concrete (IEA, 2024). The cement industry is a significant contributor to global anthropogenic CO₂ emissions, accounting for approximately 7% (Fennell et al., 2022). Cement production is carbon-intensive, with roughly 40% of emissions from burning fossil fuels for heating and 60% from the chemical process of calcination (IEA, 2024). Studies like Shi (2001) indicate population growth as a major driver of global CO₂ increases, and projected cement demand in developing countries with growing populations suggests a potential for substantial emission increases (Sussex, 2023).

2 Link to the refinery industry and carbon emissions:

Population growth also increases the demand for energy, particularly for transportation and industrial processes reliant on refined petroleum products (IEA, 2025). A larger population typically leads to more vehicles, increased travel, and higher demand for transported goods, all requiring refined fuels. The refining process is energy-intensive, releasing greenhouse gases (Environmental and Energy Study Institute, 2018). Research often links population growth to increased energy demand and CO₂ emissions (Shi, 2001; York et al., 2003; Dangote Cement PLC, 2024).

While specific studies isolating population-driven refinery emissions may be less common, the connection between population growth, increased activity, higher fuel demand, and greater refining emissions is evident in energy-environment literature (IEA, 2025; Rehman et al., 2023).

2.1.2 Case studies in West Africa

The following sections provide an overview of population trends and carbon emissions in selected West African countries between 1980 and 2022.

2.1.2.1 Nigeria population increase and emissions of carbons

Nigeria, Africa's most populous black country, experienced significant population growth from approximately 45.1 million in 1960 to over 218 million in 2022 (Worldometers, 2023; United Nations Data, 2019, 2023). Per capita CO₂ emissions in Nigeria also increased from 0.075 metric tons in 1960 to 128,760 Kt in 2022 (World Bank, 2019; Worldometers, 2023). While Nigeria and Southern Africa are major emitters on the continent, higher industrial activity in South Africa has historically contributed to a larger share of emissions compared to Nigeria (World Development Indicator Database, 2012).

2.1.2.2 Ghana population increase and emissions of carbons

Ghana's population grew from 6.6 million in 1960 to over 33.4 million in 2022 (Worldometers, 2023; UN Data, 2019). Carbon emissions per capita rose from 0.22 metric tons in 1960 to 0.6 tons per person in 2022 (Worldometers, 2023). Increased population and energy consumption are cited as drivers of this rise.

2.1.2.3 Senegal's population increase and emissions of carbon

Senegal's population increased from an estimated 16.3 million in mid-2019 to over 17.3 million in 2022 (Worldometers, 2023; UN Data, 2019). Carbon emissions also saw an increase, reaching 13.60 metric tons in 2022, with per capita emissions around 0.55 tons in 2016 (Worldometers, 2023).

2.1.2.4 Niger republic population increase and emissions of carbon

Niger's population grew from 23.7 million in late 2019 to over 26.2 million in 2022 (Worldometers, 2023). Per capita carbon emissions in Niger, while relatively low compared to the other case studies, increased from 0.009 metric tons in 1960 to 0.148 metric tons in 1983, followed by some fluctuations, reaching 2,698,898 metric tons in 2022 (Worldometers, 2023).

2.1.3 Population control strategies

Population control has been a long-standing global issue, with a significant focus on empowering women through education and economic opportunities. This approach is recognised for its dual benefits of influencing demographic trends and fostering broader societal development (United Nations Population Fund, 2023).

2.1.3.1 The role of women's education

Education is a potent tool for women's empowerment and influencing demographic trends. Educated women tend to have fewer children, marry later, and make more informed decisions about family planning. Research consistently demonstrates a strong inverse correlation between female education levels and fertility rates (United Nations Population Fund, 2023; World Bank, 2022). Investing in girls' education can therefore significantly impact population growth.

2.1.3.2 Women's empowerment and economic opportunities

Economic empowerment of women is also linked to lower fertility rates. Access to employment opportunities often leads women to delay marriage, have fewer children, and invest more in their children's well-being. Economic empowerment enhances women's decision-making power within households regarding family size and reproductive health (United Nations Development Programme, UNDP, 2021).

2.1.3.3 Mechanisms through which women's empowerment and education reduce population growth

- 1 Delayed marriage and childbearing: education provides women with opportunities beyond traditional roles, often leading to delayed marriage and the onset of childbearing (Amin et al., 1995; Cleland et al., 1996). The increased opportunity cost of early marriage and childbearing for educated women pursuing careers also contributes to this delay (Becker, 1991).
- 2 Increased use of family planning: educated women generally have greater awareness and access to information about family planning methods and reproductive health services (Ainsworth et al., 1996; Bongaarts, 2010). Empowerment enhances women's autonomy in household decisions, including family size and contraceptive use (Doss, 2014; Sraboni et al., 2014).
- 3 Lower desired family size: education can shift women's perceptions of ideal family size, with increased awareness of child-rearing costs and the benefits of smaller families often leading to a preference for fewer children (Caldwell, 1982). Empowered women may also have greater control over their reproductive lives, reducing susceptibility to social pressures for large families (Upadhyay and Karasek, 2012).
- 4 Improved child survival rates: education equips women with better knowledge of health, nutrition, and childcare, leading to improved child survival rates (Cleland, 1990). Increased confidence in child survival can reduce the perceived need for larger families as insurance against mortality.
- 5 Increased economic opportunities: education enhances women's economic participation and earning potential (World Bank, 2000). Financial independence can diminish the economic rationale for large families (e.g., for labour or old-age security), and empowered women may prioritise investing more resources in fewer children.

2.1.3.4 Access to reproductive health services

Access to quality reproductive health services, including contraception and family planning, is vital for empowering women and managing population growth. When women have access to a range of contraceptive options, they can make informed choices about their reproductive health and family size (UNFPA, 2023). Investing in comprehensive sexual and reproductive health services is crucial for empowering women and contributing to population stabilisation.

Overall, empowering women through education, economic opportunities, and access to reproductive health services represents a comprehensive strategy for addressing population challenges, promoting sustainable development, and enhancing the quality of life globally.

2.1.4 Importance of green finance and FDI in reducing carbon emissions

The transition to a low-carbon economy presents significant implications for governments and financial industries globally (IFC Report, 2023), making green finance a critical area of focus. Heim and Zenklusen (2005) broadly define green finance as financial flows directed towards sustainable development projects, environmental goods, and solutions that foster a more sustainable economy. This includes increased financing from public, private, and non-profit sectors to support environmental priorities. ‘Green-tech FDI’ refers to international investments specifically targeting the development of environmental technologies (Mahamene et al., 2024). The terms green finance, climate finance, and sustainable finance are often used interchangeably.

Green finance supports environmentally friendly programs and organisations through instruments like green bonds, renewable energy financing, green banks, and green credit cards. Financial instruments in green finance include corporate bonds, green securitisation, green sovereign bonds, green project bonds, and green loans, while equity instruments encompass public-private partnerships, private equity, joint ventures, and investment trusts. Foreign direct investment (FDI) also plays a crucial role in financing green initiatives.

The IMF and OECD define FDI as a resident entity obtaining a lasting interest in an enterprise resident in another economy. The World Bank defines it as net investment inflows to acquire a lasting management interest (typically at least 10% of voting stock). In the context of carbon emissions, FDI can involve foreign companies investing in environmentally sustainable projects in host countries, such as renewable energy, clean technology, and sustainable infrastructure. Dicken’s (1992) analysis highlighted the positive relationship between FDI and GDP growth in China. Temitope’s (2024) study in Nigeria using a nonlinear autoregressive distributed lag (NARDL) model showed a nonlinear relationship between FDI and green growth, supporting the Porter’s hypothesis that environmental regulations can spur innovation and economic benefits.

Green finance and FDI are crucial for reducing carbon emissions by lowering risk perceptions for green projects and fostering job creation and business opportunities. Addressing the coordination challenges between financial and environmental objectives is essential. Research has consistently highlighted the positive impact of green FDI on environmental quality (Mahamene et al., 2024), the sensitivity of investors to environmental compliance (Heim and Zenklusen, 2005), and the need for standardised environmental accounting and reporting (Wagner and Schaltegger, 2006). Studies have

also explored the linkage between green finance and renewable energy development (Ranila et al., 2024), the potential of green finance as a long-term investment for economic growth (Madhu and Amadi, 2024), and the importance of green economic opportunities in global value chains (Nathapompan, 2023). Interestingly, Devlina and Santosh's (2022) study found a negative relationship between corruption and per-capita carbon emissions in most income groups, suggesting that lower corruption may be associated with higher emissions in some contexts.

2.2 *Theoretical review*

This study is theoretically grounded in the Malthusian theory of population growth, developed by Thomas Robert Malthus (1766–1834). Sulaiman and Abdul-Rahim (2018) theoretically suggest that population growth increases greenhouse gas emissions through heightened human activities and environmental interventions. Malthus posited that while population grows geometrically (exponentially), food production increases arithmetically (linearly at specific intervals). He warned that unchecked population growth would inevitably outstrip resource availability, leading to crises.

Malthus proposed two types of checks on population growth:

- 1 preventive checks: these are conscious decisions to limit fertility, such as delaying marriage and practicing moral restraint (abstinence)
- 2 positive checks: these are factors that increase mortality rates, such as famine, disease, and war, which occur when population exceeds the carrying capacity of the land.

The rapid population growth observed in many West African countries in recent decades aligns with Malthus's prediction of geometric population increase. While Malthus focused primarily on food scarcity, his underlying principle of population growth exerting pressure on finite resources can be extended to environmental resources and the capacity of the environment to absorb pollutants like carbon emissions. A larger population inherently demands more resources and generates more waste, including greenhouse gases, through increased consumption, industrial activity, and land use changes.

However, it is crucial to acknowledge the limitations and critiques of the Malthusian theory in the context of carbon emissions. Technological advancements have significantly increased resource efficiency and food production, mitigating some of Malthus' dire predictions regarding food scarcity. Similarly, technological innovations in cleaner energy and carbon capture could potentially decouple population growth from escalating carbon emissions. Furthermore, the Malthusian perspective often overlooks the role of consumption patterns and inequality. As discussed in the conceptual review, high per capita consumption in developed nations contributes significantly more to carbon emissions than population growth alone, particularly in less developed countries with lower consumption levels.

Despite these limitations, the Malthusian theory provides a foundational understanding of the potential pressure that increasing population can place on environmental resources and contribute to environmental challenges like rising carbon emissions. This study, while acknowledging the complexities and mediating factors, uses the Malthusian lens to explore the relationship between population growth and carbon

emissions in the selected West African countries, where rapid population growth continues to be a significant demographic trend. The analysis will consider how this population growth interacts with other factors, such as economic development, technological adoption, and governance, to influence carbon emission trajectories in the region.

2.3 Empirical review

Several studies on carbon emissions exists outside the West African clime, though some of the work did not agree on the nature of relationship between the variables of interest. Some of these studies include:

Chotia and Pankaj (2020) studied the impact of population and economic growth on carbon dioxide (CO₂) emissions. A dataset of nine countries, three each from developed (Japan, USA, UK), fast developing (India, China and Brazil) and slow developing categories (Congo, Bangladesh and Malaysia), over 30 years was considered for the study. The research used a stochastic model containing CO₂ emissions as its dependent variable, while population wealth was measured using GDP per capita and technology (resources used per unit production), were employed as independent variables. The study found that population growth and economic growth were prime contributors to CO₂ emissions globally in the past two decades.

Sulaiman and Abdul-Rahim (2018) in their study showed that in the long run, CO₂ emissions were not determined by population. In the short-term, CO₂ emissions were affected by population, economic growth and energy consumed. Noah et al. (2017) investigated population growth and carbon dioxide emissions, the study revealed that population is directly proportional to social cost of CO₂ (SCC) while average zenith temperature is inversely proportional to the dynamic integrated climate-economy model.

Khan et al. (2013) study indicated that consumption of energy raises the rate of carbon-dioxide (CO₂) emissions in Pakistan.

Ohlan (2015) investigation showed that population density, trade openness and economic growth had positive effect on carbon-dioxide (CO₂) in both long run and short run. This result contrasted the long-run submission of Sulaiman and Abdul-Rahim (2018). Sulaiman (2014) study concluded that population growth affects carbon-dioxide emissions while energy consumption increases CO₂ emissions. The study believes there exists a two-way effect between population rise and consumption of energy.

Liddle (2015) investigation asserts that increase in population increases energy use causing a rise in CO₂ emissions in subsequent decades. Dantama et al. (2012) suggested that energy consumption in forms of petroleum and electricity consumption promotes economic growth in Nigeria. This explains the fact that the larger the population, the more the rate of energy consumption. Zhao et al. (2022) claim that human capital pursuits in industrialised nations produce above 60% of the world's CO₂ emissions, which has a detrimental impact on the atmosphere (Mehmood, 2022). Due to rising income disparities and poor living conditions brought on by globalisation, many nations are witnessing habitat degradation and rising GHG releases. This study in an attempt to measure the impact of possible wealth growth on carbon emission, will make additions to the variables (FDI, ratio of CPS to GDP, and total domestic credit from financial institutions to GDP) used by Zhao et al. (2022).

Further studies from notable scholars have revealed that several other factors could contribute to increase carbon emissions, some of which include Sharma (2011), in a study of 69 countries discovered that per capita GDP and urbanisation are two of the main determinants of global carbon (CO₂) emissions. Similarly, Hubler (2009) and Chen et al. (2011) discovered that the continuous development of FDI has a significant positive impact on CO₂ emissions intensity.

2.4 *Gap analysis*

This study intends to cover the following gaps:

- 1 West African specificity: the empirical review highlights that many existing studies on the relationship between population growth and carbon emissions have focused on countries outside of Sub-Saharan Africa, including developed, fast-developing, and slow-developing nations across various continents (Chotia and Pankaj, 2020; Khan et al., 2013; Ohlan, 2015; Liddle, 2015; Sharma, 2011; Hubler, 2009; Chen et al., 2011; Zhao et al., 2022). While the conceptual and theoretical reviews provide a general framework, this study specifically focuses on selected West African countries, a region with unique demographic and economic characteristics. This regional focus allows for a more nuanced understanding of the dynamics at play within this specific context.
- 2 Temporal scope within Sub-Saharan Africa: by focusing on the period of 1980–2022, this study aims to provide a longitudinal analysis of the relationship between population growth and carbon emissions within the selected West African countries. This longer-term perspective can reveal trends and patterns specific to the region that might be missed in cross-country studies with different regional focuses or shorter timeframes.
- 3 Robustness of theoretical framework in the West African context: while the study anchors itself in the Malthusian theory, the gap lies in empirically testing the applicability and robustness of this theory within the specific socio-economic and environmental realities of Sub-Saharan Africa. The study can explore whether the Malthusian prediction of population pressure on resources (in this case, the environment's capacity to absorb carbon emissions) holds true in this regional context, considering factors like technological adoption, economic development, and governance structures that might mediate this relationship.
- 4 Inclusion of green finance and FDI: the conceptual review emphasises the importance of green finance and FDI in mitigating carbon emissions. While some studies in the empirical review mention FDI's impact on emissions (Hubler, 2009; Chen et al., 2011; Zhao et al., 2022), this study, based on its conceptual framework, aims to investigate the role of green finance and potentially differentiate its impact from general FDI within the West African context. This could provide valuable insights into policy levers for sustainable development in the region.

- 5 Contextualising contradictory findings: the empirical review reveals mixed findings regarding the relationship between population and carbon emissions (Sulaiman and Abdul-Rahim, 2018 vs. Ohlan, 2015; Sulaiman, 2014; Chotia and Pankaj, 2020). This study, by focusing on a specific region and time frame, will contribute to understanding why these relationships might vary across different contexts and potentially reconcile some of these contradictory findings within the West African experience.
- 6 Building on existing work with additional variables: the empirical review mentions Zhao et al.'s (2022) study and the intention of this study to add variables like FDI, the ratio of CPS to GDP, and total domestic credit from financial institutions to GDP. This indicates a gap in the existing literature, particularly within the West African context, regarding the comprehensive impact of these specific financial and economic indicators alongside population growth on carbon emissions.

In summary, this study aims to fill the gap in the existing literature by providing a focused, longitudinal analysis of the relationship between population growth and carbon emissions within selected West African countries, while also considering the role of green finance, FDI, and other relevant economic indicators, and grounding its analysis within a robust theoretical framework relevant to the regional context.

3 Material and methods

This section outlines the methodological framework employed to investigate the impact of population growth and other macroeconomic variables, and other variables (e.g., FDI), on carbon dioxide emissions in selected West African countries. The study adopts a post-facto research design, leveraging secondary data to analyse historical trends and relationships between the variables of interest.

3.1 Research design

The study utilises a post-facto (ex post facto) research design. This design is appropriate as the study examines relationships between variables that have already occurred and cannot be manipulated by the researchers. The focus is on analysing existing secondary data to identify potential causal links and correlations between population growth, and carbon emissions within the selected countries over the specified time period.

3.2 Data source and period of study

The study relies exclusively on secondary data to conduct its analysis. The primary data source is the World Bank Group database (World Development Indicators), a comprehensive repository of socio-economic and environmental statistics for countries worldwide. The dataset covers the period from 1980 to 2022, providing a substantial time series dimension for each of the selected countries. This timeframe is chosen to capture significant economic and demographic shifts in the region and to allow for the analysis of both short-term and long-term relationships between the variables.

3.3 *Sample selection*

The study focuses on a panel of four West African countries, namely – Nigeria, Ghana, Senegal and Niger. These countries were selected based on their varying levels of population growth, economic development, and historical carbon emission trajectories within the West African sub-region. Including countries with diverse characteristics allows for a more robust and comparative analysis of the factors influencing carbon emissions.

3.3.1 *Statistical technique: panel data econometric model*

Given that the study examines multiple countries over a significant time period, the panel data econometric model is the chosen statistical technique. Panel data analysis offers several advantages:

- increased degrees of freedom: combining cross-sectional and time series data provides more data points, leading to more efficient and reliable estimates
- control for unobserved heterogeneity: panel data techniques can account for unobservable country-specific effects that remain constant over time but may influence the dependent variable
- analysis of dynamic relationships: panel data allows for the investigation of how variables change over time and the potential for lagged effects.

The study will employ various panel data estimation techniques, including pooled ordinary least squares (OLS), fixed effects (FE) and random effects (RE) models, to analyse the relationship between the variables. The appropriateness of each model will be determined through diagnostic tests such as the F-test for fixed effects and the Hausman test to decide between fixed and random effects.

3.4 *Data and model specification*

This study builds upon the existing literature, particularly the works of Sulaiman (2014), Liddle (2015) and Zhao et al. (2022), which have explored the drivers of carbon dioxide emissions. The baseline model is adapted to include an additional variable for green finance (DCPGDP) and foreign direct investment (FDI) to capture its potential impact on carbon emissions within the selected West African context. The initial model specification is as follows:

$$\text{CO2EM_it} = \alpha_0 + \alpha_1 \text{ENCSP_it} + \alpha_2 \text{POPGR_it} + \alpha_3 \text{CPSGDP_it} \\ + \alpha_4 \text{DCPGDP_it} + \alpha_5 \text{EXCR_it} + \alpha_6 \text{FDI_it} + \mu_it$$

where

- CO2EM_it – carbon dioxide emission (metric tons per capita) for country, i in year, t. This is the dependent variable, representing the level of carbon emissions.
- ENCSP_it – energy consumption (kg of oil equivalent per capita) for country i in year t. This variable measures the level of energy use within the economy.

- POPGR_it – population growth rate (annual %) for country i in year t. This is a key independent variable, representing the rate at which the population is increasing.
- CPSGDP_it – ratio of credit to private sector to gross domestic product (%) for country i in year t. This variable, as in Zhao et al. (2022), aims to measure the impact of wealth change and financial deepening on carbon emissions.
- DCPGDP_it – proportion of domestic credit from financial institutions to gross domestic product (%) for country i in year t. This variable also intends to capture the impact of wealth change and the potential inflow of green finance channelled through domestic institutions.
- EXCR_it – exchange rate (local currency per US\$) for country i in year t. The exchange rate is included as a control variable to account for potential impacts of currency fluctuations on economic activities and consequently, emissions.
- FDI_it – foreign direct investment (net inflows as % of GDP) for country i in year t. This newly incorporated variable aims to capture the effect of foreign investment on carbon emissions. FDI can potentially increase emissions through industrial expansion or decrease them through the introduction of cleaner technologies.
- Poverty (POVETY_it) and inequality (INEQUALITY_it), the study aims to empirically investigate whether higher levels of poverty and/or income inequality in the selected West African countries are associated with higher or lower carbon emissions, controlling for other factors like energy consumption, population growth, and FDI. The signs and significance of the coefficients for these variables will provide insights into the complex interplay between socio-economic development and environmental outcomes in the region. This can help policymakers design more targeted and effective strategies for both poverty reduction and climate change mitigation.
- α_0 – constant term.
- α_1 – α_6 – parameters to be estimated, representing the coefficients of the respective independent variables.
- μ_{it} – error term, capturing unobserved factors that may affect carbon emissions.

To account for the panel structure of the data, the model will be transformed into panel data specifications:

3.4.1 Pooled effect model

$$\begin{aligned}
 \text{CO}_2\text{EM}_{it} &= \text{CO}_2\text{EM}_{it} \\
 &= \alpha_0 + \alpha_1 \text{ENCSP}_{it} + \alpha_2 \text{POPGR}_{it} + \alpha_3 \text{CPSGDP}_{it} + \alpha_4 \text{DCPGDP}_{it} \\
 &\quad + \alpha_5 \text{EXCR}_{it} + \alpha_6 \text{POVETY}_{it} + \alpha_7 \text{INEQUALITY}_{it} + \alpha_8 \text{FDI}_{it} + \mu_{it}
 \end{aligned} \tag{2}$$

This model assumes that the coefficients are constant across all countries and over time, essentially treating the panel data as a single large cross-section.

3.4.2 Fixed effects model

$$\text{CO2EM_it} = \alpha_0 + \alpha_1 \text{ENCSP}_{it} + \alpha_2 \text{POPGR}_{it} + \alpha_3 \text{CPSGDP}_{it} + \alpha_4 \text{DCPGDP}_{it} + \alpha_5 \text{EXCR}_{it} + \alpha_6 \text{POVETY}_{it} + \alpha_7 \text{INEQUALITY}_{it} + \alpha_8 \text{FDI}_{it} + v_{it} \quad (3)$$

This model allows for country-specific intercepts to capture time-invariant unobserved heterogeneity across the selected countries. It assumes that these country-specific effects are correlated with the independent variables.

3.4.3 Random effects model

$$\begin{aligned} \text{CO}_2\text{EM_it} &= \alpha_0 + \alpha_1 \text{ENCSP}_{it} + \alpha_2 \text{POPGR}_{it} + \alpha_3 \text{CPSGDP}_{it} + \alpha_4 \text{DCPGDP}_{it} \\ &+ \alpha_5 \text{EXCR}_{it} + \alpha_6 \text{POVETY}_{it} + \alpha_7 \text{INEQUALITY}_{it} + \alpha_8 \text{FDI}_{it} + \omega_{it}; \quad (4) \\ \omega_{it} &= \eta_i + v_{it} \end{aligned}$$

This model also accounts for country-specific unobserved heterogeneity (η_i), but it assumes that these effects are uncorrelated with the independent variables and treats them as random draws from a common distribution.

3.4.4 *Apriori expectations*

Based on economic theory and prior empirical studies:

- Energy consumption (ENCSP): a positive and significant relationship is expected. Higher energy consumption generally leads to increased carbon emissions, especially in economies reliant on fossil fuels (Khan et al., 2013; Sulaiman, 2014; Liddle, 2015).
- Population growth rate (POPGR): a positive and significant relationship is anticipated (Chotia and Pankaj, 2020; Sulaiman, 2014; Liddle, 2015). A larger population typically demands more goods and services, leading to increased production and consumption, thereby driving up energy use and emissions.
- Ratio of credit to private sector to GDP (CPSGDP): the expected sign is positive. Increased credit to the private sector may fuel economic activities and consumption, potentially leading to higher emissions (Zhao et al., 2022).
- Proportion of domestic credit from financial institutions to GDP (DCPGDP): while increased financial credit can stimulate economic growth and potentially raise emissions, it could also facilitate investments in cleaner technologies and green projects, leading to a negative or insignificant relationship if green finance constitutes a significant portion.
- Exchange rate (EXCR): currency depreciation (an increase in local currency per US\$) might make imports of energy and carbon-intensive goods more expensive, potentially reducing emissions. Conversely, it could boost export-oriented industries, leading to increased production and emissions.
- Foreign direct investment (FDI): the ‘pollution haven’ hypothesis suggests that FDI might flow to countries with lax environmental regulations, leading to increased emissions. Conversely, the ‘pollution halo’ hypothesis posits that FDI can bring in

cleaner technologies and management practices, potentially reducing emissions (Hubler, 2009; Chen et al., 2011). The net effect in the selected West African countries will be empirically determined.

3.4.5 Estimation procedures and diagnostic tests

The study will employ appropriate econometric software to estimate the panel data models. Following the estimation, several diagnostic tests will be conducted to ensure the robustness and validity of the results. These tests may include:

- Tests for heteroskedasticity and autocorrelation: to address potential issues with the error term that could lead to biased and inefficient estimates.
- Unit root tests for panel data: to check for the stationarity of the variables, as non-stationary data can lead to spurious regression results. If necessary, appropriate panel cointegration techniques will be employed.
- Model selection tests (F-test and Hausman test): to determine the most appropriate panel data model (pooled OLS, fixed effects or random effects) for the analysis.
- Robustness checks: to assess the sensitivity of the results to changes in model specification or the inclusion/exclusion of specific countries or time periods.

By employing this rigorous methodological framework, the study aims to provide robust empirical evidence on the impact of population growth on carbon emissions in the selected West African countries, contributing valuable insights for policymakers in the region.

4 Data and analysis

This section employs basic econometric tests methods in ascertain the effects of the dependent variable of the panel series on the independent variables as modelled in section three of this study.

4.1 Diagnostics tests

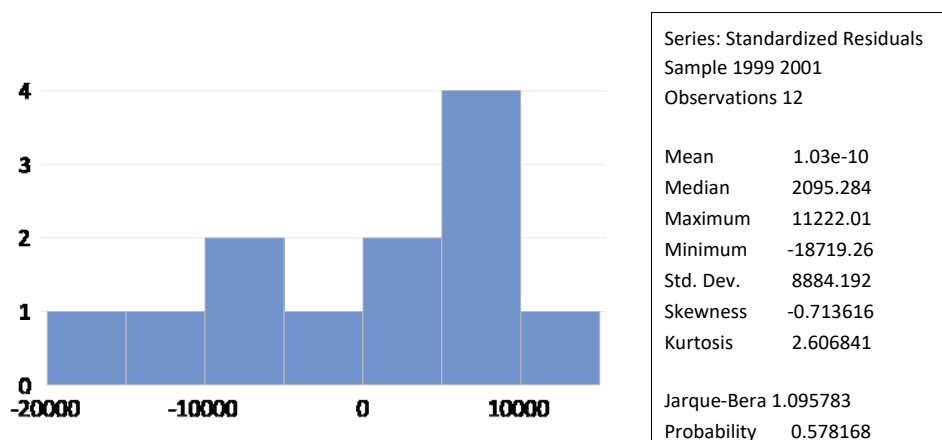
The diagnostic tests are a collection of selected tests carried out on the selected variables of each selected sample in the panel series to determine their conformity and suitability for the model estimations. These preliminary tests include – panel descriptive tests, normality tests, and panel stationarity tests.

Table 1 shows the diagnostic tests for the panel series where the mean, median and standard deviation reveal even spread and variation of the series. The values of the mean, medium, maximum and standard deviation show positive and healthy trends. The average kurtosis is in excess of 3, showing that the series are mainly platykurtic. The Jarque-Bera and probability of the pooled panel data show strong evidence of normality considering the variable spread and significant probability of 0.000 at the 5% chosen level of significance for a majority of the independent variables. This implies that any plausible outlier in the individual country series have been corrected through the panel pool effect.

Table 1 Panel descriptive statistics

	CO2E	CPSGDP	DCPGDP	ENCSP	EXCR	POPGR	POVETY	INEQUALITY	FDI
Mean	20,536.85	12.24	12.35	152.056	260.049	2.779	14.42	12.48	12.30
Median	4,279,389	11.3	11	129.67	264.69	2.681	12.3	11.5	11.72
Maximum	131,685,637	29.6	30	408.254	733.64	3.907	2.1089	301	167.23
Minimum	0	1.5	2	0	0	0	1.5	2	2
Std. dev.	33,888,859	7.007	7.059	136.357	240.283	0.576	6.0235	7.059	5.9846
Skewness	1.881	0.731	0.7168	0.1901	0.2796	-1.4666	0.7366	0.9468	1.1252
Kurtosis	5.3030	2.9128	2.8769	1.5869	1.5820	11.3513	1.0351	2.7769	1.9968
Jarque-Bera	132.0872	14.5479	14.0624	14.5434	15.7803	532.1202	1.0322	14.4524	12.5461
Probability	2.0779	0.000693	0.00088	0.000695	0.000374	2.8286	0.01247	0.00287	0.00201
Sum	3,347,507.94	1,994.6	2,013	24,785.125	42,387.930	452.910	20,564	2,013	1,956
Sum sq. dev.	186,049,666	7,953.839	8,073.067	3,012,095.85	9,353,192.18	53.780	87,2351	8,073.067	54,7409
Observations	217	217	217	217	217	217	217	217	217

Source: Author's Eviews 12 computation

Figure 1 Histogram and panel data normality (see online version for colours)

Source: Author's Eviews 12 computation

The histogram in Figure 1 shows is not bell shaped but rather cyclical with Jarque-Bera and insignificant probability of 0.5782 at the significance level of 5%, thus showing that the distribution is not normal.

Table 2 Test of stationarity – using Levin, Lin and Chu unit root panel test

<i>Variable</i>	<i>ADF test statistic</i>	<i>t-statistics</i>	<i>Probability</i>	<i>Integration level</i>
CO2EM	-6.87223	-9.0570	0.0000	I(1)
ENCSP	-6.20722	-9.3090	0.0000	I(1)
POPGR	-6.53892	-11.014	0.0000	I(1)
EXCR	-4.01183	-7.9520	0.0000	I(1)
CPSGDP	-6.35919	-5.59910	0.0000	I(1)
DCPGDP	-6.71912	-5.12912	0.0000	I(1)
POVETY	-6.20366	-5.69611	0.0000	I(1)
INEQUALITY	-6.20366	-5.69611	0.0001	I(1)
FDI	-6.71912	-5.12910	0.0003	I(1)

Source: Author's Eviews 12 computation

Table 2 shows the stationarity test using Levin, Lin and Chu test for the panel series and shows that they are all statistically significant, stationary and integrated at level one at the chosen 5% level of significance.

4.2 Hypothesis testing

The two-hypothesis set up in Section 1 of this study and modelled in Section 3, are tested hereunder to determine whether there exists a correlation or a co-integration relationship between the variables of interest.

4.2.1 Restatement of Hypothesis 1

H₀ Population growth rate of the selected West African countries has no significant effect on carbon emission (CO₂) in the short-term period.

H₁ Population growth rate of the selected West African countries has significant effect on carbon emission (CO₂) in the short-term period.

This hypothesis was tested using panel least square regression analysis as detailed in Table 3.

The panel least square result in Table 3, shows that while energy consumption in the West African region has insignificant and negative effect on carbon dioxide emission at a lag of 12, population growth had significant and positive effect on carbon dioxide emission in the region at a lag of 2. Exchange rate in the panel series serves as a moderating variable at a lag of 2, while the credit to private sector as a ratio of gross domestic product (CPSGDP) and domestic credit by banks to gross domestic product (DCPGDP), which shows credit or wealth availability to the population growth rate at a lag of 19 and a lead of 19 respectively, both exhibiting insignificant relationship to carbon emission; hence, increase in wealth does not have immediate and significant effect on carbon emission. The implication of this result is that a 1% increase in population growth, will result to a 1.74969% rise in carbon dioxide emission in the sub-region (i.e., West Africa) at the 5% chosen level of significance. The effect of POVERTY and FDI are both found to be significant (p-value = 0.0372 and 0.0026 respectively), however, while increase in poverty generates increase carbon emissions (positive relationship), increase in FDI results to low carbon emission (negative relationship), possibly due to the importation of cleaner and more efficient energy sources. Inequality generates positive relationship with carbon emission.

Table 3 Panel least square regression result

Dependent variable: CO2E				
Method: Panel least squares				
Date: 04/20/25; Time: 17:26				
Sample (adjusted): 1999–2004				
Periods included: 3				
Cross-sections included: 4				
Total panel (balanced) observations: 15				
<i>Variable</i>	<i>Coefficient</i>	<i>Std. error</i>	<i>t-statistic</i>	<i>Prob.</i>
C	–40,527.1	21,431.6	–2.02135	0.0813
POPGR(–2)	174.969	51,107.27	2.548754	0.0224
ENCSP(–12)	–9.24291	83.91096	–0.466820	0.4315
DCPGDP(19)	129.516	4,260.139	1.350547	0.2256
CPSGDP(–19)	–1,015.570	1,517.980	–1.044441	0.2605
EXCR(–13)	142.7149	165.5919	1.092960	0.3163
POVETY	1,047.025	1,027.121	1.232451	0.0372
INEQUALITY	966.234	399.468	1.753911	0.1249
FDI	754.382	3,022.33	1.41532	0.0026

Note: See Appendix for details.

Source: Author's E-views 12 computation

Decision rule: based on the outcome of this test, we convincingly reject the null hypothesis to accept the alternative that population growth rate has positive and significant effect on carbon dioxide emissions in the short run.

4.2.2 Restatement of Hypothesis 2

H_0 Population growth rate of the selected West African countries has no significant effect on carbon emission (CO_2) in the long-term period.

H_1 Population growth rate of the selected West African countries has significant effect on carbon emission (CO_2) in the long-term period.

A co-integration econometric analysis was conducted to determine whether population rise had any effect on carbon emission (CO_2) with the underlying result.

The result of a long run, co-integration test carried out in Table 4 using the Johansen Fisher panel cointegration test of trace indicating four co-integrating vectors and maximum eigenvalue showing two cointegrating vectors. The result shows a total of six (6) co-integrating vectors at the 5% chosen level of significance with p-values of 0.0000, 0.0000, 0.0017, 0.0441, 0.0000 and 0.0061 respectively.

Table 4 Johansen Fisher panel co-integration test

Series: CO2E CPSGDP DCPGDP ENCSP EXCR POPGR POVETY INEQUALTY FDI				
Date: 04/20/25; time: 15:08				
Sample: 1980–2022				
Included observations: 224				
Trend assumption: linear deterministic trend				
Lags interval (in first differences): 1 1				
Unrestricted co-integration rank test (trace and maximum eigenvalue)				
<i>Hypothesised</i> <i>No. of CE(s)</i>	<i>Fisher stat.*</i> <i>(from trace test)</i>	<i>Prob.</i>	<i>Fisher stat.*</i> <i>(from max-eigen test)</i>	<i>Prob.</i>
None	85.34	0.0000	53.09	0.0000
At most 1	41.11	0.0000	21.43	0.0061
At most 2	24.84	0.0017	13.55	0.0943
At most 3	15.88	0.0441	9.167	0.3284
At most 4	12.85	0.1172	10.14	0.2557
At most 5	13.09	0.1087	13.09	0.1087

Source: Author's E-views 10 computation

Decision rule: based on the overwhelming result of this test, we accept the alternative hypothesis to, reject the null that population growth has positively significant effect on carbon emission in the selected West African countries in the long run.

5 Discussion

This paper focused on the study whether population growth had any effect on carbon (CO₂) emission using selected West African countries namely Nigeria, Ghana, Senegal and Niger covering a 42 year period from 1980 to 2022. Basic diagnostic tests were carried out using descriptive statistics, normality tests and stationarity tests to appropriately prepare the data in the panel series for relevant econometric analysis.

The first hypothesis tested population growth effect on carbon emissions in the short run and least square regression test was. It was discovered that is considered that while energy consumption in the West African region has insignificant and negative effect on carbon dioxide emission at a lag of 12 [with a p-value of 0.4315], population growth had significant and positive effect on carbon dioxide emission in the region at a lag of 2 with a probability value of 0.0224]. Exchange rate in the panel series serves as a moderating variable at a lag of 2 [p-value = 0.3163], while the credit to private sector as a ratio of gross domestic product (CPSGDP) and domestic credit by banks to gross domestic product (DCPGDP), which shows credit or wealth availability to the population growth rate at a lag of 19 and a lead of 19 respectively, both exhibiting insignificant relationship to carbon emission [p-values of 0.2605 and 0.2256 respectively]; hence, increase in wealth does not have immediate and significant effect on carbon emission. The implication of this result is that a 1% increase in population growth, will result to a 1.74696.% rise in carbon dioxide emission in the sub-region (i.e., West Africa) at the 5% chosen level of significance. Based on the regression results, a 1% increase in the population growth rate (POPGR(-2)) is associated with an increase of approximately 174.97 units (or 1.7469% increase) in CO₂ emissions, which is above global average of 1.28%, according to Shi (2001). This suggests that population growth is a statistically significant factor contributing to higher CO₂ emissions in the analysed dataset.

This outcome is corroborated by the findings of the study of Sulaiman (2014), Liddle (2015), Chotia and Pankaj (2020) and Zhao et al. (2022), of a positively significant effect of population growth on carbon emission. This position is equally supported by the Malthus theory of population. The co-integration test similarly showed that population rise had significant effect on carbon emission, which is equally supported by the findings in the study of Ohlan (2015) showed that population increase had a positively significant effect on carbon emission.

The research findings of poverty, inequality and carbon emission, suggest a positive relationship between poverty, inequality, and carbon emissions in the selected West African countries. For instance, for poverty and carbon emission, p-value of 0.0372, indicating a relatively low probability of a significant relationship and coefficient of 1,047.025, suggesting that a 1% increase in poverty is associated with a 10.47% increase in carbon emissions, holding other factors constant. Similarly, inequality and carbon emission regression reveals a probability value of 0.1249, indicating a higher probability of an insignificant relationship compared to poverty while, the coefficient of 966.230, suggests that a 1% increase in inequality is associated with a 9.66% increase in carbon emissions, holding other factors constant. Overall, both poverty and inequality are positively correlated with carbon emissions in the study area. However, the relationship between inequality and carbon emissions is statistically insignificant than the relationship between poverty and carbon emissions. This implies that addressing poverty reduction, might be a more effective strategy for reducing carbon emissions in these countries compared to solely focusing on inequality. The plausible causes of these may include;

- energy consumption: poorer and more unequal societies may rely on more carbon-intensive energy sources, such as firewood and charcoal, for cooking and heating (UNDP, 2024)
- economic development: economic growth often leads to increased energy consumption and emissions, but the benefits of this growth may not be evenly distributed, exacerbating inequality and poverty (World Bank, 2023)
- policy and governance: weak governance and inadequate environmental policies may contribute to higher emissions, especially in countries with high levels of poverty and inequality.

6 Conclusions

The findings from this study, shows that there is a direct proportional relationship between population growth rate and carbon dioxide emissions (1% growth in population growth will translate to a 174.969 unit or 1.74969% increase in carbon dioxide emissions in the West African communities, which is above globally recommended average of 1.28% (Shi, 2001), and we thus conclude, that population growth has positive and significant effect on carbon emissions in West African region. Based on this result, we recommend among others that;

- 1 West African Governments should take conscious steps towards the reduction in utilisation of fossil fuels within the sub-region. Some of these conscious steps may include payments of annual carbon taxes or permit fees by individuals and institutions that generate carbon to setting limits on carbon emissions with increase in population; taking conscious steps to attract foreign direct investments and green financing, which is a quality source for attracting cleaner and efficient energy sources.
- 2 West African Governments should invest heavily in climate smart agriculture and reforestation in order to cope with increasing population and carbon emissions while minimising possible humanitarian disasters such as prolonged period of extreme droughts or even flooding.
- 3 West African Governments should evolve deliberate population control measures to check the alarming growth in population rate. Some of these deliberate measures could include birth controls, additional birth tax, women education, women empowerment, access to reproductive health services, etc.

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Based on the policy and our ethical obligation as authors, we declare that we have no potential competing interests to disclose.

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Appendix

Table 5 Panel least square regression result

Dependent variable: CO2E				
Method: Panel least squares				
Date: 04/20/25; Time: 17:26				
Sample (adjusted): 1999–2004				
Periods included: 3				
Cross-sections included: 4				
Total panel (balanced) observations: 15				
<i>Variable</i>	<i>Coefficient</i>	<i>Std. error</i>	<i>t-statistic</i>	<i>Prob.</i>
C	−40,527.1	21,431.6	−2.02135	0.0813
POPGR(−2)	174.969	51,107.27	2.548754	0.0224
ENCSP(−12)	−9.24291	83.91096	−0.466820	0.4315
DCPGDP(19)	129.516	4,260.139	1.350547	0.2256
CPSGDP(−19)	−1,015.570	1,517.980	−1.044441	0.2605
EXCR(−13)	142.7149	165.5919	1.092960	0.3163
POVETY(1)	1,047.025	1,027.121	1.232451	0.0372
INEQUALITY(2)	966.234	399.468	1.753911	0.1249
FDI	754.382	3,022.33	1.41532	0.0026
Root MSE	8,505.966	R-squared	0.919684	
Mean dependent var	19,979.96	Adjusted R-squared	0.852755	
S.D. dependent var	31,348.60	S.E. of regression	12029.25	
Akaike info criterion	21.93492	Sum squared resid	8.68E+08	
Schwarz criterion	22.17738	Log likelihood	−125.6095	
Hannan-Quinn criter.	21.84516	F-statistic	13.74107	
Durbin-Watson stat	2.004980	Prob (F-statistic)	0.003098	

Source: Author's E-views 12 computation