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RESEARCH ARTICLE

Achieving carbon neutrality through Economic and Institutional Reforms: Evidence from the Belt and Road Initiative Countries

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Abstract

The increasing concern over carbon dioxide emissions necessitates a comprehensive understanding of the factors influencing environmental degradation, particularly in Belt and Road Initiative (BRI) countries. This study investigates the impact of economic, institutional, and environmental variables on carbon emissions using Fixed Effect and dynamic panel models covering the period from 2000 to 2020. The findings reveal that economic freedom has a negative and significant effect on carbon emissions, suggesting that higher levels of economic freedom promote investments in green energy and efficiency, which ultimately reduce emissions. Financial development, however, is consistently shown to positively and significantly increase emissions, indicating that economic expansion, without sustainable practices, exacerbates environmental degradation. Renewable energy consumption demonstrates a significant negative relationship with emissions across models, reinforcing its role in mitigating pollution. Industrial growth is positively correlated with carbon emissions, highlighting the reliance on fossil fuels for production in BRI countries. The robustness check using control of corruption and rule of law confirms the main model results, demonstrating that weak institutional quality exacerbates emissions. The study underscores the importance of strengthening institutional frameworks and promoting renewable energy to reduce carbon emissions in BRI countries. The results have significant policy implications for integrating economic, environmental, and institutional reforms to achieve sustainable development.

Keywords: Carbon Dioxide Emissions; Economic Freedom; Institutional Quality; Renewable Energy; Industrial Growth

Introduction

Countries around the world, particularly those with developing and emerging economies, are increasingly confronted with the challenge of balancing economic growth with environmental sustainability. Economic activities such as industrialization, international trade, and urban development are central to these countries' strategies for improving their economic standing and raising living standards. However, these activities often rely heavily on non-renewable energy sources, leading to significant carbon dioxide emissions and subsequent environmental degradation. Khan et al. (2022) highlight that while economic growth is essential for development, it is also crucial to manage its impact on the environment. Achieving this balance requires effective institutional frameworks that not only facilitate economic growth but also enforce measures to protect environmental quality. High institutional quality is therefore critical as it enables governments to establish and enforce policies that drive sustainable development (Khan, Han et al., 2021). Government arrangements and institutions can exert both direct and indirect influences on environmental quality. Institutions serve as predecessors and indicators for numerous developmental outcomes, making their role in influencing carbon dioxide emissions particularly significant. Some researchers argue that economic institutions can provide the necessary funds for green energy projects and advanced technologies, ultimately improving environmental quality by decreasing the reliance on non-renewable resources (Diallo & Masih, 2017; Lee, Chen, & Cho, 2015). Previous studies have examined the economic, social, and institutional factors contributing to environmental degradation, focusing on variables such as energy consumption, financial development, and economic growth as key determinants of environmental sustainability (Abbasi et al., 2022; Alola et al., 2022; Khan, Weili, & Khan, 2022c; Sunday Adebayo et al., 2022; Zhao et al., 2022). Institutions play a critical role by enforcing regulations, creating a stable legal and cultural context for socioeconomic activities, and managing the resources needed for sustainable development (Acemoglu & Robinson, 2008). The quality of institutions, therefore, reflects a government's ability to develop and implement laws and policies that foster private sector growth while maintaining environmental integrity. This includes enhancing contract enforcement, protecting property rights, upholding the rule of law, and ensuring that institutions remain impartial and free from political influence (Canh, Schinckus, & Thanh, 2019). Conversely, ineffective institutions often lead to corruption, inefficient bureaucracies, and weak environmental regulations (Asoni, 2008). In recent years, economists, scientists, and policymakers have increasingly focused on the role of institutional quality in addressing environmental challenges, emphasizing that governments have the power to shape environmental outcomes both directly and indirectly. Olson (1996) posits that competent and impartial government institutions are crucial for fostering productive collaboration among market participants, which is vital for addressing environmental concerns. The rule of law, in particular, becomes an essential tool in managing carbon emissions and environmental policies. Strong institutions are therefore necessary to enforce processes aimed at reducing emissions, ensuring that businesses comply with these regulations. In the absence of high institutional quality, businesses may easily bypass regulations, prioritizing economic gains over environmental protection, as noted by Welsch (2004). Despite the recognition of institutional quality as a critical factor in the nexus between economic activities and environmental quality, there is still a research gap concerning its multifaceted impact. Previous studies have often focused on single indicators of institutional quality, such as government effectiveness or rule of law, without considering the broader array of institutional factors. This study seeks to address this gap by investigating multiple aspects of institutional quality, including the legal and political systems, and their combined influence on carbon emissions. Specifically, the study examines the effects of political system indicators such as control of corruption, political stability, and government effectiveness, alongside legal system indicators like regulatory quality, voice and accountability, and rule of law. By comprehensively analyzing these factors, the research aims to provide a deeper understanding of the various institutional elements that impact economic activities and environmental outcomes.

This research innovatively integrates institutional quality indicators with other variables, such as non-renewable energy consumption, renewable energy usage, and financial development, to explore their collective impact on carbon emissions. It posits that improved institutional quality can lead to better policies that support financial institutions in funding renewable energy projects, thereby reducing reliance on fossil fuels. By promoting renewable energy, quality institutions can help mitigate environmental degradation. Furthermore, the study examines how institutional policies can influence the behavior of financial institutions, making them more environmentally conscious and supportive of sustainable development. This comprehensive approach to studying institutional quality and its interaction with other economic and environmental factors is relatively new and provides valuable insights into how BRI countries, which are still in various stages of economic development, can achieve growth without sacrificing environmental quality. The choice of BRI countries for this study is crucial, as these nations represent a diverse group of developing and emerging economies that are still striving to increase economic growth and improve living standards. However, this growth often comes at the cost of environmental degradation. By focusing on these countries, the study aims to develop policy recommendations that can guide them toward a balanced approach to development. These recommendations may include strengthening governance structures, enhancing institutional frameworks, improving financial sector support for sustainable projects, and promoting the use of renewable energy sources. The study's findings indicate that institutional quality factors have both negative and positive impacts on carbon emissions, depending on their strength and implementation. For instance, regulatory quality, voice and accountability, and other aspects of governance that are well-established help reduce emissions, while weaker institutional elements contribute to environmental degradation. The study also finds that renewable energy usage significantly reduces emissions and improves environmental quality, while fossil fuel-based energy consumption, industrial growth, and financial development are the primary drivers of carbon emissions in the BRI countries. This research is structured as follows: after the introduction, the next section provides a detailed literature review, examining past studies and highlighting the gaps this research aims to fill. The third section outlines the methodology, including econometric techniques and data sources used to conduct the analysis. The fourth section presents the results and discussions, offering insights into the research gap and how this study addresses it through its innovative approach. Finally, the conclusion and policy implications are provided, summarizing the study's findings and offering recommendations for policymakers and future research directions. By comprehensively examining the role of institutional quality and its interaction with economic and environmental factors, this study contributes to the literature and provides practical solutions for countries aiming to achieve sustainable development.

Literature review

Institutional Quality, Economic growth, and Carbon dioxide emissions

There have been conducted large number of studies on the effect of different factors on carbon dioxide emission such as economic growth, financial development, trade and so on however there is still conflicting view in this investigation. Institutional quality has also been considered by large number of researchers which argues that institutional quality can help imped the harmful effect of economic factors on environmental quality. For instance, (Abid, 2017) used the data of 41 European Union and 58 Middle East and African (MEA) nations for the period of 1990 - 2011. They found that institutional quality is vital in the designated countries reducing carbon dioxide emissions. Though, (Godil, Sharif, Agha, & Jermsittiparsert, 2020) claimed that as institutional quality increases, the carbon dioxide emissions also increases. This can be the reason that institutional quality in the countries are still below the standard level. (H. P. Le & Ozturk, 2020) examined the effect of institutional quality on carbon dioxide emission for 47 developing and Emerging Market for the period of 1990 - 2014. Noticeably, the increasing institutional quality promotes investment activities, attract more trade, and economic activities using economic globalization which as a result increases the scale effects economic activities on emissions of carbon dioxide. As mentioned above, economic growth increase carbon dioxide emission as increased economic activities while institutional quality might be needed to facilitate these activities as well to protect environmental quality. For instance, (Yuelan et al., 2019) studied the impacts of economic growth on environment for the period of 1980-

2016, which confirmed that economic growth deteriorated the quality of environment. Though, (Wang & Li, 2021) found that the role of economic growth per capita with per capita carbon dioxide emissions, as GDP per capita increases, it decreases per capita emissions of carbon dioxide. Good institutions are sources of growth in the country. Institutions can improve or deteriorate the environmental sustainability of a country. (Anser, Hanif, Alharthi, & Chaudhry, 2020) studied 16 lower middle and middle income economies from 1990 - 2015.Their empirical findings show that industrial development prominently increasing emissions of carbon dioxide in these economies. (Rahman & Kashem, 2017) investigated the relation of industrial progress and carbon dioxide emissions in Bangladesh from 1972 - 2011. Their result show that industrial progress have significant and positive influence on the emissions of carbon dioxide for short run as well as in long run. (Ali, Audi, Senturk, & Roussel, 2022) examined the influence of sectorial progress and emissions of carbon of Pakistan from 1970 - 2019. They found that industrial progress significantly positively linked with emissions of carbon dioxide. (U. Ali et al., 2022) studied Malaysia from 1971 - 2016. Their result show that emissions of carbon dioxide have an informal association with carbon dioxide and industry. Energy is vital driver of economic development. The growth of demand of energy at various phases of economic growth needs a practical solution for problems of environment. For instance, (Zhang et al., 2017) demonstrated the EKC theory for 10 new industrialized nations for the period of 1971 - 2013 and found that real GDP demonstrated conflicting effects. (Van & Bao, 2018) examined the effects of GDP per capita on environment in Vietnam for the period of 1985 - 2015 using ARDL and found that GDP per capita increases carbon dioxide emissions.

Renewable energy use, non-renewable energy consumption and carbon dioxide emission

Energy is needed to facilitate economic activities such as industrialization, production and other related factors however an increase in energy consumption raise carbon dioxide emissions and leads to environmental degradation. Renewable energy as a substitute of fossil fuels might be beneficial to be used in economic activities and safeguard environmental quality. However, developing, and emerging economies are not yet reached the desired level of use renewable energy sources. This is among the most argued issues of the last recent decades. For instance, (Waheed, Chang, Sarwar, & Chen, 2018) studied energy consumption and carbon emission in Pakistan from 2014 5o 2019 and found that renewable energy had significant negative relationship with carbon dioxide emission. (T.-H. Le, Chang, & Park, 2020) studied a global panel of 102 countries, found that green energy decreases carbon emission in high-income countries. because these economies' have strict environmental rules. (Chen, Wang, & Zhong, 2019) explored the instance of BRICS economies for the time period of 2000-2013, green energy decreases toxin emissions. (Nathaniel & Iheonu, 2019) explored Africa for the period of 1990-2014, and found a one directional association existing from green energy towards emissions of carbon. (Pata, 2018) examined Turkey for the period of 1974 to 2014 between consumption of renewable energy and emissions of carbon dioxide. Their results show that emissions of carbon dioxide has no relationship with renewable energy. (Vural, 2020) studied the association between emissions of carbon dioxide and non renewable energy for eight Sub Saharan African economies 1980 - 2014. Their results demonstrates that, non renewable energy have crucial part in growing emissions of carbon dioxide. (Chen, Wang, et al., 2019) found that non-renewable energy give raise to carbon emissions. (Chen, Zhao, Lai, Wang, & Xia, 2019) found that non-renewable has significant positive influence on carbon dioxide emissions. (Inglesi-Lotz & Dogan, 2018) studied carbon dioxide emissions for ten main power producers in Sub-Saharan Africa during 1980-2011. Growth in non-renewable energy usage increases pollution. Forests are vital to consider as the main source for captivating carbon dioxide emissions from the air. According to (World Bank, 2013) forests is one of the most mishandled resource in different countries of the world. For instance, (Farooq, Shahzad, Sarwar, & ZaiJun, 2019) suggested that greater afforestation activities can aid to lessen carbon dioxide emissions. (Minnemeyer, Harris, & Payne, 2017) claimed that discontinuing disforestation in the biosphere will decrease 7 billion of carbon dioxide emissions per annum, and 42 percent of the entire emission reductions might be attained via replantation in forested eco-regions. (Abbasi, Adedoyin, Radulescu, Hussain, & Salem, 2022) examined the association between forest area with emissions of carbon dioxide for 22 countries for time period of 1980-2019. They found that forest areas significant positive adverse effect on environmental damage. (Sarwar, Waheed, Farooq, & Sarwar, 2022) examined the existence of investment in forest and forest area, where forest is a carbon source or a sink. Their results show that just growing the forest area is not a productive approach to lessen carbon dioxide emissions. At the same time their empirical results stated that greater forest investment is a useful approach to decrease the carbon amount in the environment.

Financial development, and carbon dioxide emissions

Financial development plays an important part in cultivating the quality of the environment. Expansion of the economic sector will enable financing investment at low cost in the environmental project. (Anwar et al., 2022) studied the effect of financial growth on emissions of carbon dioxide in Asian nations from 1990 - 2014. Their results proves that financial growth significantly increases emissions of carbon dioxide. (Ling, Razzaq, Guo, Fatima, & Shahzad, 2022) investigated the relation of emissions of carbon dioxide and financial growth for the period of 1980-2017. Their study found that the positive shocks of the financial growth had significant positive effects on emissions of carbon dioxide. (Bayar, Diaconu, & Maxim, 2020) studied the influence of financial growth and emissions of carbon dioxide in European countries. They found that financial growth have positive effects on emissions of carbon dioxide in the long run. (Manta et al., 2020) explored the relationship amid carbon dioxide emissions and financial growth in Eastern and Central European countries. Their empirical results show that, financial growth will increase emissions of carbon dioxide. However, (Odhiambo, 2010) explored emissions of carbon dioxide and financial growth in sub Saharan African nations. They used GMM, and their findings reveals a declining unconditional effect of financial growth on emissions of carbon dioxide.

Methodology

This research examines the impact of institutional quality, energy consumption, and economic growth on carbon dioxide emissions in the Belt and Road Initiative (BRI) countries from 2002 to 2020. Data on renewable energy consumption is sourced from the Energy Information Administration (EIA), while economic freedom data is obtained from the Heritage Foundation. Institutional quality indicators are collected from the World Governance Indicators, and the remaining variables are gathered from the World Development Indicators. The list of countries included in the study is provided in Table 7, and a detailed description of the data sources and variable symbols is presented in Table 8 in the appendix. The baseline model analyses the effects of institutional quality, energy consumption, and economic growth on carbon dioxide emissions.

$$CO2_{it} = \beta_0 + \beta_1 CO2_{it-1} + \beta_2 INST_{it} + \beta_3 EF_{it} + \beta_4 REC_{it} + \beta_5 FD_{it} + \beta_6 FOR_{it} + \beta_7 IND_{it} + \beta_8 GDP_{it} + \beta_9 NREC_{it} + \epsilon_{it} \quad (1)$$

In the above equation, CO2 represents carbon dioxide emissions; INST denotes institutional quality; EF stands for economic freedom; REC indicates renewable energy consumption; FOR represents forest cover; IND stands for industrial structure; GDP is economic growth; and NREC refers to non-renewable energy consumption, while ϵ is the error term. $CO2_{it-1}$ is the lag of previous year effect of carbon emission which shows the effect of the previous year's emissions on the current year. The inclusion of this lag follows the understanding that a country's carbon dioxide emissions are likely to be influenced by its previous emissions levels, as suggested by Dogan & Seker (2016). Therefore, the lag of carbon dioxide emissions is incorporated into the model. All variables, except for institutional quality and forest area, are transformed using the natural logarithm. CO2 is measured in metric tons per capita, as used in recent studies by Khan, Weili, & Khan (2022a). Extensive literature indicates that carbon dioxide emissions are a primary cause of environmental degradation (Khan et al., 2020), and countries with higher emissions levels tend to have poorer environmental quality.

Institutional quality is included in the model to examine its effect on environmental quality. Numerous studies suggest that high-quality institutions play a critical role in enhancing environmental quality by formulating and enforcing environmental protection policies and regulations. In Model 1, INST represents institutional quality, constructed using six indicators: regulatory quality (RQ), voice and accountability (VA), control of corruption (CC), government effectiveness (GE), political stability (PS), and rule of law (RL) (Kumar, 2022; Khan, Weili, & Khan, 2022c). The study applies principal components analysis (PCA) to construct an institutional quality index. It is believed that environmental degradation varies across countries due to differences in institutional quality. High-quality institutions can effectively manage corruption, enforce regulations, and ensure better governance, thereby improving environmental outcomes by monitoring the inflow of polluting foreign direct investment (FDI) and promoting the use of green energy resources. Strong and efficient institutions discourage polluting industries from investing and instead attract environmentally friendly FDI. An effective monitoring system ensures the efficient use of energy, thereby improving environmental quality (Claessens & Feijen, 2007).

Economic freedom is also introduced in the model as it has been extensively debated in the literature regarding its effect on environmental quality. The economic freedom index is constructed from twelve components, grouped into four base categories. This index has been used recently by Mahmood, Shahab, & Shahbaz (2022), Alola et al. (2022), Joshi & Beck (2018), and Graafland (2019) in environmental economics research. The study also incorporates renewable energy consumption, supported by literature that shows renewable energy use from environmentally friendly sources enhances environmental quality, unlike non-renewable fossil fuel-based energy (Hayat et al., 2021). The study measures renewable energy consumption as electricity net consumption in billion kWh, following the methodologies of Kirikkaleli, Güngör, & Adebayo (2022), Ling et al. (2022), Ali et al. (2022), and Apergis & Payne (2014) in examining its impact on carbon dioxide emissions.

Financial institutions also play a pivotal role in environmental quality. Previous research shows that strong financial institutions can fund renewable energy projects, promoting a cleaner environment (I. Khan et al., 2022). However, weak financial institutions and low levels of financial development may lead to environmental degradation. Financial development in this study is measured using domestic credit to the private sector by banks as a percentage of GDP, as recently applied by Sunday Adebayo et al. (2022) and Odhiambo (2020).

Several other factors are also included to explore the nexus between institutional quality and carbon dioxide emissions. These factors include forest area (measured in square kilometers) as used by Raihan & Tuspekova (2022), and industrial structure (IND), proxied by the logarithm of annual industry growth (including construction) as a percentage of GDP, following Rauf et al. (2018). Economic growth (GDP) is measured as the logarithm of GDP per capita annual growth, in line with Wang & Li (2021). Non-renewable energy consumption (NREC) is proxied by fossil fuel energy consumption as a percentage of total energy use, following the methodologies of Rasoulinezhad & Saboori (2018) and Koengkan et al. (2020). To further analyze the relationship between the response and explanatory variables, the study first uses the institutional quality index as mentioned in the empirical model. Then, the institutional quality indicators are divided into two categories: legal system indicators and political system indicators, to explore their deeper role in enhancing environmental quality. The legal system encompasses a country's laws and regulations, while the political system is the institutional framework that forms the state or government. Institutions have the potential to increase or decrease a country's sustainability. Therefore, this study examines how the legal and political frameworks influence carbon dioxide emissions. Legal system indicators include political stability and absence of violence/terrorism (PS), control of corruption (CC), and government effectiveness (GE), which together form the legal system index (LEG). Similarly, we use political system indicators (POL), including regulatory quality (RQ), voice and accountability (VA), and rule of law (RL), as previously used by Khan, Weili, & Khan (2022b). To study the combined effect of legal system indicators, a political index (LEGDX) is constructed using principal component analysis (PCA) from the three indicators: CC, GE, and PS. To examine the collective impact of political system indicators on carbon dioxide emissions, a political system index (POLDX) is created using PCA from three indicators: RL, RQ, and VA. For robustness checks, the study uses two indicators separately in different models that are commonly used to proxy institutional quality: control of corruption (from the legal system) and rule of law (from the political system). These indicators have recently been used as single proxies for institutional quality by Hunjra et al. (2020) and Khan, Weili, & Khan (2021). Countries may adopt various strategies to control carbon emissions, such as implementing advanced technologies, carbon taxation, promoting public transportation, and substituting polluting energy sources with clean alternatives. These strategies, however, are long-term in nature and may not significantly reduce carbon emissions within a short time frame.

For the analysis, this study employs the Fixed Effects model, two-step system GMM (SGMM), and difference GMM (DGMM). The primary model used is the two-step SGMM. The Fixed Effects or Random Effects models may encounter issues with autocorrelation between lagged response variables, the error term, and endogeneity (Amuakwa-Mensah & Adom, 2017). The SGMM estimator, introduced by Arellano & Bover (1995), addresses these issues, providing a robust solution for autocorrelation and endogeneity. The two-step SGMM estimator further addresses potential instrument weaknesses, making it a more reliable and efficient estimator. The research ultimately relies on the SGMM model to examine the relationships between dependent and independent variables. The instruments used in the GMM approach mitigate the issue of endogeneity among explanatory variables, which is advantageous given the panel's structure where the number of countries exceeds the time periods in the sample. Additionally, the GMM model retains the cross-country variation, avoiding its elimination (Asongu et al., 2019). It also has the ability to manage overidentification restrictions and reduces heteroscedasticity of the instruments used, ensuring the model's robustness. The identification restrictions and overidentification tests are applied to evaluate the model's validity. Asongu et al. (2019) explain that GMM allows for the selection of explanatory, exogenous, and endogenous variables. The identification restriction confirms the impact on the response variable when strict exogenous variables are employed alongside endogenous variables. Asongu & Le Roux (2017) and Roodman (2009) clarify that endogenous variables are predictors, while exogenous variables remain time-invariant. The Hansen test results, which evaluate instrument exogeneity for overidentifying restrictions, indicate that if the null hypothesis is accepted, the model assumptions are valid. The AR2 test examines the second-order serial correlation, validating the model's assumptions concerning error term behavior and overall serial correlation.

Results and discussion

Preliminary Results

The results section analyses the effect of institutional quality and other variables on carbon dioxide emissions, presenting both descriptive statistics and correlations to offer insights into the data characteristics. The average carbon dioxide emissions (CO_2) is 6.192 metric tons per capita (mtpc), with a standard deviation (SD) of 6.983.

Over the observed period, financial development (FD) has a mean value of 3.542% with an SD of 0.848, and renewable energy consumption (REC) averages 3.065 billion kWh, showing an SD of 1.731. Industrial growth (IND) has an average of 1.64 and an SD of 0.955.

Table 1. Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
CO2	6.192	6.983	.034	50.954
CC	-.24	.797	-1.71	2.33
GE	-.056	.789	-2.31	2.44
PS	-.293	.99	-3.18	1.62
RL	-.19	.798	-2.09	1.88
RQ	-.083	.873	-2.34	2.26
VA	-.445	.892	-2.26	1.21
EF	1.906	.137	1.206	2.177
REC	3.065	1.731	-2.395	8.825
FD	3.542	.848	-1.681	5.542
FOR	229281	1040909	3.7	8153116
IND	1.64	.955	-4.43	3.916
ED	1.314	.848	-4.581	3.902
NREC	4.295	.424	2.154	4.605

Institutional quality indicators such as Control of Corruption (CC), Government Effectiveness (GE), Political Stability (PS), Rule of Law (RL), Regulatory Quality (RQ), and Voice and Accountability (VA) reveal mean and SD values of -0.24 (0.797), -0.056 (0.789), -0.293 (0.99), -0.19 (0.798), -0.083 (0.873), and -0.445 (0.892), respectively.

Table 2. Correlation

	CO2	CC	GE	PS	RL	RQ	VA	EF	REC	FD	FOR	IND	ED	NREC
CO2	1													
CC	0.50	1												
GE	0.41	0.88	1											
PS	0.43	0.66	0.64	1										
RL	0.43	0.89	0.93	0.67	1									
RQ	0.34	0.81	0.89	0.59	0.90	1								
VA	-0.02	0.53	0.61	0.39	0.67	0.70	1							
EF	0.25	0.63	0.69	0.56	0.69	0.79	0.61	1						
REC	0.18	0.05	0.15	-0.13	0.08	0.05	-0.03	-0.17	1					
FD	0.29	0.51	0.64	0.39	0.61	0.56	0.34	0.46	0.33	1				
FOR	0.08	-0.13	-0.03	-0.09	-0.12	-0.06	-0.09	-0.13	0.38	0.06	1			
IND	-0.11	-0.19	-0.21	-0.03	-0.23	-0.19	-0.11	-0.14	-0.15	-0.21	-0.05	1		
ED	-0.16	-0.10	-0.11	0.04	-0.13	-0.10	-0.03	-0.02	-0.03	-0.09	0.02	0.50	1	
NREC	0.32	0.18	0.18	0.15	0.14	0.12	-0.05	0.09	0.40	0.15	0.05	-0.09	-0.13	1

Other variables include economic freedom (EF), with an average of 1.906 and an SD of 0.137, and non-renewable energy consumption (NREC), averaging 4.295 with an SD of 0.424. The forest area (FOR) has a mean of 229,281 and an SD of 1,040,909, while the education level (ED) averages 1.314 with an SD of 0.848.

The correlation analysis shows that carbon dioxide emissions have a positive correlation with several institutional indicators such as CC (0.50), GE (0.41), PS (0.43), RL (0.43), and RQ (0.34). Renewable energy consumption (REC) has a relatively low positive correlation with carbon emissions (0.18). Financial development (FD) is positively correlated with CO2 emissions (0.29), while forest area (FOR) and industrial growth (IND) show weaker correlations of 0.08 and -0.11, respectively. Economic freedom (EF) also has a mild positive correlation with CO2 (0.25), while non-renewable energy consumption (NREC) exhibits a moderate positive correlation of 0.32. The correlations among the institutional indicators themselves are generally strong, indicating interdependence between different aspects of institutional quality.

The variance inflation factor (VIF) analysis for the legal system, political system, and institutional quality variables is presented in Table 3. VIF is a diagnostic tool used to detect multicollinearity, which arises when two or more explanatory variables in a model are highly correlated. Multicollinearity can distort the estimation of coefficients, making it difficult to assess the true impact of each variable. VIF is calculated by regressing each explanatory variable against all others and using the resulting coefficient of determination to measure the degree of multicollinearity.

$$VIF_i = 1 / R_i^2$$

According to the guidelines by Curto & Pinto (2011) and Alin (2010), a VIF value equal to or greater than 10 indicates the presence of multicollinearity. However, the results in Table 3 show that none of the variables have VIF values reaching this threshold, suggesting that multicollinearity is not an issue in this model. Therefore, the explanatory variables in the analysis are not significantly correlated, allowing for accurate interpretation of the regression results.

Table 3. Multicollinearity

VIF results					
Legal (Variables)	VIF	Political (Variables)	VIF	Institutional (Variables)	VIF
GE	6.58	RQ	8.084	INST	2.477
CC	5.942	RL	7.379	LREC	1.954
PS	2.144	VA	2.325	LEF	2.176
LREC	2.149	LREC	1.941	LFD	1.779
LEF	2.196	LEF	3.178	LED	1.606
LFD	1.788	LFD	1.84	LIND	1.613
LED	1.63	LED	1.642	LNREC	1.394
LIND	1.615	LIND	1.628	FOR	1.388
LNREC	1.505	LNREC	1.408		
FOR	1.424	FOR	1.503		
Mean VIF	2.697	Mean VIF	3.093	Mean VIF	1.798

The data stationarity is checked before going to the formal analysis where the results are given in table 4. There has been improvement of unit root tests of panel data some of which are (Breitung, 2001; Breitung & Das, 2005; Choi, 2001; Hadri, 2000; Im, Pesaran, & Shin, 2003; Levin, Lin, & Chu, 2002). These researches show that unit root tests of panel will be less likely to have type II error. As the unbalanced nature and individual time series gaps of the data this study will use Fisher type unit root tests based on Augment Dickey Fuller tests. Given by (Choi, 2001) for which balanced data is not required and individual series gaps are allowed. Fisher-type Augment Dickey Fuller tests used by (Fayissa & Nsiah, 2013; Mehrara, Fazaeli, Fazaeli, & Fazaeli, 2012). For panel data unit root, Fisher-type Augment Dickey Fuller test conduct individual test for each panel for unit root and the gather all p-values for generating the results.

Table 4. Panel unit root tests

Fisher-type unit-root test based on augmented Dickey–Fuller tests				
Variables	I (0)		I (1)	
	Statistic	p-value	Statistic	p-value
CO2	103.943	0.955	993.112	0.000
CC	240.582	0.000	1187.825	0.000
GE	179.948	0.002	1159.976	0.000
PS	180.817	0.002	1023.000	0.000
RL	160.507	0.035	1119.338	0.000
RQ	193.816	0.000	1069.064	0.000
VA	148.060	0.132	965.073	0.000
LEF	312.299	0.000	578.893	0.000
LREC	124.392	0.622	1069.065	0.000
LFD	261.912	0.000	578.893	0.000
FOR	944.070	0.000	306.006	0.000
LIND	452.250	0.000	1319.262	0.000
LED	552.994	0.000	1412.518	0.000
LNREC	148.088	0.023	889.615	0.000

All of the variable are stationary at level excluding carbon dioxide emissions, VA and REC. No variable is stationary at two differences. All the variables are stationary at I(1).

Model results

Table 5 presents the empirical results of the Fixed Effect (FE) model, two-step difference Generalized Method of Moments (DGMM), and two-step system Generalized Method of Moments (SGMM) models for Belt and Road Initiative (BRI) countries over the period 2000-2020. The table is structured with the first column listing the variables, followed by columns two and three, which display the results of the FE and two-step DGMM models based on the institutional quality index. Column four shows the two-step SGMM model results for legal system indicators, while column five provides the results for the two-step SGMM model using the legal system index. Column six reports the two-step SGMM model for political system indicators, column seven presents the SGMM results for the political system index, and column eight shows the two-step SGMM model based on the institutional quality index.

In the FE model, economic freedom exhibits a negative but non-significant relationship with carbon dioxide emissions. However, in the two-step DGMM and SGMM models, economic freedom shows a negative and highly significant relationship with carbon dioxide emissions. These findings suggest that increased economic freedom is associated with reduced emissions, supporting the argument that greater economic freedom leads to improved political stability, which in turn encourages investments in clean, renewable energy sources and energy-efficient businesses (Shabani & Shahnazi, 2019). This outcome aligns with previous studies, including those by Bjørnskov (2020), Carlsson & Lundström (2001), Majeed et al. (2021), and Wu et al. (2022), which also found a negative relationship between economic freedom and emissions. In contrast, studies by Adesina & Mwamba (2019) and Bae, Li, & Rishi (2017) report conflicting results, indicating that the impact of economic freedom may vary depending on regional or structural factors not fully captured in this analysis.

Table 5. Results of FE, two-step dynamic GMM and system GMM

(1)	(FE-INSTDX)	(DGMM-INSTDX)	(SGMM-LEG)	(SGMM-LEGDX)	(SGMM-POL)	(SGMM-POLDX)	(SGMM-INSTDX)
$CO2_{it-1}$		0.202***	0.867***	0.882***	0.880***	0.879***	0.882***
		(0.017)	(0.020)	(0.011)	(0.015)	(0.014)	(0.011)
CC			0.152*				
			(0.087)				
GE			-0.032				
			(0.050)				
PS			0.109***				
			(0.028)				
EF	-0.344	-4.381***	-1.137**	-1.629***	-1.382***	-1.428***	-1.629***
	(0.730)	(0.377)	(0.459)	(0.384)	(0.184)	(0.386)	(0.384)
REC	0.598***	1.161***	-0.128***	-0.146***	-0.138***	-0.161***	-0.146***
	(0.185)	(0.098)	(0.037)	(0.028)	(0.036)	(0.029)	(0.028)
FD	0.068	0.255***	0.259***	0.271***	0.252***	0.309***	0.271***
	(0.085)	(0.038)	(0.043)	(0.022)	(0.035)	(0.031)	(0.022)
FOR	0.000***	0.000***	0.000	-0.000**	-0.000***	-0.000*	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
IND	0.003	0.0171*	0.113***	0.102***	0.091***	0.114***	0.102***
	(0.056)	(0.009)	(0.008)	(0.012)	(0.015)	(0.012)	(0.012)
ED	-0.023	0.0743***	0.005	0.001	-0.018	-0.027*	0.001
	(0.072)	(0.019)	(0.015)	(0.019)	(0.024)	(0.015)	(0.019)
NREC	1.242***	1.317***	0.260**	0.297***	0.224***	0.308***	0.297***
	(0.441)	(0.219)	(0.097)	(0.092)	(0.082)	(0.106)	(0.092)
INSTDX	-0.410**	0.153***					0.169***
	(0.191)	(0.038)					(0.036)
LEGDX				0.169***			
				(0.036)			
RL					0.625***		
					(0.100)		

Table 5 continue . . . .

RQ					-0.248***		
					(0.028)		
VA					-0.244***		
					(0.048)		
POLDX						0.135***	
						(0.043)	
Constant	-6.695***		1.135	1.891**	1.868***	1.415	1.891**
	(2.201)		(0.926)	(0.773)	(0.470)	(0.963)	(0.773)
Obs	439	310	415	415	415	415	415
R-squared	0.223						
No. of CID	54	48	54	54	54	54	54
AR2		-0.56	-0.63	-0.66	-0.62	-0.64	-0.66
		(0.577)	(0.529)	(0.508)	(0.537)	(0.524)	(0.508)
Sargan test		130.49	136.93	134.46	133.08	135.18	134.46
		(0.002)	(0.008)	(0.017)	(0.015)	(0.016)	(0.017)

Note: Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Regarding renewable energy consumption (REC), the FE and two-step DGMM models indicate a significantly positive relationship with carbon dioxide emissions. However, the most reliable estimators come from the SGMM models, which show that renewable energy usage is highly significantly negative. This implies that increased renewable energy usage effectively reduces carbon dioxide emissions. The results suggest that a 1% increase in renewable energy usage leads to a reduction in emissions of approximately 14.6% (LEGDX), 16.1% (POLDX), and 14.6% (INST-IND). This finding underscores the importance of transitioning from non-renewable to green energy sources in BRI countries to mitigate emissions effectively. The results align with the conclusions of previous studies, such as those by Apergis, Ben Jebli, & Ben Youssef (2018), Jebli, Farhani, & Guesmi (2020), and Sinha & Shahbaz (2018), which also demonstrate the emissions-reducing impact of renewable energy consumption. However, contrasting evidence comes from Apergis, Payne, Menyah, & Wolde-Rufael (2010), who found a positive relationship between renewable energy consumption and carbon dioxide emissions when examining 19 developing and developed economies from 1984 to 2004. The divergence in findings could be attributed to different time periods, regions, or the stages of economic development and energy transition in the countries studied.

The findings indicate that financial development has a highly significant and positive effect on carbon emissions. This suggests that as financial development progresses, carbon emissions increase, a pattern observed in other studies such as those by Guo, Hu, & Yu (2019), Ling et al. (2022), and Nasir, Huynh, & Tram (2019). The reasoning behind this relationship is that financial development often stimulates economic growth, leading to increased industrial activities and energy consumption, which in turn raises emissions. The positive relationship is consistently observed across most models, though it is non-significant in the FE model. These results contradict the findings of studies like Boutabba (2014), Diallo & Masih (2017), Jian et al. (2019), Jiang & Ma (2019), Omri et al. (2015), Raza & Shah (2018), and Zhang & Cheng (2009), which reported differing impacts of financial development on carbon emissions, potentially due to differences in the stages of economic development or variations in the implementation of environmental regulations across countries.

The empirical evidence further confirms that forest area has a significant negative impact on carbon emissions, aligning with the findings of Stern (2006) and Waheed et al. (2018). This is explained by the fact that forests play a critical role in absorbing carbon dioxide through photosynthesis, thus acting as a natural carbon sink. These findings highlight the importance of forest conservation and expansion in mitigating carbon emissions. Preventing deforestation and promoting reforestation and afforestation are effective strategies for reducing emissions, as forests are essential in balancing the carbon cycle. The significant negative effect observed in the results underscores the urgent need to integrate forest preservation into national and regional environmental policies, a factor often overlooked in previous research.

The analysis also shows that industrial growth has a significantly positive impact on carbon emissions. This is consistent with studies by Afawubo & Ntouko (2016), Martínez-Zarzoso & Maruotti (2011), Rauf et al. (2018), and Shahbaz et al. (2014). The positive relationship suggests that as industrial activities expand, they rely heavily on energy primarily derived from fossil fuels thus increasing emissions. In developing economies, environmental policies may not be stringent enough, and globalization often promotes the growth of pollution-intensive industries. As industrialization and globalization advance, the demand for energy intensifies, typically supplied by non-renewable sources such as coal and oil. This further explains why industrial growth is positively correlated with emissions, as noted by Sabir & Gorus (2019). However, some studies, including those by Aslam et al. (2021), Dodman (2009), Dong et al. (2020), and Fan et al. (2006), found that industry, when supported by appropriate environmental regulations and energy-efficient practices, can also reduce emissions, highlighting the potential for policy interventions to mitigate the negative environmental impacts of industrialization.

Economic development shows a mixed relationship with carbon emissions. In the FE and two-step SGMM (political system) models, it is non-significant and negative, while it is non-significant and positive in the two-step SGMM (legal system) and two-step SGMM (legal system index) models. In the political system index, it is significantly negative. These variations are consistent with Wang & Li (2021), who argue that the influence of economic development on emissions may depend on the strength of governance and institutional quality. Studies such as those by Abdallh & Abugamos (2017), Balibey (2015), Muhammad (2019), Saidi & Hammami (2015), Saidi & Mbarek (2017), Sharif Hossain (2011), and Zaman & Abd-el Moemen (2017) found a positive relationship between GDP per capita and emissions, indicating that as economies grow, emissions tend to rise. This is expected in developing economies where growth often relies on energy-intensive sectors. Conversely, Kasman & Duman (2015) found that GDP could have a discouraging influence on emissions, particularly when countries adopt cleaner technologies and environmental policies. Additionally, studies by Salahuddin & Gow (2014), Acheampong (2018), Gorus & Aydin (2019), and Soytas et al. (2007) present evidence that GDP may have no significant effect on carbon emissions, suggesting that the impact of economic growth on emissions is complex and varies depending on the context.

Non-renewable energy consumption consistently shows a strongly significant and positive relationship with carbon emissions across all models. This indicates that reliance on fossil fuels, a major energy source in BRI countries, is detrimental to the environment. Most countries in the sample are classified as low-income or lower-middle-income economies (World Bank, 2021), where economic growth is heavily dependent on energy from non-renewable sources. This reliance leads to environmental degradation, as fossil fuel consumption contributes significantly to carbon emissions. These findings emphasize the need for a transition to green energy sources to reduce emissions effectively. The results are consistent with studies by Chen et al. (2019), Dogan & Seker (2016), Liu et al. (2017), and Vural (2020), which highlight the importance of renewable energy in reducing emissions.

The legal system index, political system index, and institutional quality index all show a positive and significant relationship with carbon emissions. Weak institutional quality can lead to environmental damage and economic risks, as suggested by Le et al. (2016) and Shah et al. (2019). The study shows that financial development depends on institutional quality (La Porta et al., 1997), and when institutional quality is low, it can degrade the environment (Ling et al., 2022). The analysis identifies specific variables within the political and legal systems such as regulatory quality, voice and accountability, and government effectiveness that have significant negative impacts on carbon emissions (Karim et al., 2022; Khan et al., 2022; Piabuo et al., 2021). Conversely, other variables like political stability, control of corruption, and rule of law show positive and significant influences on emissions, consistent with findings from Abid (2016), Cansino et al. (2019), and Damania et al. (2003). Olson (1996) highlighted that the quality of political institutions can foster productive competition. A well-structured political system is crucial in enforcing emission control measures. If clear and robust regulations exist, firms are likely to comply, reducing emissions. In contrast, weak regulatory frameworks may allow firms to evade compliance, exacerbating environmental harm. Poor institutional quality can hinder economic development without addressing environmental impacts (Lopez & Mitra, 2000; Welsch, 2004).

In models 3, 5, 7, and 8, the construction of legal system index, political system index, and institutional quality index using principal component analysis shows that these indices are strongly significant. The positive sign indicates that weaknesses in indicators such as rule of law, voice and accountability, government effectiveness, control of corruption, political stability, and regulatory quality contribute significantly to increased carbon emissions. This highlights that deficiencies in these institutional aspects have adverse consequences for environmental quality, underscoring the importance of strengthening institutions to manage and mitigate carbon emissions effectively.

Robustness Check

The robustness check results for the legal and political system indexes, using the control of corruption (CC) from the legal system and rule of law (RL) from the political system, are presented in Table 6. These variables have been utilized recently by studies such as Hunjra et al. (2020) and Khan et al. (2022b). The findings are consistent with the main model results, confirming the robustness of the selected variables. In the two-step system GMM results, the lagged carbon dioxide emissions (LCO2) variable shows a highly significant positive relationship with coefficients of 0.876 and 0.879 in the CC-LEG and RL-POL models, respectively, indicating that past emissions positively influence current levels. The rule of law (RL) also shows a positive and significant coefficient of 0.169 in the RL-POL model, supporting the impact of political system strength on emissions. Economic freedom (LEF) displays a significant negative relationship with carbon emissions, with coefficients of -1.284 and -1.428 in the CC-LEG and RL-POL models, respectively. This aligns with the expectation that higher economic freedom reduces emissions through investments in cleaner technologies. Renewable energy consumption (LREC) is significantly negative in both models, with coefficients of -0.140 and -0.161, suggesting that increased renewable energy use leads to lower emissions.

Conversely, financial development (LFD) exhibits a significant positive relationship with emissions, with coefficients of 0.272 and 0.309 in the CC-LEG and RL-POL models, respectively. This reinforces the earlier findings that financial development, while essential for economic growth, may increase emissions if not accompanied by sustainable practices. Forest area (FOR) shows a non-significant result in the CC-LEG model but is weakly significant ($p<0.1$) with a negative coefficient in the RL-POL model, indicating the importance of forest preservation in emission reduction efforts. Industrial growth (LIND) is positively associated with carbon emissions, with coefficients of 0.105 and 0.114, reflecting the emissions-intensive nature of industrial activities. Education level (LED) shows a weak negative association in the RL-POL model, but it remains non-significant in the CC-LEG model. Non-renewable energy consumption (NREC) has a strong and significant positive impact on emissions, with coefficients of 0.207 and 0.308, highlighting the role of fossil fuel consumption in increasing carbon emissions. The control of corruption (CC) variable also shows a significant positive coefficient of 0.202 in the CC-LEG model, indicating that despite the intention of improving governance, its current influence still correlates with higher emissions.

Table 6. Robustness check (Two step system GMM results)

Variables	CC-LEG	RL-POL
LCO2	0.876***	0.879***
	(0.013)	(0.014)
RL		0.169***
		(0.054)
LEF	-1.284**	-1.428***
	(0.490)	(0.386)
LREC	-0.140***	-0.161***
	(0.032)	(0.0292)
LFD	0.272***	0.309***
	(0.038)	(0.0312)
FOR	-0.000	-0.000*
	(0.000)	(0.000)
LIND	0.105***	0.114***
	(0.013)	(0.0127)
LED	-0.000	-0.027*
	(0.017)	(0.015)
NREC	0.207***	0.308***
	(0.051)	(0.106)
CC	0.202***	
	(0.055)	
Constant	1.644*	1.447
	(0.942)	(0.970)
Obs.	415	415
No. of CID	54	54
AR2	-0.64	-0.64
	(0.520)	(0.524)
Sargan test	136.55	135.18
	(0.013)	(0.016)

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

The constant term is weakly significant in the CC-LEG model ($p<0.1$) but non-significant in the RL-POL model. The robustness check models include 415 observations with 54 cross-sectional IDs, and the results for the AR2 test indicate no autocorrelation issues, as the p-values (0.520 and 0.524) are not significant. The Sargan test results (136.55 and 135.18 with p-values of 0.013 and 0.016, respectively) suggest that the instruments used are valid and the models are appropriately specified.

Conclusion

The Belt and Road Initiative (BRI) countries, primarily composed of developing and emerging economies, face significant environmental challenges due to their reliance on fossil fuels, rapid industrial growth, and evolving economic structures. These countries contribute substantially to global carbon emissions, affecting climate change and environmental sustainability. As international efforts focus on reducing emissions, understanding the economic, institutional, and environmental factors driving emissions in these countries is crucial. This research evaluates the impact of various factors such as institutional quality, economic freedom, non-renewable and renewable energy consumption, industrial growth, financial development, economic development, and forest cover on carbon emissions in 65 BRI countries between 2000 and 2020. The study employs econometric models, including Fixed Effects (FE) and dynamic panel models like the two-step difference Generalized Method of Moments (DGMM) and the two-step system Generalized Method of Moments (SGMM), to provide a robust analysis of these relationships. The findings reveal that economic freedom has a significantly negative impact on carbon emissions, demonstrating that when countries promote economic freedom with strong regulatory frameworks, they can reduce emissions. Without adequate governance, however, economic freedom can lead to environmental harm. These results emphasize that BRI countries must combine economic freedom with institutional reforms to maximize its environmental benefits. Renewable energy consumption also shows a strong negative relationship with emissions, indicating that increasing the use of renewable energy sources can significantly reduce emissions by up to 16.1% across the sample countries. Given that many of these nations are lower-income economies heavily reliant on non-renewable energy, the findings highlight the need for substantial investment and policy support to transition towards green energy. Policymakers should prioritize green energy initiatives, offering incentives to adopt cleaner technologies and reduce dependence on fossil fuels. On the other hand, non-renewable energy consumption has a strong positive association with carbon emissions, consistent across all models. The results underline the urgent need for BRI countries to reduce reliance on fossil fuels and increase the use of renewable energy to mitigate environmental impact and create new economic opportunities through the development of green technologies. Financial development is also found to have a positive effect on carbon emissions. Although financial development is essential for economic growth, it can lead to environmental degradation if not aligned with sustainability goals. In BRI countries, the financial sector often prioritizes short-term gains and traditional energy sectors, underscoring the need for policymakers to reorient financial institutions towards sustainable investments. Forest cover is shown to have a negative relationship with emissions, underscoring its importance in carbon sequestration. However, deforestation, driven by land clearance for urbanization and agriculture, remains prevalent in many of these countries, exacerbating environmental degradation. Policymakers must implement strict regulations to control deforestation while promoting reforestation and afforestation to expand forest areas, which is an effective strategy for reducing emissions. The study finds economic development to be non-significant in relation to carbon emissions, suggesting that growth in BRI countries does not inherently increase emissions. However, given that many economies in the region depend heavily on fossil fuel industries, this implies that without a shift toward greener industries, economic growth alone cannot lead to sustainable development. To achieve sustainable growth, policymakers must diversify economies and promote clean technology sectors. Industrial growth is associated with increased emissions, particularly in lower-income countries that focus on expanding energy-intensive manufacturing industries. In the early stages of industrialization, these economies often rely on pollution-heavy industries, accelerating environmental degradation. As countries become wealthier, they have the opportunity to invest in cleaner technologies. Therefore, governments should prioritize policies that promote advanced, environmentally friendly technologies as their economies develop. Institutional quality shows mixed results. Strong institutions, indicated by regulatory quality, government effectiveness, and voice and accountability, negatively affect emissions, highlighting their importance in protecting the environment. Conversely, weak institutional elements, such as inadequate rule of law, poor control of corruption, and political instability, contribute to increased emissions. These findings suggest that when institutional quality is low, regulatory gaps may be exploited, leading to greater pollution. The study finds that legal, political, and overall institutional quality indexes are associated with higher emissions, indicating the need for improvement to reduce emissions and support sustainable development. Robustness checks using control of corruption (CC) and rule of law (RL) confirm the consistency and reliability of these results, emphasizing the importance of strong governance frameworks. Despite its comprehensive nature, the study has limitations. The focus on BRI countries may limit the generalizability of the findings, as these countries have unique development trajectories that may not apply to other regions. The panel data models provide a broad view but may overlook specific local factors influencing emissions, such as governance practices and technological capabilities. Additionally, the study's macro-level approach might not capture firm-level practices or technological innovations that could influence emissions outcomes.

Future research should expand to a global sample, categorizing countries by income levels to understand the impact of economic disparities on emissions. This approach could reveal whether higher-income countries exhibit different emissions patterns compared to lower-income nations. Further exploration of the moderating role of economic freedom on environmental outcomes could provide deeper insights into how institutional and economic environments affect emissions. Future studies should also integrate micro-level data to better understand how innovation, firm-level practices, and local governance influence emissions control. Such research would provide a more detailed understanding of emissions reduction strategies, helping identify effective policies for promoting sustainability.

Appendices

Appendix 1

Table 7. One Belt One Road countries list with income level

Country	Income	Country	Income	Country	Income	Country	Income	Country	Income
Afghanistan	L	China	UM	Israel	H	Montenegro	UM	Slovak Republic	H
Albania	UM	Croatia	H	Jordan	UM	Myanmar	LM	Slovenia	H
Algeria	LM	Cyprus	H	Kazakhstan	UM	Nepal	LM	Sri Lanka	LM
Armenia	UM	Czech Republic	H	Kuwait	H	Oman	H	Syrian Arab Republic	L
Azerbaijan	UM	Egypt, Arab Rep.	LM	Kyrgyz Republic	LM	Pakistan	LM	Tajikistan	LM
Bahrain	H	Estonia	H	Lao PDR	LM	Philippines	LM	Thailand	UM
Bangladesh	LM	Georgia	UM	Latvia	H	Poland	H	Turkey	UM
Belarus	UM	Greece	H	Lebanon	LM	Qatar	H	Turkmenistan	UM
Bhutan	LM	Hungary	H	Lithuania	H	Romania	H	Ukraine	LM
Brunei Darussalam	H	India	LM	Malaysia	UM	Russian Federation	UM	United Arab Emirates	H

Table 7 continue. . . .

Bulgaria	UM	Indonesia	LM	Maldives	UM	Saudi Arabia	H	Uzbekistan	LM
Burkina Faso	L	Iran,	LM	Moldova	UM	Serbia	UM	Vietnam	LM
Cambodia	LM	Iraq	UM	Mongolia	LM	Singapore	H	Yemen, Rep.	L

Appendix 2

Table 8. Description of symbols and data sources

Symbol	Unit/Proxied by	Data Source
CO2	CO2 emissions (metric tons per capita)	
CC		
GE		
PS	WGI Indicators	World Bank
RL		(www.govindicators.org)
RQ		
VA		
LEF	Log of economic freedom. This index was normalized on a scale of 0-10 with 10 the highest score	Heritage Foundation
LREC	Log of electricity net consumption (billion kWh)	EIA
LFD	Log of domestic credit to private sector by banks (% of GDP)	World Bank
FOR	Forest area (sq. km)	EIA
LIND	Log of industry (including construction), value added (annual % growth)	World Bank
LED	Log of GDP per capita growth (annual %)	World Bank
NREC	Log of fossil fuel energy consumption (% of total)	World Bank
LEG-IND	Constructed from CC, GE, PS	
POL-IND	Constructed from RL, RQ, VA	World Bank
INST-IND	Constructed from RL, RQ, VA, CC, GE, PS	
FE	Fixed Effects	
DGMM	Difference generalised method of moments	
SGMM	System generalised method of moments	
GDP	Gross domestic product	
OBOR	One Belt One Road	
GHG	Greenhouse gas	
L	Low income	
LM	Lower middle income	World Bank Classification
UM	Upper middle income	
H	High income	
ADF	Augment Dickey Fuller	

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RESEARCH ARTICLE

Carbon, Capital, and the Climate: The Economic Puzzle of CO_2 Emissions in South Asia

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Abstract

The rapid rise in carbon dioxide (CO_2) emissions is a major contributor to global warming, making it crucial to understand the key drivers, especially in vulnerable regions like South Asia. This study analyzes the determinants of CO_2 emissions in South Asia from 2000 to 2021 using Environmental Kuznets Curve (EKC) modeling, multiple linear regression, and panel data analysis. Findings indicate that GDP per capita is a primary driver of emissions, while renewable energy helps mitigate carbon emissions. However, the EKC model does not confirm an inverted U-shaped relationship, suggesting South Asia has yet to reach the turning point where economic growth curbs emissions. The findings also suggest that urbanization, industrialization, and per capita energy use contribute to emissions. Panel data analysis, incorporating the Paris Agreement as a structural break, reveals its limited impact on reducing emissions in the region, stressing the need for stronger policy enforcement. The study underscores the importance of accelerating renewable energy adoption, promoting sustainable urbanization, and decarbonizing industries to address climate challenges. Policymakers need to enhance regional cooperation and integrate low-carbon strategies to achieve sustainable development while combating climate change in South Asia.

Keywords: Environmental Kuznets Curve; CO_2 Emissions; South Asia; Renewable Energy; Paris Agreement

Introduction

The relationship between economic development and environmental deterioration has been a crucial area of research in environmental economics. The role of economic factors in determining carbon emissions remains an important issue for countries undergoing rapid industrialization and urbanization (Li and Lin, 2015). South Asia is a prime example in this regard. The region has a unique combination of developing economies, diverse energy portfolios and high population density (Fang, Liu and Putra, 2022), which makes it a pivotal case for examining the determinants of carbon emissions and their effects on sustainable economic growth. South Asia is one of the world's most vulnerable regions to the impacts of climate change. Increased frequency of severe weather events along with rising temperatures and erratic rainfall patterns in the region have profound implications for the livelihoods and food security (Caesar and Janes, 2018; Khalid and Ahmad, 2021). Rising sea-level further threatens densely populated coastal areas (Sivakumar and Stefanski, 2011). These vulnerabilities underscore the urgency of striving for robust climate policies aimed at climate change mitigation and adaptation to minimize the repercussions of the climate-induced disruptions. Despite these vulnerabilities, South Asia's share in the global greenhouse gases (GHGs) emissions remains uneven. India is the largest economy in the region and accounts for about 7% of the global emissions. However, its per capita emissions are considerably lower than those of developed economies (International Energy Agency (IEA), 2022). The contribution of other countries in the region, such as Pakistan, Bangladesh and Nepal, are far lower and Bhutan has achieved carbon neutrality (Yangka, Rauland and Newman, 2023). The region's progress in fulfilling the commitments under the Paris Agreement is yet to be explored. However, greater ambition is required to enhance its leadership in efforts directed at global emission reduction (Fulton et al., 2017). Economic growth fueled by industrialization in South Asia has considerably contributed to rising CO2 emissions, with key sectors such as energy production and manufacturing playing a dominant role. Islam, Raihan and Islam (2024) report that the brick manufacturing industry in Bangladesh, India and Nepal has expanded significantly in recent years, which has resulted in severe environmental degradation on account of either lack of regulations or weak compliance to the existing laws.

A key demographic trend in South Asia is urbanization (Das and Paul, 2021), which further complicates the situation because it not only drives energy demand but also exacerbates environmental degradation. Rampant urbanization poses challenges concerning waste management along with other issues, which exacerbates environmental degradation (Kaur and Punera, 2023). The region's renewable energy demand remains mostly untapped despite considerable strides in recent years (Asif, Khan, Pandey, 2024). Moreover, industrialization driven economic growth is on the rise in the region, which is generally associated with a rise in carbon emissions, while clean energy adoption along with improvements in energy efficiency are termed as effective mitigation strategies (Stern, 2004). The integration of these variables may provide a comprehensive analysis of the interactions of economic and energy factors with carbon emissions in the region. For instance, Pakistan aims to generate 60% of its energy requirement from renewable resources by 2030 in comparison to the 32% (7% solar and wind and 25% hydro) share at present (International Trade Administration, 2024). Moreover, renewable energy accounts for 40% of India's total capacity and aims to achieve the target of 500 GW of renewable energy production by 2030 (IEA, 2024). However, progress towards achieving ambitious renewable energy production goals varies across the region, which necessitates coordinated efforts to enhance investments in clean energy technologies and infrastructure.

This study examines the determinants of CO_2 emissions per capita in South Asia during the period 2000-2021, with a focus on key drivers like GDP per capita, renewable energy consumption, urban population, energy use per capita and industry value added to GDP. Such relationships have rarely been explored in the context of South Asia. The study is a valuable addition to the growing body of knowledge regarding the impact of economic activities and energy usage on climate change in the developing countries. This paper provides empirical evidence to inform policy decisions in South Asia by examining the relationships between economic and energy variables and their impact on CO_2 emissions per capita. The findings of this study highlight the need for holistic strategies aimed at balancing growth with environmental sustainability. Such strategies are crucial for mitigating climate risks and position South Asia as a proactive participant in the global transition to a low-carbon economy.

This paper is structured as follows: the introduction is followed by a comprehensive literature review, discussing the theoretical framework and key economic and energy variables in light of existing literature. It is followed by methodology, explaining the empirical methods employed in the analysis. Results and discussion section encompass data analysis through econometric models and a detailed discussion of the results. The last part of the study provides a conclusion, summarizing the findings of the study along with policy recommendations.

Literature Review

The relationship between economic growth and environmental degradation has been studied extensively in the environmental economics literature. Theoretical and empirical research aim to examine the dynamics between economic operations and carbon emissions, provide insights into ways through which sustainable development can be achieved. The EKC hypothesis is an influential framework in this discourse. It provides a far-reaching perspective on how economic development impacts environmental outcomes.

Environmental Kuznets Curve (EKC)

The EKC hypothesis suggests an inverted U-shaped relationship between economic growth and environmental deterioration (Grossman and Krueger, 1995). It posits that the early stages of economic development are characterized by rapid industrialization and urbanization, leading to a rise in pollution levels on account of increased fossil fuel consumption and resource exploitation. However, when per capita income increases beyond a certain threshold, the demand for technological advancements, cleaner environmental and strict regulations result in a reduction in pollution levels. The turning point occurs when societies have the political will and resources to prioritize environmental sustainability (Dinda, 2005). Empirical studies provide mixed evidence regarding the validity of the EKC. Stern (2004) argues that the EKC's applicability varies depending on the economic structure of a country, the time period and the type of pollutant. Dinda (2005) stipulates that although several developed countries exhibit the EKC pattern, its relevance for the developing world remains debatable. In South Asia, rising GDP per capita, particularly in India, has led to considerable increase in carbon emission on account of industrial growth and heavy reliance on coal (Sharma and Mehrotra, 2020). While countries like Pakistan and Bangladesh have lower emission levels, their upward economic trajectories may result in similar challenges. Policies aimed at renewable energy adoption along with energy efficiency are crucial for shifting these economies toward the downward slope of the EKC (Rahman and Velayutham, 2020). Environmental degradation is caused by several economic and energy related factors in the post-industrial world (Gorova et al., 2012). Some of these key factors and their relation with CO_2 emissions are discussed here in light of existing literature.

Economic Growth and CO_2 Emissions

Economic development is one of the most important drivers of CO_2 emission around the world. Economic growth, as a result of industrial production, energy consumption and transportation, result in higher emissions (Duan et al., 2022). The positive relationship between economic growth and carbon emissions is well-documented in the economic literature. For instance, Onofrei, Vatamanu and Cigu (2022) examine the relationship between economic growth and CO_2 emissions in the EU and find that the two variables have a cointegrating relationship. Similarly, Ang (2007) concludes that GDP per capita has a strong positive relationship with carbon emissions in France. The study highlights the importance of technological and regulatory interventions in mitigating environmental deterioration. Chang and Lee (2014) also show a long-term correlation between GDP per capita growth and carbon emission in industrialized countries. Some studies show that when income levels reach beyond a certain threshold, countries may experience a reduction in carbon emission, as highlighted by the EKC hypothesis. However, the declension point varies among countries depending on factors like regulatory strength, energy mix and technological advancement (Stern, 2004). It implies that economic growth may not ensure environmental improvements in isolation. Deliberate policy measures promoting energy efficiency and clean energy are necessary in this regard (Lu et al., 2020).

In addition to the developed countries, environmental protection has come to the forefront of contemporary issues for developing countries in the recent past due to concerns about the after effects of climate change (Uddin et al., 2017). South Asia is no exception in this regard. The region's economic landscape is characterized by rapid economic growth over the last few decades, particularly in India, Bangladesh and Pakistan. However, such growth has come at a considerable environmental cost. GDP per capita has increased significantly in India alongside a consistent rise in carbon emissions on account of industrialization and heavy reliance on fossil fuels (Tiwari, 2011). Alam et al. (2012) argue that the relationship between GDP growth and carbon emissions is positive in South Asia, as emission increases with an increase in income. They argue that it indicates the early stage of the EKC pattern. Industrialization of the region's certain economies reinforces this trend, driven by urbanization and energy-intensive production (Rahman and Velayutham, 2020). Pakistan's emission trajectory follows a similar economic growth-carbon emissions link, with an immediate need for cleaner energy technologies and effective environmental regulations (Mirza and Kanwal, 2017). It shows that GDP growth continues to be tightly linked with fossil fuel consumption in the entire region, which highlights the absence of widespread adoption of sustainable industrial practices and renewable energy. The region's heavy reliance on oil and coal for energy production amplifies the environmental impact of economic expansion. A decoupling of economic growth and emissions remains elusive in South Asia. It is in contrast to the developed regions, where effective regulations and technological innovations mitigate carbon emissions relative to economic growth (Huisingh et al., 2015). Economic development strategies need to be integrated with carbon reduction mechanisms to prevent locking in high-emissions growth pathways (Bhattacharya et al., 2016).

Renewable Energy Consumption and CO_2 Emissions

The relationship between renewable energy consumption and carbon emissions has gained increasing attention as countries continue their efforts to mitigate climate change. Renewable energy sources like solar, wind, and hydropower are influential in contributing to lower GHG emissions. These are regarded as cleaner alternatives to fossil fuels (Dincer and Acar, 2015). Evidence concerning the negative relationship between renewable energy consumption and CO_2 emission exists in literature. For instance, Al-Mulali, Ozturk and Lean (2015) report that a rise in renewable energy use tends to reduce CO_2 emission in both developed and developing countries. Similarly, Namahoro et al. (2021) argue that in developing countries, an increase in the share of renewables in total energy consumption leads to a reduction in carbon intensity. It is important to mention that the extent to which renewable energy reduces carbon emissions depends on several factors, including policy frameworks (Agupugo et al., 2022), technology adoption rates and energy infrastructure (Usman and Radulescu, 2022). Bhattacharya et al. (2016) also argue that the effectiveness of renewable energy consumption depends on regulatory support and the level of investment in renewable technology. Moreover, political environment and market conditions are also influential in the success of renewable energy consumption in reducing carbon emissions (Marques and Fuinhas, 2012).

South Asia's energy sector is heavily reliant on fossil fuels, as discussed above. However, renewable energy adoption has gained momentum in the recent past as part of efforts directed at climate change mitigation strategies (Asif, Khan and Pandey, 2024). Renewable energy capacity has expanded considerably in India, contributing to a reduction in carbon intensity. Moreover, investments in solar and wind energy in the country have also helped offset carbon emissions despite a steep rise in energy demand (Shahbaz et al., 2021). Rahman and Velayutham (2020) conclude that the impact of renewable energy on carbon emissions in Bangladesh has been modest on account of the meagre share of renewables in the national energy mix. They suggest that financial incentives for clean energy along with enhancing renewable energy infrastructure may enhance the effectiveness of carbon emission reductions. Similarly, Sinha and Shahbaz (2018) stipulate that while renewable energy use is negatively correlated with CO_2 emissions but lack of required infrastructure in the country hinders large-scale renewable energy adoption. Based on the above discussion, it is evident that the share of renewables in total energy consumption remains insufficient across South Asia to alter carbon emission trajectories. Alam et al. (2012) underscore that policy frameworks in the region are not yet robust enough to stimulate large-scale renewable transitions, resulting in continued reliance on fossil fuels for industrial growth and urbanization.

Urban Population and CO_2 Emissions

The rapid expansion of urban areas has significant implications for CO_2 emissions on account of industrial activity, higher energy demand and transportation. Urbanization results in higher fossil fuels consumption for heating, mobility and electricity, thereby accelerating emissions (Wang et al., 2021). Studies have validated the positive relationship between urbanization and carbon emission. For instance, Martínez-Zarzoso and Maruotti (2011) report a positive relationship between the two variables in developing countries, as expansion of urban areas leads to infrastructure development and higher fossil fuel-based energy consumption. Similarly, Wang, Li and Fang (2018) state that the relationship between urbanization and emissions in low- and middle-income countries depends on the stage of economic development. Urbanization has been a key driver of carbon emissions in South Asia. Raihan et al. (2022) argue that a rapid rise in the rate of urbanization in countries like Bangladesh has led to an increase in energy consumption, contributing to higher CO_2 emissions. Similarly, Franco, Mandla and Rao (2017) report that urban expansion in India has resulted in a rise in CO_2 emissions on account of higher energy consumption. Acharya and Acharya (2023) argue that urbanization in South Asia has resulted in a steep rise in carbon emissions and infrastructure development is a major source of these emissions. These studies underscore that while urbanization drives economic growth it necessitates effective policies for sustainable urban development.

Energy Use per Capita and CO_2 Emissions

One of the most direct determinants of CO_2 emission is energy use per capita because literature suggests that higher energy consumption often correlates with increased fossil fuel burning (Andres et al., 2011). Empirical research has shown that rising energy consumption results in higher CO_2 emissions. For instance, Ang (2007) concludes that energy use and CO_2 emissions have a statistically significant positive relationship after analyzing data from 54 countries. Ozturk and Acaravci (2010) also validated Ang's findings and argue that energy efficiency improvements are pivotal for reducing emission. Energy use per capita has increased substantially in South Asia on account of industrialization and urbanization. Some studies have focused on the entire South Asian region and report that fossil fuel-based energy consumption has led to a steep rise in CO_2 emissions in the region (Alom, 2014; Murshed, Ali and Banerjee, 2021), while others have focused on individual countries. For instance, Ahmad et al. (2016) report that energy consumption patterns in India are heavily reliant on fossil fuels, which makes the country a major CO_2 emitter in the region. Bangladesh is no different in this regard as Alam at el. (2012) argue that per capita energy use in the country is on the rise in the country, which drives carbon emissions. Similarly, Lin and Raza (2019) conclude that economic activities along with urbanization have increase energy consumption in Pakistan, which has resulted in increased CO_2 emissions.

Industry Value Added and CO_2 Emissions

Industrial sector is one of the major contributors to CO_2 emissions, particularly in countries undergoing rapid industrialization (Li and Lin, 2015). Industry value-added represents the industrial sector's contribution to GDP and is generally correlated with increased carbon emissions on account of energy-intensive production processes (Lin and Tan, 2017). The relationship between industry value added and CO_2 emissions is intricate and may vary across different contexts. While some studies suggest that industrialization results in a rise in emissions (Wang et al., 2021; Duan et al., 2022; Vatamanu and Cigu, 2022), other suggest a more nuanced relations between the two variables, where industrial value added may not necessarily increase CO_2 emissions (Lin, Omoju and Okonkwo, 2015). Several studies have explored the relation between industry value added and CO_2 emissions in different contexts. For instance, Du et al. (2018) explore this relation in China and report that a higher industry value added to GDP leads to a rise in CO_2 emissions. The study highlights that energy intensive industries are major contributors to emissions in this regard. The relation between industry value-added and CO_2 emissions may vary across developed and developing countries. Industrialization contributes to pollution in both cases but developed countries are more likely to adopt environmentally friendly technologies (Çelik and Deniz, 2009). Like other developing regions, South Asia presents a similar picture. Industrial growth in the region has a positive impact on GDP but it has resulted in a rise in CO_2 emissions (Islam, 2021). Lao and Luo (2024) report that a 1% increase in industrial value added is linked with a 0.7 rise in CO_2 emissions across South Asian economies. Similarly, Sharmin (2022) and Das (2024) find that a higher industry value added to GDP leads to a significant rise in CO_2 emissions across South Asia.

Paris Agreement and South Asia

The Paris Climate Agreement was adopted in December 2015 under the United Nations Framework on Climate Change (UNFCCC) and regarded as a landmark international accord to limit global temperature rise to below 2°C above pre-industrial levels, with efforts to restrict it to 1.5°C (UNFCCC, 2015). It emphasizes voluntary and nationally determined contributions (NDCs), fostering global collaboration in climate action. South Asia is one of the most vulnerable regions to the adverse impacts of climate change on account of its geographical and socioeconomic characteristics (IPCC, 2019). While some countries in this region, like India, Bangladesh. Pakistan and Sri Lanka, have committed to ambitious NDCs, balancing economic growth with environmental sustainability remains a major challenge (Dewasiri et al., 2024).

Research Gaps

While the EKC hypothesis offer valuable insights into the interplay of economic growth and environmental degradation, their applicability to South Asia requires further evidence. Key questions remain regarding the specific roles of urbanization, energy use per capita, renewable energy usage and industry value added in shaping the region's carbon emissions trajectory. While there is substantial literature on the relationship between the above discussed variables and CO_2 emissions, the impact of economic growth (GDP per capita growth) on CO_2 emissions while renewable energy consumption, urbanization, energy use and industry value moderating this relation, particularly in the case of South Asia, has rarely been studied so far. Moreover, there is limited research investigating how the Paris Agreement has influenced CO_2 emissions and related determinants. Existing literature focus more on global or developed regions, leaving a gap in understanding the dynamic relationships between economic activities and environmental outcomes in South Asia post-2015 (Alam et al., 2017). This study aims to fill these gaps by integrating these variables into a comprehensive empirical analysis to provide insights that may not only inform region-specific climate policies but also contribute to literature by providing a holistic analysis of these relationships in the context of a rapidly developing region. The study aims to provide actionable recommendations for sustainable economic growth by integrating theoretical insights with recent empirical data.

Methodology

Data and Variables

This study conducts empirical analysis to determine the impact of key economic and energy variables on CO_2 emission per capita across South Asia. The study uses annual data from 2000 to 2021 from eight countries in the region, namely Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka. The data is retrieved from the World Bank's World Development Indicators database. Table. 1 provides an overview of the variables included in this study. The dependent variable in the analysis is CO_2 emissions per capita (*CO_2_per_capita*), while the independent variables are GDP per capita (*GDP_per_capita*) along with key economic and energy variables like renewable energy consumption (*Renewable_Energy*), urban population (*Urban_Population*), energy use per capita (*Energy_Use*) and industry value added (*Industry_Value*). The analysis encompasses correlation analysis, multiple linear regression and panel data analysis.

Table.1. Source and Description of Variables

Variables	Description	Unit of Measurement	Source
CO_2_per_capita	CO_2 emissions per capita	metric tons	World Bank
GDP_per_capita	Real GDP per Capita	Current US$	World Bank
Renewable_Energy	% of total energy consumption	Percent (%)	World Bank
Urban_Population	Urbanization Rate	Percent of total population	World Bank
Energy_Use	Energy use per capita	Kg of oil equivalent per capita	World Bank
Industry_Value	Industry value added as % of GDP	Percent (%)	World Bank

Empirical Methods

The study follows a sequential modeling approach in line with the study by Shafik and Bandyopadhyay (1992), beginning with *GDP_per_capita* as independent variable in the EKC regression model before integrating variables like *Renewable_Energy*, *Urban_Population*, *Energy_Use* and *Industry_Value* in the multiple linear regression model, it is followed by panel data analysis which estimates the relationship between *CO_2_per_capita* and *GDP_per_capita, Renewable_Energy and Urban_Population*. These analyses are preceded by descriptive statistics to gain insights into the data and correlation analysis to determine the level of association among variables.

EKC Regression Model

The EKC regression model aims at estimating the relationship between CO_2 emission per capita and GDP per capita in South Asia. The model encompasses a quadratic term to test the EKC hypothesis of an inverted U-shaped curve. The proposed model is here as follows.

$$CO_2\_per\_capita = \beta_0 + \beta_1.GDP\_per\_capita + \beta_2.GDP\_per\_capita\hat{}2 + \varepsilon$$

where *CO_2_per_ capita* is the dependent variable, *GDP_per_capita* is the independent variable, β_0 is the intercept, β_1 represents the marginal effect of GDP per capita on CO_2 emissions per capita, β_2 represents the non-linear relationship by examining the quadratic term. It aims to determine whether CO_2 emissions show a turning point behavior as GDP increases, as stated in the EKC framework and ε is the error term.

The model includes only *GDP_per_capita* as it follows the theoretical foundation of the EKC hypothesis and simplifies its interpretation. *GDP_per_capita* and its squared term form the core of the EKC framework and provide a fundamental test of whether an inverted U-shaped curve exists in the data. The inclusion of additional variables at this stage may obscure the primary relationship between economic growth and pollution. Grossman and Krueger (1995), Panayotou (1997), Stern (2004) and Dinda (2004) also employed GDP per capita and environmental degradation in their studies to test the EKC hypothesis. Moreover, starting with a simpler model helps avoid multicollinearity and complexity that may arise from including several variables (Perman and Stern, 2003). It allows for clearer interpretation of the direct impact of GDP.

Multiple Linear Regression Model

To provide a more comprehensive coverage to the aforementioned relationship between *CO_2_per_capita* and *GDP_per_capita*, three other key variables are included in a multiple linear regression model. Several studies like Saboori and Sulaiman (2013), Alam at al. (2017) and Balsalobre-Lorente et al. (2018) have employed multiple linear regression analysis to determine the impact of different economic and/or energy variables on emissions.

The regression model for this study is as follows:

$$\begin{aligned} CO_2\_per\_capita = \beta_0 + \beta_1.GDP\_per\_capita + \beta_2.Renewable\_Energy + \\ \beta_3.Urban\_Population + \beta_4.Energy\_Use + \\ \beta_5.Industry\_Value + \varepsilon \end{aligned}$$

Where:

CO_2_per_capita is the dependent variable, *GDP_per_capita, Renewable_Energy, Urban_Population, Energy_Use and Industry_Value* are independent variables. $\beta_0, \beta_1, \beta_2 \ldots\ldots \beta_5$ are coefficient estimates, and ε is the error term.

Panel Data Analysis

This study compliments regression analysis with panel data analysis as the former may overlook unobserved heterogeneity, potentially resulting in biased estimates. Panel data analysis has the ability to account for such heterogeneity by introducing fixed and/or random effects. These effects control for country specific factors that remain constant over time. Furthermore, it may provide more reliable estimates on account of additional data points, which may enhance estimates' efficiency and reduce issues linked with multicollinearity. Amin, Song and Farrukh (2022), Ashiq, Ali, Siddique (2023).and Adeleye et al. (2023) employed panel data analysis to determine the determinants of carbon emissions in South Asia.

Panel data shows changes within countries over time and reveals dynamic relationships between variables. It may also reduce omitted variable bias by controlling for time-variant and time-invariant effects, influencing CO_2 emissions per capita. Fixed and random effects models also include individual intercepts in the form of fixed effects and/or random variations across countries in the form of random effects that may distort the results otherwise. As the dataset used in this study includes 8 countries across 22 years, panel data analysis creates a balanced panel with cross-sectional and time series data. Similar to the multiple linear regression model, the dependent variable is CO_2_per_capita and the independent variables are *GDP_per_capita*, *Renewable_Energy*, *Urban_Population*, *Energy_Use* and *Industry_Value*. Panel data analysis includes a structural break in 2015 on account of the *Paris Agreement*. It is included in the analysis to determine whether this agreement has any impact on the relationship between CO_2 emissions per capita and GDP per capita in South Asia. It is included as a dummy variable in the model

To decide between fixed effects and random effects models, a Hausman test is performed. If individual effects are correlated with the predictors, a fixed effects model is preferred. Otherwise, a random effects model is a better alternative.

The model is here as follows;

$$CO_{2it} = \alpha_i + \beta_1.GDP\_per\_capita_{it} + \beta_2.Renewable\_Energy_{it} + \beta_3.Urban\_Population_{it} + \beta_4.Energy\_Use_{it} + \beta_5.Industry\_Value_{it} + \beta_6.Paris\_dummy_{it} + \mu_{it}$$

Where:

α_i represents fixed or random effects depending on the choice made after the Hausman test. It is included in the model to account for time-invariant/variant country characteristics that may influence CO_2 emissions. $\beta_1, \beta_2 \ldots\ldots \beta_6$ are the coefficients of the respective independent variables and β_6 is the coefficient of the dummy variable.

GDP_per_capita$_{it}$ is the Gross Domestic Product per capita for country i at time t. *Renewable_Energy*$_{it}$ is the proportion of energy derived from renewable sources for country i at time t. *Urban_Population*$_{it}$ is the percentage of urban population for country i at time t. *Energy_Use*$_{it}$ is the energy use per capita for country i at time t. *Industry_Value*$_{it}$ is the industry value added as percent of GDP for country i at time t.

Paris_dummy$_{it}$ is a dummy variable representing the Paris Agreement, where 0 for years before 2015 and 1 for 2015 and beyond. μ_{it} represents the error term.

Data is analysed through R version 4.4.2.

Results and Discussion

This section presents results from the estimated methods discussed in the methodology part of this study.

Descriptive Statistics

Descriptive statistics depicted in Table.2 provide a summary of the variables included in this study. These statistics demonstrate considerable economic and energy use disparities across South Asia, which are pivotal for understanding region-wide CO_2 emissions trends and for designing differentiated policy measures.

Table.2 Descriptive Statistics

Variables	Mean	Median	St. Deviation	Minimum	Maximum
CO_2_per_capita (metric tons)	1.077	0.765	1.053	0.039	5.323
GDP_per_capita (USD)	2041.23	1161.28	2306.04	142.90	11349.85
Renewable_Energy (%)	47.418	46	27.513	1.2	92
Urban_Population (%)	28.446	29.639	7.817	13.397	43.008
Energy_Use	6244.09	3637.16	7034.59	204.23	27785.35
Industry_Value	23.317	23.810	8.494	8.058	41.621

The wide range of *CO_2_per_capita* values, combined with a high standard deviation reveals significant variations across South Asia and in different years. It reflects diverse levels of industrialization and energy consumption patterns in the region. *Renewable_Energy* values suggest that renewable energy contributes significantly to the energy mix in the region but the wide range reflects considerable disparities in renewable energy adoption across countries. Moreover, the large standard deviation relative to the mean of *GDP_per_capita* indicates wide economic inequality in South Asia. The wide range reflects different stages of economic development in different countries. Urbanization has also a wide range (13.4% to 43%), which shows varying levels of urban expansion, affecting energy use and emissions patterns differently across the region. Furthermore, *Energy_Use* per capita shows a large disparity, depicted from the minimum and maximum values along with a high standard deviation. It suggests heterogeneity in energy consumption habits, possibly driven by industrialization, energy efficiency and economic status. Industrial contribution demonstrates moderate variation, with a mean value of 23.32%, ranging from 8% to 41%. It reflects structural differences in the dependence of the economies on industrial sectors.

Correlation Analysis

The correlation matrix shown in Figure. 1 reveals the relationships among variables included in this study. The matrix depicts strong positive correlation between *CO_2_per_capita* and *GDP_per_capita*, suggesting that higher GDP per capita is linked with higher CO_2 emissions, potentially due to industrialization and other economic activities. A strong positive correlation also exists between *CO_2_per_capita* and *Energy_Use*, indicating that a rise in energy use is associated with higher CO_2 emissions. Moreover, *GDP_per_capita* and *Energy_Use* have also a strong positive correlation. It shows that relatively wealthier countries tend to use more energy.

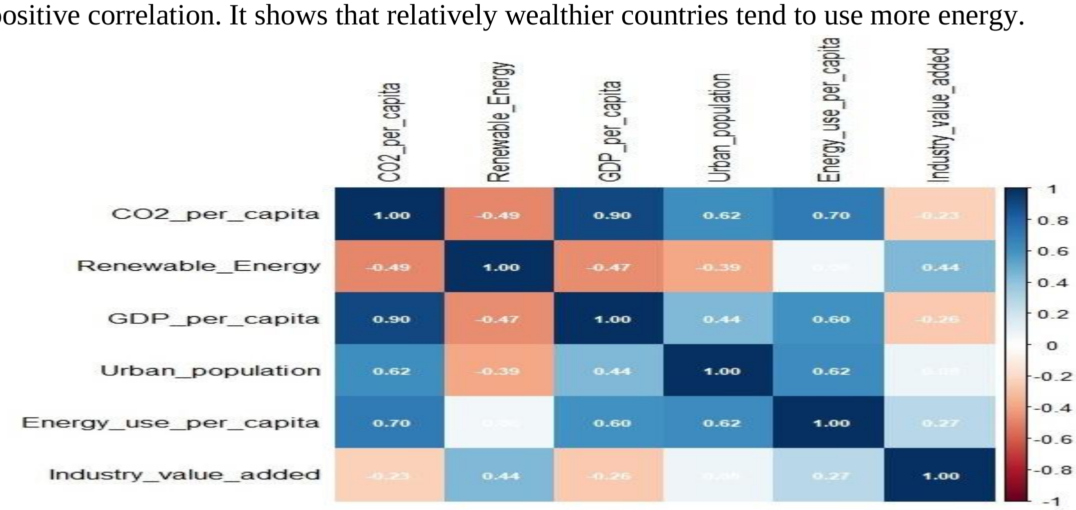

Figure 1. Correlation Matrix

In contrast to the above positive correlations, *CO_2_per_capita* and *Renewable_Energy* has a negative correlation, suggesting that high reliance on renewable energy is linked with lower CO_2 emissions. Interestingly, *Renewable_Energy* is also negatively correlated with *GDP_per_capita* and *Urban_Population*. It shows that countries with higher GDP rely less on renewable energy. It could be due to existing investments in non-renewable infrastructure. Negative correlation with urbanization is possibly due to high energy demands in cities.
Figure.1 shows that *Urban_Population* has a moderate positive correlation with *CO_2_per_capita* and a weak positive correlation with *GDP_per_capita*. It shows that urban areas emit higher emissions. Furthermore, Industry Value added has a weak positive correlation with renewable energy, indicating that some industrial sectors in the region have incorporated renewable energy to a certain extent. *Industrial_Value* has a weak negative correlation with *CO_2_per_capita*. It shows that industrialization may not be the sole heavy contributor to CO_2 emissions, potentially reflecting varied industrial technologies and compositions.

EKC Regression Model

The EKC regression model is employed to investigate the relationship between *CO_2_per_capita* and *GDP_per_capita* in South Asia, incorporating a quadratic term to assess the non-linear behavior postulated by the EKC hypothesis. The model's results provide interesting insights into the relationship between *GDP_per_capita* and *CO_2_per_capita* as shown in Table.3. The high R-squared value (0.81) shows that *GDP_per_capita* is able to explain a significant portion of the variance in *CO_2_per_capita*. The coefficient for GDP per capita is also positive and highly significant, suggesting that as income level rises, *CO_2_per_capita* also increases initially. It aligns with the early upward phase of the EKC, where economic growth results in higher resource use and pollution. The quadratic term's coefficient is negative and statistically insignificant, implying that there is no clear evidence of a turning point (inverted U-shape curve) for *CO_2_per_capita* within the observed *GDP_per_capita* range. This finding aligns with Stern (2004), who is of the view that turning point of the curve may only be found in case of developed countries. Pao and Tsai (2010) also conclude that there is a positive relationship between CO_2 emissions and economic growth but the quadratic term remains insignificant.

Table.3. EKC Model Results

Coefficients	Estimate	Std. Error	t-value	Pr (> | t |)
(Intercept)	1.851 e-01	6.354 e-02	2.913	0.00406 **
GDP_per_capita	4.622 e-04	4.632 e-05	9.979	< 2e-16***
$(\text{GDP\_per\_capita})^2$	-5.381 e-09	4.794 e-09	-1.122	0.26331

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 0.4525 on 173 degrees of freedom
Multiple R-squared: 0.8178, Adjusted R-squared: 0.8157
F-statistic: 388.2 on 2 and 173 DF, p-value: < 2.2e-16

Since the EKC model does not confirm a significant turning point in South Asia, it indicates that either South Asian countries have not reached income levels high enough to experience a decline in emissions as suggested by the EKC hypothesis or economic growth alone may not result in lower emissions in this region. It supports the view that in the absence of targeted environmental policies and investment in cleaner technologies, economic growth may continue to drive emissions. These findings are consistent with Stern (2004), who stressed the importance of technology, structural changes and policy interventions in reducing emissions beyond a certain income level. The findings are also in line with Dinda (2004) and Stern (2017) who are of the view that EKC is context dependent and regional differences in industrial composition, environmental awareness and regulatory frameworks affect the relationship between income and pollution. Figure. 2 shows that at lower levels of *GDP_per_capita*, *CO_2_per_capita* are relatively low but as GDP rises, emissions also increase, possibly due to industrialization, and high energy use. The graph stops at a point where the curve seems to level out, which suggests that the relationship between economic growth and CO_2 emissions continues to rise linearly at higher GDP levels.

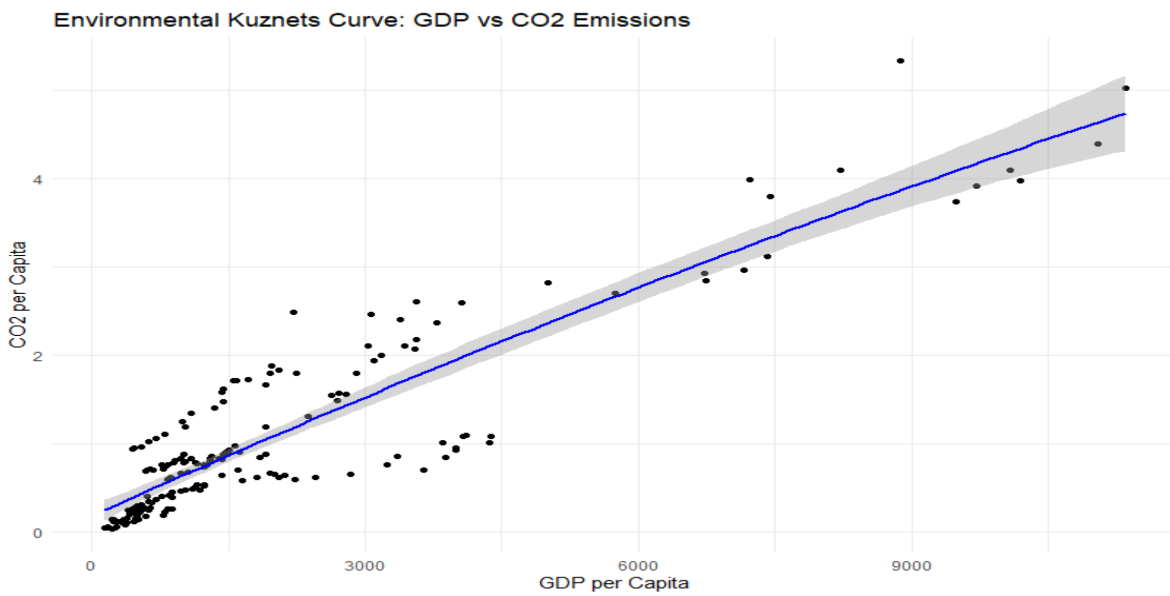

Figure. 2 Environmental Kuznets Curve: GDP vs CO_2 Emissions (South Asia)

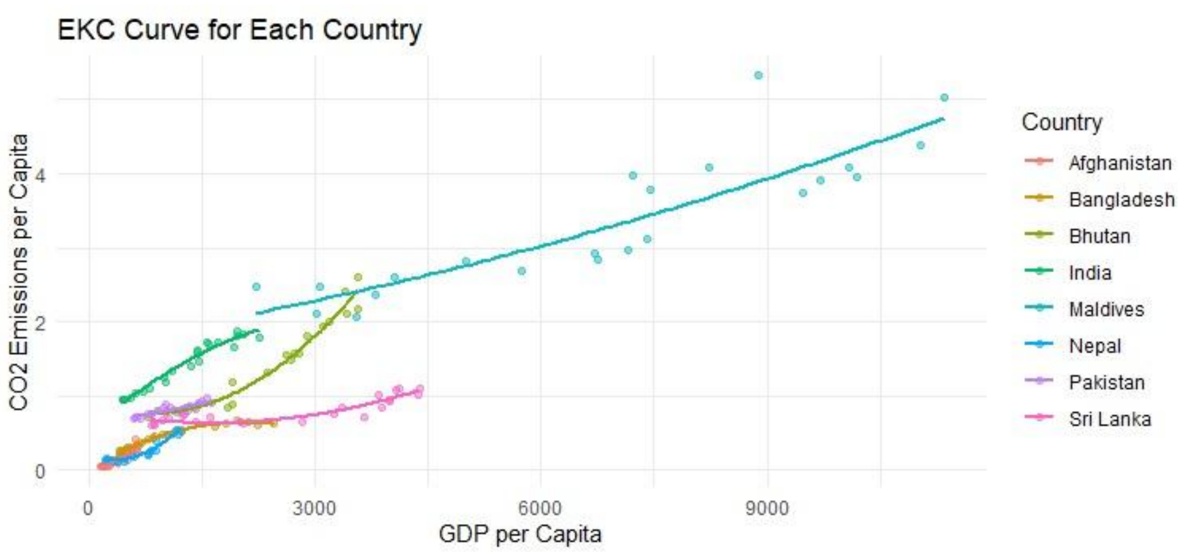

Figure. 3 Environmental Kuznets Curve: GDP vs CO_2 Emissions (Country-Wise Analysis)

Country wise EKC analysis provides interesting insights. Figure. 3 reveals that India (olive green curve) follows an uptrend trend with higher GDP and increasing emissions, suggesting growing industrialization. However, no signs of an inverted U-shaped curve could be observed. Pakistan (purple curve) shows moderate GDP growth with increasing emissions, indicating industrial expansion. Similarly, Bhutan (green curve) and Bangladesh (red curve) depict moderate GDP growth with a steady rise in CO_2 emissions. However, Sri Lanka (magenta curve) is showing relatively stable emissions, indicating controlled economic and environmental policies. Nepal (pink curve) and Afghanistan (orange curve) have low GDP growth and lower emissions, suggesting minimal industrialization in these countries. Maldives (light blue) has the highest GDP per capita in the region, showing a rising trend in CO_2 emissions.

The insignificant quadratic term suggests the need to explore additional factors for a more comprehensive understanding of emissions trends. Therefore, this study employs a multiple regression model, in which additional key economic and energy variables are used.

Multiple Linear Regression Model

The multiple linear regression model for this study encompasses *CO_2_per_capita* as the dependent variable, while *GDP_per_capita*, *Renewable_Energy*, *Urban_Population*, *Energy_Use* and *Industry_Value* are independent variables.

Table. 4 represents results of the regression model. The R-squared value (0.905) shows that the model explains 90.5% of the variation in *CO_2_per_capita* emissions, indicating a strong fit. It shows that the independent variables are highly explanatory of CO_2 emissions in the region.

Table.4. Multiple Linear Regression Model Results

Coefficients	Estimates	Std. Error	t-value	Pr (> | t |)
Intercept	5.328 e-01	1.997 e-01	2.694	0.00776**
GDP_per_capita	2.396 e-04	1.972 e-05	12.146	2 e-16***
Renewable_Energy	-6.247 e-03	1.466 e-03	-4.261	3.36 e-05***
Urban_Population	1.361 e-02	5.110 e-03	2.663	0.00850 **
Energy_Use	5.568 e-05	7.509 e-06	7.415	5.49 e-12***
Industry_Value	-1.641 e-02	3.650 e-03	-4.495	1.28 e-05***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Residual standard error: 0.3246 on 170 degrees of freedom
Multiple R-squared: 0.9079, Adjusted R-squared: 0.9052
F-statistic: 335.1 on 5 and 170 DF, p-value: < 2.2e-16

The coefficient of *GDP_per_capita* is positive and considerably higher, indicating that economic growth is strongly associated with CO_2 emissions. The higher negative coefficient for renewable energy shows that renewable energy has a negative impact on emissions. These findings align with Shahbaz et al. (2013), who found that GDP per capita is positively related with carbon emissions and renewable energy consumption is negatively related with emissions in case of Indonesia. Moreover, the positive coefficient of Urban Population reveals that urbanization leads to higher CO_2 emissions. Poumanyyong and Kaneko (2010) also found that urbanization results in higher emissions in developing countries. The model's results also suggest that *Energy_Use* per capita is also a major driver of emissions in the region. The stronger t-value suggests acute dependence on energy use for CO_2 emissions along with inefficient energy use. However, *Industry_Value* added has a negative coefficient, showing that industrial sectors are not the only major contributor to emissions in South Asia. These results confirm the findings by Al-Mulali et al. (2015), who concluded that energy consumption and urbanization drive emissions and industrialization show mixed impact on CO_2 emissions.

Multiple Linear Regression Model Diagnostics

Variance Inflation Factors (VIF)

VIF measures the inflation of a variable's variance on account of multicollinearity. A rule of thumb is that if its value is lower than 5, it has low to moderate multicollinearity, while a value above 5 is an indication of high multicollinearity (Stine, 1995). Table. 5 shows the VIF values for the independent variables included in this study. None of the variables show high multicollinearity.

Table. 5. VIF Values for Independent Variables

Variable	VIF Value	Interpretation
GDP_per_capita	3.44	Moderate multicollinearity, acceptable
Renewable_Energy	2.70	Low Multicollinearity, no concern
Urban_Population	2.65	Low Multicollinearity, no concern
Energy_Use	4.63	Moderate multicollinearity, acceptable
Industry_Value	1.60	Low Multicollinearity, no concern

Residuals

Residuals histogram as shown in Figure. 4 reveal that residuals are mostly centred around zero. It indicates that the model's predictions neither overestimate nor underestimate CO_2 emissions per capita in South Asia. However, the histogram shows slight skewness to the right, suggesting that some predictions may have larger positive errors. The spread of residuals is fairly even, revealing there is no major pattern indicating heteroscedasticity. Furthermore, a small bar to the far right can be observed in the figure, with relatively large positive residuals. These could be outliers, where the model overestimates emissions. Nevertheless, the residuals show a reasonably good fit for the model.

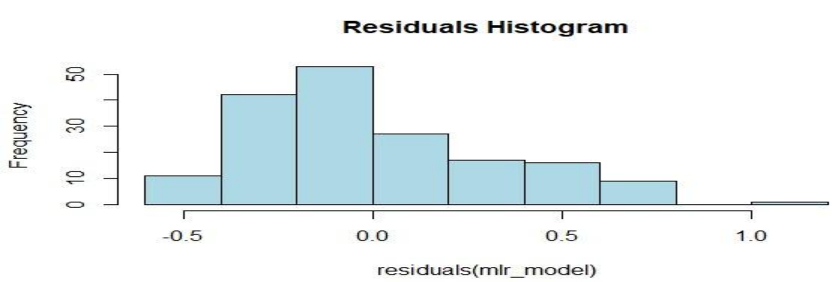

Figure. 4. Residuals Histogram

Normal Q-Q Plot

Normal Q-Q plot is employed to examine whether the residuals of the regression model follow a normal distribution. Ideally, the residuals need to align closely with 45˚ red reference line, showing normality (Ben and Yohai, 2004). Figure. 5 shows that most of the residual points fall near the red line, indicating that the residuals are approximately normally distributed, with some minor deviations. This supports the assumption of normality in the regression model used in this study.

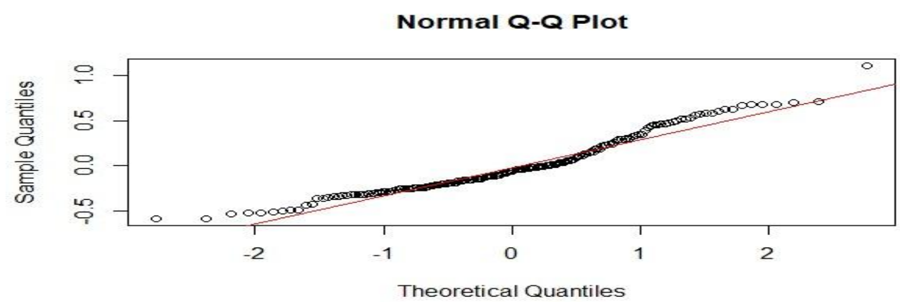

Figure. 5. Normal Q-Q Plot

Actual vs Predicted CO_2 Emissions

The actual vs predicted CO_2 emissions plot is an important tool to evaluate the performance of the regression model. Figure. 6 shows that besides some minor deviations, the data points closely follow the 45-degree dashed line, suggesting that the model has made relatively accurate predictions. It suggests that the independent variables are good predictors of CO_2 emissions in South Asia.

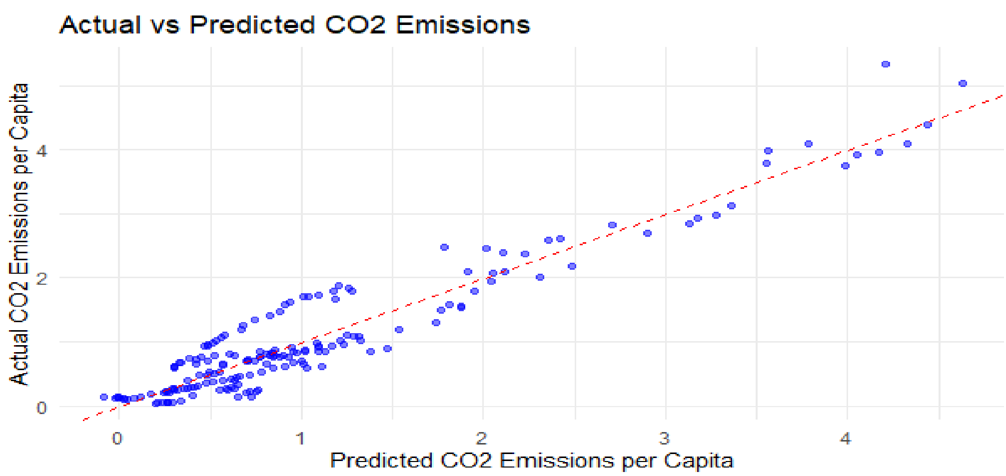

Figure. 6. Actual vs Predicted CO_2 Emissions

Panel Data Analysis

Panel data analysis enables us to account for heterogeneity overlooked by regression analysis. The analysis encompasses fixed or random effects, controlling for country specific factors and providing more data points. Thus, enhancing the efficiency of estimates along with reducing multicollinearity. Panel data analysis model estimates the relationship between *CO_2_per_capita* and key independent variables, namely *GDP_per_capita, Renewable_Energy, Urban_Population, Energy_Use and Industry_Value*.

Hausman Test

A Hausman test is performed to determine the preferred model between fixed and random effects models. The null hypothesis is that the random effects model is appropriate. If the p-value is less than 0.05, the null hypothesis is rejected. The results show a p-value of 0.02547 and the null hypothesis is rejected. It suggests that there is correlation between the regressors and the individual-specific-effects as shown in Figure. 7. It can be concluded that the fixed effects model is the appropriate choice for this analysis.

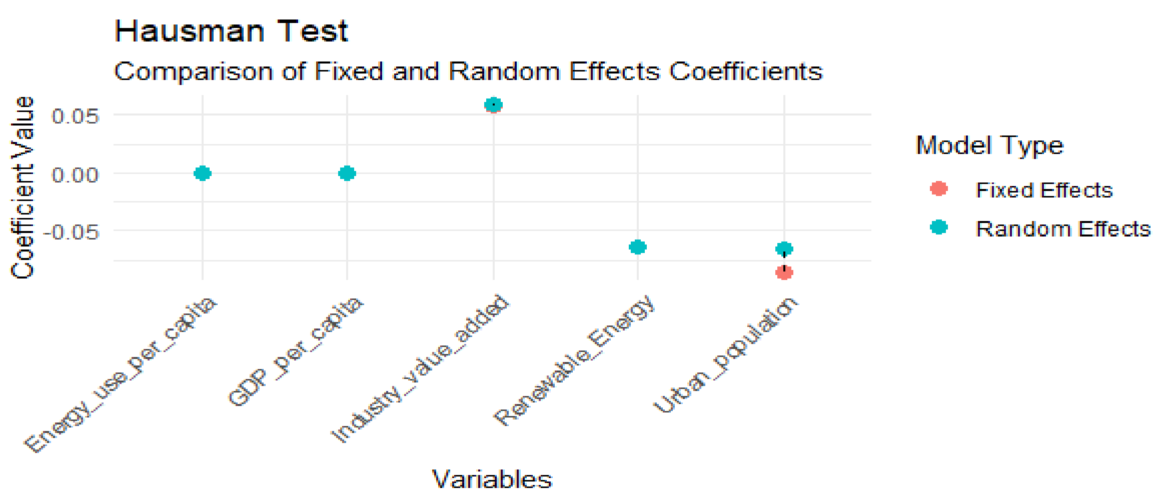

Figure. 7. Hausman Test

Table. 6 show results of the panel data analysis. The model as a whole is statistically significant and explains a large portion of variance in CO_2 emissions in South Asia. It is evident from the table that the coefficient of *GDP_per_capita* is positive and statistically significant, indicating that higher GDP per capita results in higher emissions. The strong positive relationship is in alignment with the EKC in its early stage, where economic growth results in higher emissions.

Unlike the multiple linear regression model, renewable energy has a positive but insignificant impact on CO_2 emissions. It means that renewable energy consumption does not have a statistically significant impact on emissions in South Asia. Moreover, urbanization has a positive but insignificant impact on emissions. Energy use per capita has a positive and statistically significant coefficient, suggesting that higher energy use results in higher emissions. Industry value has a negative and statistically significant coefficient like the regression model, indicating that higher industry value added is linked with lower emissions. The Paris Agreement dummy variable is positive but statistically insignificant. It shows that the Paris Agreement has not significantly impacted emissions trends in the sample period. This variable captures the structural break in 2016. The lack of significance indicates that the agreement's policies have not led to immediate measurable changes in CO_2 emissions. It is common, as policy impacts often take several years to manifest (Aldy et al., 2016).

Table. 6. Panel Data Analysis Results

Coefficients	Estimate	Std. Error	t-value	Pr (> | t |)	Significance
GDP_per_capita	1.8562 e-04	1.7623 e-05	10.5329	< 2.2 e-16 ***	Highly Significant
Renewable_Energy	3.5459 e-04	3.0350 e-03	0.1168	0.907136	Not Significant
Urban_Population	1.5524 e-02	9.7203 e-03	1.5971	0.112191	Not Significant
Energy_Use	5.3911 e-05	8.6257 e-06	6.2500	3.489 e-09 ***	Highly Significant
Industry_Value	-1.7244 e-02	5.2505 e-03	-3.2843	0.001253 **	Significant at 1%
Paris_dummy	1.3661 e-02	4.7198 e-02	0.2894	0.772611	Not Significant

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Total Sum of Squares: 30.057
Residual Sum of Squares: 5.7102
R-Squared: 0.81002
Adj. R-Squared: 0.79478
F-statistic: 115.122 on 6 and 162 DF, p-value: < 2.22e-16

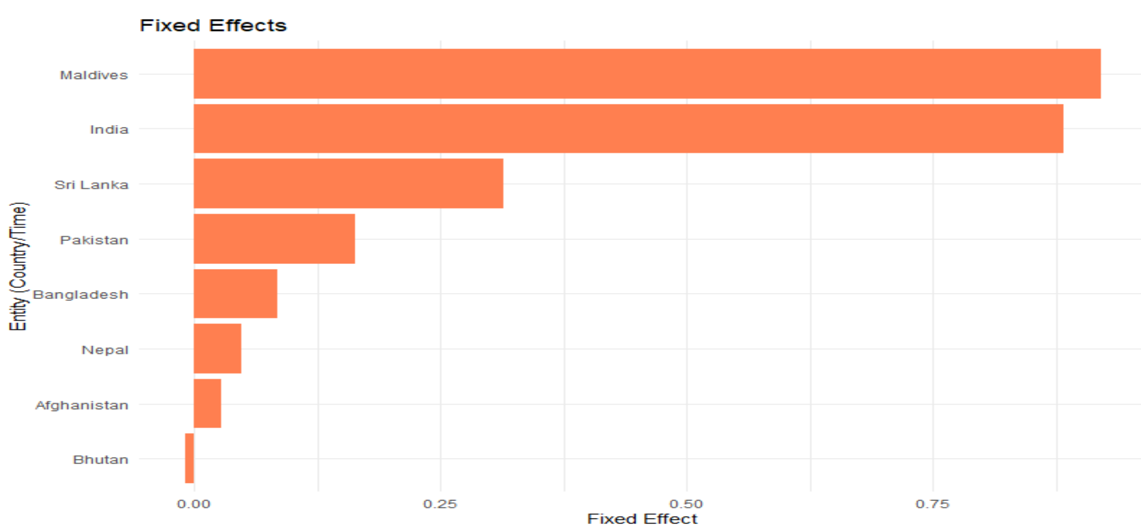

Figure. 8. Fixed Effects (country wise)

Figure.8 highlights the varying importance of country-specific fixed effects across 8 South Asian countries in determining CO_2 emissions per capita in the region. It is evident in the figure that Maldives has the highest fixed effects, indicating that country-specific factors in Maldives have a strong influence on CO_2 emissions per capita relative to other countries. India follows with a slightly lower but significant fixed effects, suggesting that India's specific characteristics also play a vital role in determining CO_2 emissions in the region. Sir Lanka's fixed effects are also significant but lower than Indian and Maldives. However, rest of the countries, i.e., Pakistan, Bangladesh, Nepal and Afghanistan show progressively lower fixed effects. These countries have less of an impact on CO_2 emissions per capita. Bhutan has very low fixed effects, implying that the country's specific characteristics have the least impact on emissions in the region.

Conclusion

This study explored the EKC hypothesis and analyzed the key determinants of CO_2 emissions in South Asia using different econometric models. The EKC analysis showed that GDP per capita is a major driver of CO_2 emissions, consistent with economic development being linked to environmental deterioration. However, the squared term of GDP per capita did not show statistical significance, suggesting the absence of a turning point in emissions with a rise in income. This finding challenges the applicability of the EKC hypothesis to South Asia, where emissions continue to rise as economies develop. Another interpretation could be that the turning point predicted by the EKC has not yet reached. It highlights the importance of integrating sustainable development policies to decouple economic growth from environmental degradation. The multiple linear regression model underscored the intricate relationships between CO_2 emissions and several key variables. Renewable energy was found to have a mitigating effect on emission, highlighting its potential in reducing environmental degradation. However, urbanization and energy use per capita have a positive impact on emissions, which reflects the challenges posed by rapid urbanization and increasing energy demand. Industry value added also contributes to emissions, emphasizing the need for sustainable industrial policies in South Asia. The panel data analysis added a policy dimension to the analysis by including the Paris Agreement through a dummy variable. Although this variable provided insights into the impact of international climate commitments, the findings suggest that the agreement's impact on emissions in the region remains limited. This underscores the need for stronger implementation and enforcement of climate policies to achieve tangible results. Future research needs to expand the scope by including additional variables to provide a more comprehensive understanding of emissions dynamics. Additionally, extending the dataset to include post-2020 data may allow for evaluating the full impact of the Paris Agreement and other recent policy initiatives. Policymakers need to prioritize renewable energy deployment as a key strategy for reducing carbon emissions while fostering economic growth. Urbanization also needs low-carbon planning and the integration of sustainable infrastructure to manage emissions effectively. South Asian countries should strengthen their climate commitments by adopting more ambitious policies in line with the Paris Agreement. Regional cooperation in technology transfer and capacity building may also play a vital role in supporting the transition to a low-carbon economy. By addressing these challenges, South Asia can manage a balance between economic development and environmental sustainability, contributing meaningfully to global climate goals. This study provides a foundation for policymakers and researchers to design strategies that align with sustainable development objectives while meeting international climate commitments.

Declaration

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Consent to participate: N/A

Consent for publication: N/A

Data availability: Data available on request

Authors contribution: The author was solely involved in all aspects of this work, including the study's conceptualization and design, data collection, analysis and interpretation of results, and the preparation of the manuscript.

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RESEARCH ARTICLE

Energy Consumption , Economic Development and CO_2 Emissions: A time series approach

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Abstract
Global economic growth is intrinsically linked to energy consumption, with fossil fuels accounting for over three-quarters of total energy use. A longstanding debate centers on the relationship between economic growth and CO_2 emissions, particularly regarding the potential to decouple growth from emissions. This study examines this relationship using World Bank data from 193 countries over the period 1965-2023. The analysis reveals a strong positive correlation between GDP per capita, energy consumption ($r = 0.99$), and CO_2 emissions, indicating that economic growth is closely tied to increasing energy use and emissions. Global energy consumption has grown by an average of 7.6 Exajoules annually, representing a 2% rise per year. Stationarity tests show that all variables are non-stationary in their level form but become stationary after first differencing. Cointegration analysis indicates a long-run equilibrium among the variables. VAR and Granger causality tests suggest that while past values influence each variable, short-term interactions remain weak. These findings highlight the need for structural changes and transformative policies to decouple economic growth from carbon emissions.

Keywords: Economic Growth; CO_2 Emissions; Fossil Fuels; GDP; Decouple Economic

Introduction

Energy is the driving force behind the global economy. The world's heavy reliance on energy, with fossil fuels accounting for 81.7% of total energy consumption(Raufi & Maniat, 2024b) , highlights the significant challenges in transitioning to sustainable energy sources. Over the past 28 years, the share of non-fossil energy sources has increased modestly by just 5.3%, pointing to slow progress despite ambitious global environmental goals (Raufi & Maniat, 2024b). This situation contributes to the ongoing debate over the relationship between economic growth and CO_2 emissions. According to the International Energy Agency (IEA), "The relationship between growth in GDP and CO_2 emissions has loosened"(Singh, 2024), suggesting the potential to "decouple" GDP from CO_2 emissions(Jackson & Victor, 2019). In theory, this decoupling could allow for continued economic growth while reducing emissions, largely through advances in energy efficiency and technology (Fedrigo-Fazio et al., 2016; Wu, Zhu, & Zhu, 2018). However, the effectiveness and feasibility of decoupling remain inconclusive, fueling ongoing debates about whether economic growth can truly align with environmental sustainability. Despite initiatives like the United Nations Framework Convention on Climate Change (UNFCCC), CO_2 emissions have increased by over 60% since 1990, underscoring the scale of the challenge and the complex interconnection between economic growth and environmental impact(P. A. Victor, 2019). Although relative decoupling has shown some efficiency improvements (Fedrigo-Fazio et al., 2016), the gap between economic growth and global emissions reduction remains daunting (Jackson & Victor, 2019). The debate continues as to whether continuous technological advancements can realistically reconcile economic expansion with environmental sustainability(Khan, Awais, Majeed, Beenish, & Rashad, 2024), or if alternative models are needed that prioritize ecological stability over unending economic growth (Jackson, 2016). Global evidence suggests that meeting sustainability goals may require more transformative approaches, beyond incremental decoupling, emphasizing the need to explore economic paradigms that align more closely with planetary boundaries(Bengtsson, Alfredsson, Cohen, Lorek, & Schroeder, 2018; Voulvoulis, 2022). Within the energy economics literature, the relationship between economic growth and CO_2 emissions remains a critical focus. Understanding this relationship is essential for developing policies that balance economic growth with environmental sustainability, and it remains a crucial area of research to guide future strategies in addressing global environmental challenges.

Literature Review

There are many studies that suggest a significant relationship between energy consumption, CO_2 emissions, and GDP. However, some studies argue that this relationship has weakened due to the advent of renewable energies and technological advancements. In this section, we will refer to both groups of studies to explore these contrasting perspectives. Some studies suggest an optimistic outlook on global trends by identifying a U-shaped relationship between CO_2 emissions and GDP, as illustrated in **Figure 1**. This pattern implies that, at certain income levels, economic growth can initially lead to increased emissions, followed by a phase where emissions start to decline as GDP continues to rise. This view supports the idea that economic growth does not inevitably lead to higher emissions in the long term, especially if countries implement effective environmental policies and invest in sustainable technologies(Bella, Massidda, & Mattana, 2014).

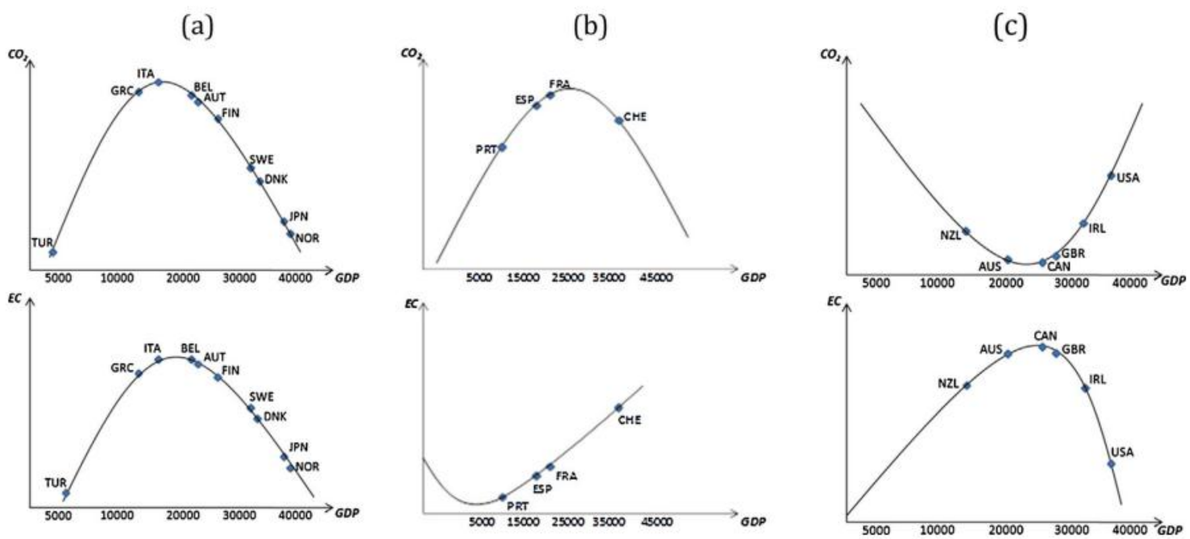

Figure 1. U-shaped relationship between CO_2 emissions and GDP(Bella et al., 2014).

However, identifying a U-shaped relationship as a special case for certain countries suggests that GDP has a low correlation with CO_2 emissions. Contrarily, a resent article published in Nature, depicted in **Figure 2**, demonstrates a significant correlation between GDP and CO_2 emissions, quantified at 0.82(Haberl et al., 2023). This finding underscores the strong and pervasive link between economic growth and carbon emissions globally, challenging the notion that GDP and CO_2 emissions can be decoupled uniformly across different contexts.

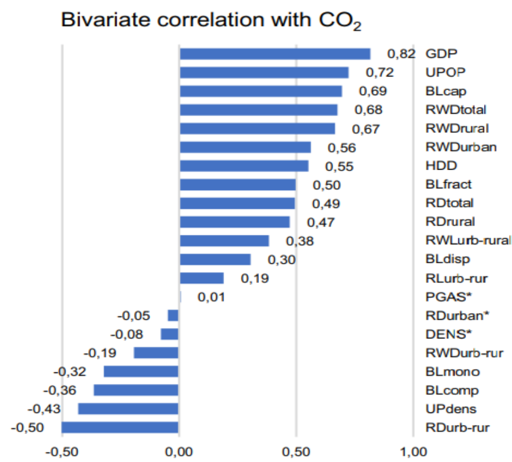

Figure 2. Correlation between GDP and CO_2 emissions(Haberl et al., 2023).

The economic relationship between GDP and CO_2 emission is significant, as numerous studies use CO_2 emissions as an indicator to predict GDP trends(Kumar & Muhuri, 2019; Kumar, Shukla, Muhuri, & Lohani, 2023; Marjanović, Milovančević, & Mladenović, 2016). A study analyzes the relationship between real GDP, CO_2 emissions, and energy use in GCC countries (1960–2013). Results show energy use drives GDP growth in Kuwait, Oman, and Qatar ("growth hypothesis"), while only Oman exhibits a long-run cointegration(Magazzino, 2016).
Research on EU countries has shown a long-run cointegrating relationship between economic growth and CO_2 emissions. Using the Dynamic Ordinary Least Squares (DOLS) method, studies indicate a statistically significant impact of GDP on emissions. On average, a 1% increase in GDP results in a 0.072% change in CO_2 emissions, underscoring the persistent link between economic activity and environmental impact(Onofrei, Vatamanu, & Cigu, 2022). CO_2 levels are influenced by various factors, including the absorption capabilities of soil and oceans. Another issue in correlation comparisons commonly used in most studies is the argument that the correlation between GDP and CO_2 emissions is lower in developed countries compared to developing ones(Qin et al., 2023). Two main conclusions can be drawn from this observation. First, the reduction in correlation can be attributed to the adoption of new technologies in developed countries over recent decades(Chen & Lee, 2020; Etesami, Raufi, & Maniat, 2024). Second, developing countries tend to produce more CO_2 emissions as they grow economically(Galeotti & Lanza, 1999). Maniat et al. demonstrated a reduction in air pollution during COVID-19 lockdowns(Maniat et al., 2023; Maniat et al., 2024) , while another study showed a concurrent decline in GDP(Gagnon, Kamin, & Kearns, 2023; König & Winkler, 2021). Although there are instances where conflicts arise between sustainable development and technological progress(Maniat, Elmie, Feli, & Mansouri, 2023; Maniat, Hayati, Talifard, & Rustaie, 2023), various international conventions continue to address the challenges of global warming(Akpuokwe, Adeniyi, Bakare, & Eneh, 2024; D. G. Victor, 2011). This study aims to evaluate whether advancements in new technology have effectively reduced CO_2 emissions or if the world remains far from achieving this goal. The discussion extends to whether continuous improvements in technology and

efficiency can realistically reconcile economic expansion with environmental sustainability. The economic relationship between GDP and CO_2 emission is significant, as numerous studies use CO_2 emissions as an indicator to predict GDP trends(Kumar & Muhuri, 2019; Kumar et al., 2023; Marjanović et al., 2016). A study analyzes the relationship between real GDP, CO_2 emissions, and energy use in GCC countries (1960–2013). Results show energy use drives GDP growth in Kuwait, Oman, and Qatar ("growth hypothesis"), while only Oman exhibits a long-run cointegration(Magazzino, 2016).

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Methodology

This study investigates the relationship between GDP per capita, energy consumption, and CO_2 emissions across 193 countries from 1965 to 2023. Data from the World Bank and other reliable global sources were utilized. The methodology consists of several stages: data collection, data preprocessing, unit root testing, correlation analysis, causality tests, regression modeling, and sectoral decomposition of energy sources. Each component is detailed below:

Data Preprocessing

The dataset was carefully preprocessed to ensure consistency and completeness. Missing values were handled using linear interpolation, especially for small gaps. For countries with significant missing data, exclusion was preferred to maintain the integrity of the analysis. Outliers were identified using z-scores (threshold: ±3) and removed where justified. All variables were converted to standard units where necessary, and GDP per capita values were adjusted for inflation to reflect economic changes over time.

Unit Root Tests

To examine the stationarity of the variables (GDP per capita, energy consumption, CO_2 emissions), Unit Root Tests were performed using the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), Kwiatkowski-Phillips-Schmidt-Shin (KPSS), and Elliott-Rothenberg-Stock (ERS) tests. These tests help determine whether the time series data for each variable exhibit a unit root, suggesting that they are non-stationary. Non-stationary data would require transformation to ensure that the statistical models yield reliable and meaningful results.

Granger Causality and Toda-Yamamoto Causality Tests

In addition to correlation analysis, we conducted Granger Causality and Toda-Yamamoto (TY) Causality Tests to examine the direction of causality between GDP per capita, energy consumption, and CO_2 emissions. The Granger Causality Test is used to determine whether past values of one variable can help predict future values of another, assessing the temporal dynamics of the relationship between these variables. However, the standard Granger Causality Test requires the series to be stationary. Therefore, the Toda-Yamamoto (TY) Causality Test was also performed, which accommodates potential non-stationarity by allowing for the inclusion of higher-order lags, making it more robust to the inclusion of unit roots in the data.

Measurements, Pearson Correlation Analysis, and Linear Regression Model

To identify the strength and significance of the relationship between GDP per capita, total energy consumption, CO_2 emissions, and other related variables, Pearson correlation coefficients were calculated. These correlations help evaluate preliminary associations among the variables, with specific attention to the GDP-energy and GDP-CO_2 emission relationships. High correlation values would suggest a strong linkage, guiding the focus for subsequent regression analysis. In the majority of studies(Ağbulut, 2022; Akalpler & Shingil, 2017; Azmodeh, Attar, Maniat, Rahmati, & Bahmani; Haldar & Sethi, 2021; Maniat, Abdoli, Raufi, & Marous; Maniat & Eebrahimzadeh, 2024; Raufi & Maniat, 2024a, 2024b), researchers commonly employ Pearson correlation for assessing the relationship between variables. While some studies use Kendall and Spearman correlation, the differences in results are not significant. To facilitate comparison with other research, we also utilize Pearson correlation. Pearson's correlation coefficient (r) is a widely used measure that evaluates the strength, type, and direction of the relationship between two variables. The Pearson correlation (r) is defined as shown in Equation (1)(Akoglu, 2018).

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 (y_i - \bar{y})^2}} \qquad (1)$$

where:

- r =correlation coefficient,
- x_i , y_i are the values of the variable in a sample i,
- $\bar{x}$,$\bar{y}$= mean of the values of the y-variable.

A linear regression model was applied to quantify the effect of GDP per capita on total energy consumption. The regression model uses total energy consumption as the dependent variable and GDP per capita as the independent variable.The model's form is as follows(Equation (2):

$$\text{Total Energy Consumption} = \beta_0 + \beta_1 \times \text{GDP per capita} \qquad (2)$$

Where:

- β_0 represents the intercept,
- β_1 denotes the slope coefficient for GDP per capita,

Model Evaluation & Statistical Significance Testing

The regression model's goodness of fit was assessed using the R^2 value, indicating the proportion of variance in energy consumption explained by GDP per capita. An Analysis of Variance was conducted to evaluate the statistical significance of the regression model, with particular attention to the F-statistics and p-values. A p-value threshold of 0.01 was applied, corresponding to a confidence level of 99%. A low p-value confirms the statistical significance of the model and its parameters.

Limitations

The study acknowledges limitations such as reliance on historical data and the inherent variability in country-level reporting, which may introduce biases. The reliance on historical data may overlook short-term fluctuations and recent developments in energy consumption patterns.The assumption of a linear relationship between GDP and energy consumption might not fully capture complex interactions, especially with technological advancements or policy interventions. Country-level data reporting inconsistencies and methodological differences across regions could introduce biases in the analysis.

Results

Figure 3 illustrates the global energy consumption trends from 1983 to 2023, measured in terawatt-hours (TWh). A significant shift towards renewable energy sources is evident, with substantial growth observed in solar, wind, biofuels, and other renewables. While fossil fuels (gas, oil, and coal) remain dominant, particularly oil and coal, their relative contribution to the energy mix has declined. Nuclear energy has experienced a slower but steady increase over the period, maintaining a relatively stable share of the overall energy consumption.

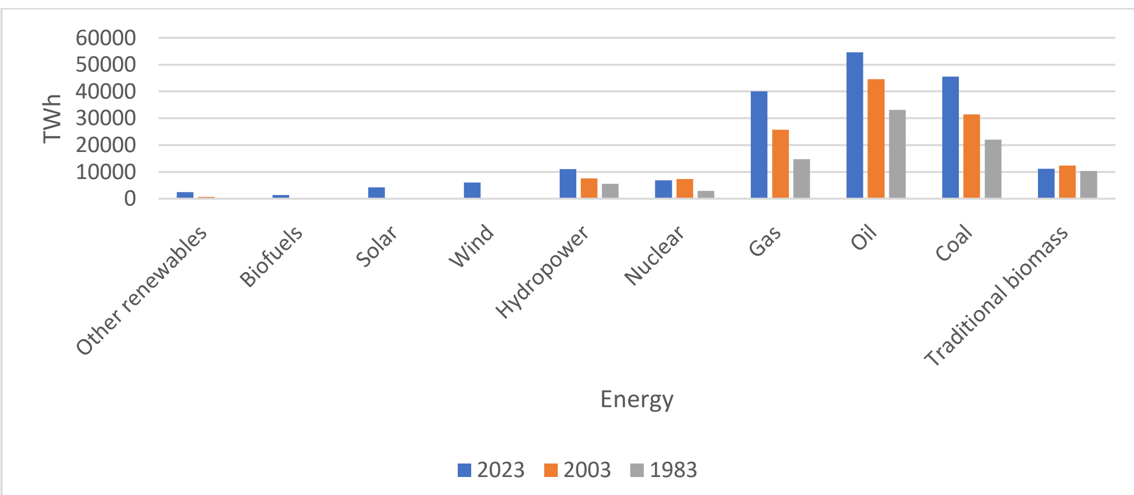

Figure 3. Energy consumption of various energy sources in three different years

Figure 4 illustrates the energy mix across three distinct years: 1983, 2003, and 2023. Each chart represents the share of various energy sources, including oil, coal, gas, nuclear, hydropower, and renewables. In 1983, fossil fuels accounted for approximately 90% of total energy consumption. By 2023, this share had decreased to around 83%, showing a steady decline over the past 40 years. Meanwhile, the share of renewable energy in the energy mix was about 6.5% in 1983 and had increased to approximately 13.7% by 2023, more than doubling over the observed period. Despite the growth in renewable energy, fossil fuels still constitute a substantial portion of global energy consumption, highlighting that a complete transition to clean energy remains a long-term goal.

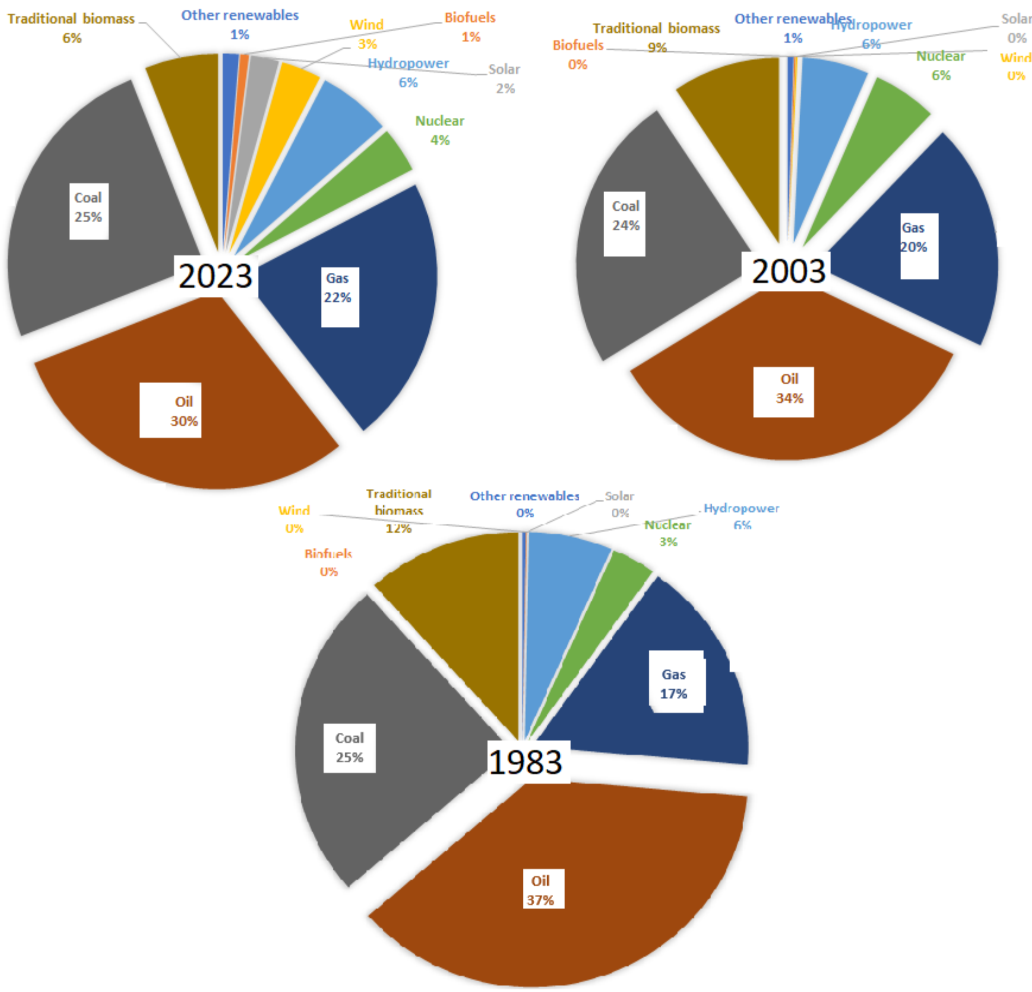

Figure 4. Shifting Global Energy Landscape

Despite the growth in renewable energy sources, fossil fuels (oil, gas, and coal) continue to play a dominant role in the global energy mix, although oil has experienced a slight decline in its share. Table 1 presents the Pearson correlation coefficients among various economic and environmental variables, including GDP, population, fossil fuel consumption, CO_2 emissions, oil, coal, gas, and total energy consumption. GDP shows a strong positive correlation with nearly all other variables, particularly with total energy consumption (0.977), CO_2 emissions (0.975), and fossil fuel use (0.977). This indicates that economic growth is closely associated with both energy consumption and CO_2 emissions. Similarly, population is highly correlated with fuel consumption (0.994), CO_2 emissions (0.986), and total energy use (0.994), suggesting that as the population increases, so do energy consumption and CO_2 emissions.Fossil fuel consumption is nearly perfectly correlated with CO_2 emissions (0.997) and total energy consumption (1.000), confirming that fossil fuels are the primary source of both energy and CO_2 emissions. Additionally, CO_2 emissions exhibit a strong correlation with total energy consumption (0.997), further suggesting that emissions are closely tied to overall energy use, particularly as fossil fuels continue to dominate the energy mix..

Table 1. Pearson correlation primary source of energy and CO_2 emissions in wolrd

Pearson Correlation									
	GDP	Population	Fuel	GDPP	Co_2	Oil	Coal	Gas	Total energy
GDP	1	.963**	.977**	.994**	.975**	.911**	.981**	.983**	.977**
Population	.963**	1	.994**	.981**	.986**	.966**	.965**	.993**	.994**
Fuel	.977**	.994**	1	.990**	.997**	.972**	.981**	.998**	1.000**
GDPP	.994**	.981**	.990**	1	.989**	.937**	.989**	.990**	.990**
Co_2	.975**	.986**	.997**	.989**	1	.973**	.988**	.991**	.997**
Oil	.911**	.966**	.972**	.937**	.973**	1	.926**	.960**	.972**
Coal	.981**	.965**	.981**	.989**	.988**	.926**	1	.975**	.981**
Gas	.983**	.993**	.998**	.990**	.991**	.960**	.975**	1	.998**
Total energy	.977**	.994**	1.000**	.990**	.997**	.972**	.981**	.998**	1

**. Correlation is significant at the 0.01 level (2-tailed).

Energy consumption has increased by an average of 7.6 EJ per year, which corresponds to a 2% annual rise. **Figure 5** illustrates the steady rise in global energy demand, driven by factors such as population growth, industrialization, and economic expansion.

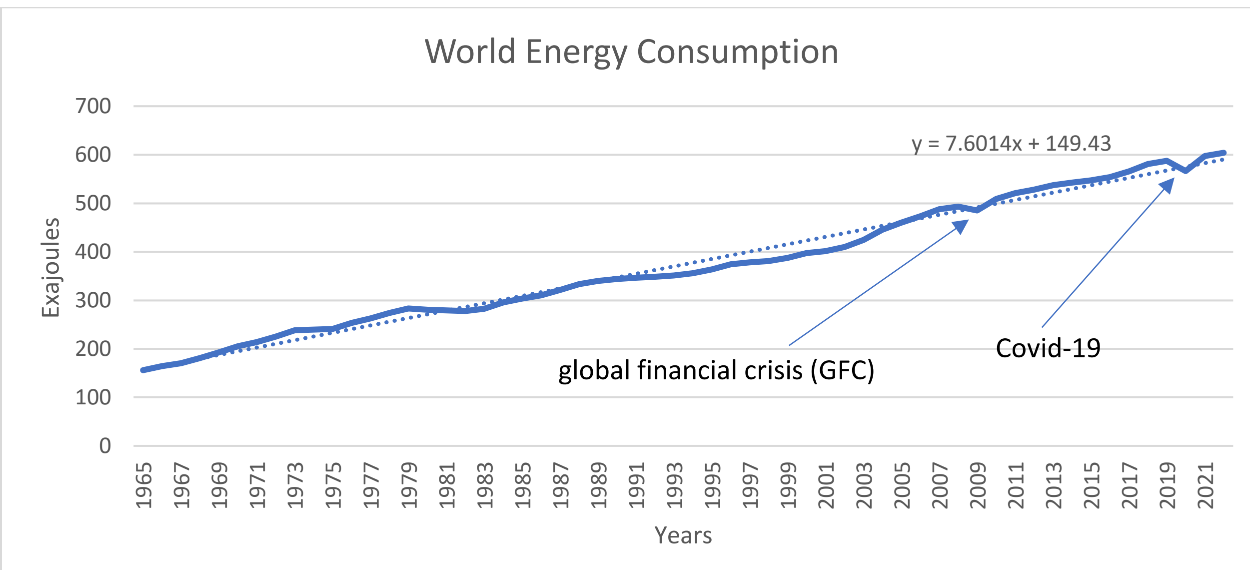

Figure 5. Trend world energy consumption

Figure 6 shows that GDP per capita has increased by an average of $215 annually, reflecting a 5.6% growth rate each year. The linear trendline illustrates consistent growth, with temporary dips during significant events such as the 2008 Global Financial Crisis (GFC) and the COVID-19 pandemic. However, following the pandemic, energy demand rebounded, demonstrating resilience. This trend underscores the ongoing link between economic health and energy consumption, highlighting the need for sustainable energy solutions to address growing demand while mitigating environmental impacts. Despite setbacks, the overall trend points to continued growth, emphasizing the importance of transitioning to more efficient, low-carbon energy sources.

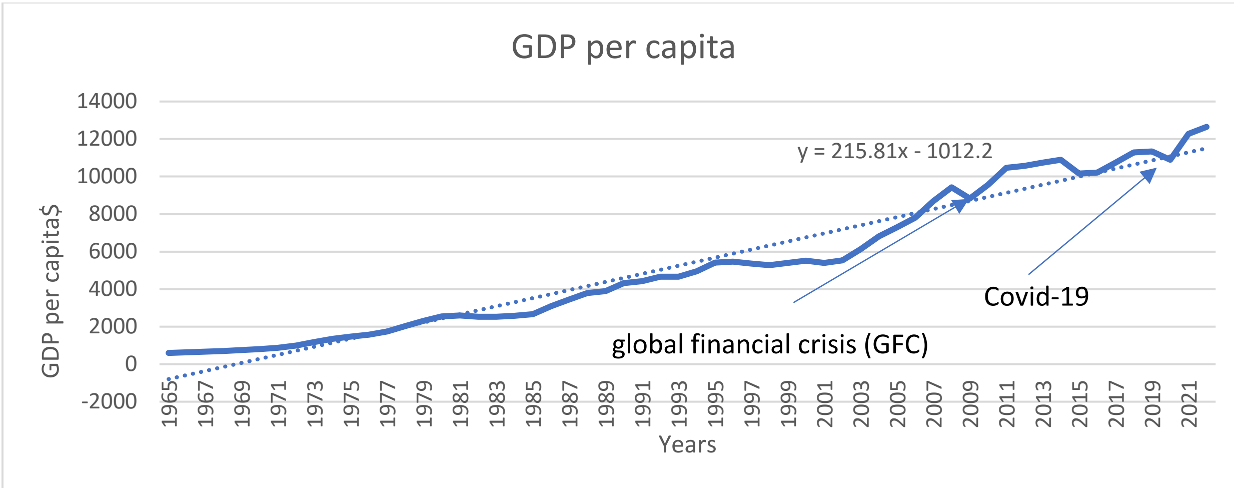

Figure 6. Trend GDP per capita in current US$

The stationarity of the data series was assessed using four common unit root tests: the Augmented Dickey-Fuller (ADF), Elliott-Rothenberg-Stock (ERS), Phillips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests. The results indicate that at the level form, the test statistics for CO_2 emissions per capita, energy consumption per capita, and GDP per capita are not statistically significant at the 1% level in the ADF, ERS, and PP tests. This suggests the presence of a unit root, implying that these series are non-stationary. However, after taking the first difference, all three variables become stationary, as evidenced by the significant test statistics in the ADF, ERS, and PP tests at the 1% level. The KPSS test, which has a null hypothesis of stationarity, confirms these findings, as the test statistics at the first difference fall below the critical value, further supporting the stationarity of the differenced series.

Table2. Unit Root Test Results for CO_2 Emissions, Energy Consumption, and GDP per Capita

	Test statistics	At Level	At First Difference
Co2 per capita	ADF	-2.418 (–4.127)	-6.169*** (–4.130)
	ERS	-1.617 (–3.743)	-6.214*** (–3.747)
	PP	-2.569 (–4.127)	-6.159*** (–4.131)
	KPSS	0.092 (0.146)	0.113 (0.146)
Energy per capita	Test statistics	At Level	At First Difference
	ADF	-2.961 (–4.127)	-6.357*** (–4.131)
	ERS	-1.696 (–3.743)	-6.375*** (–3.747)
	PP	-2.989 (–4.127)	-6.357*** (–4.131)
	KPSS	0.093 (0.146)	0.124 (0.146)
GDP per capita	Test Statistics	At Level	At First Difference
	ADF	-1.846 (–4.127)	-7.003*** (–4.131)
	ERS	-1.372 (–3.743)	-7.126*** (–3.747)
	PP	-1.904 (–4.127)	-7.005*** (–4.131)
	KPSS	0.216 (0.146)	0.037 (0.146)

The Johansen cointegration test was conducted to determine whether a long-term equilibrium relationship exists among the analyzed variables. The test results are presented using both the Trace Test and the Max-Eigenvalue

Test, each assessing the presence of cointegration at different ranks (r). The Trace Test results indicate that for r = 0, the test statistic (32.706) exceeds the 5% critical value (29.797) with a p-value of 0.0225, leading to the rejection of the null hypothesis (H_0) and suggesting at least one cointegrating relationship. However, for r ≤ 1 and r ≤ 2, the null hypothesis is not rejected, indicating no additional cointegrating vectors. Similarly, the Max-Eigenvalue Test confirms this finding, as the null hypothesis for r = 0 is rejected (28.135 > 21.132, p = 0.0044), but it is not rejected for higher values of r. These results collectively suggest the existence of a single cointegrating relationship among the variables. This implies that, despite short-term fluctuations, the variables share a stable long-run equilibrium, reinforcing the notion that GDP per capita, energy consumption, and CO_2 emissions are interlinked over time.

Table3. Johansen Cointegration Test Results for Long-Run Relationship Analysis

Test	H0	λmax / Trace Stat	CV (5%)	p-value	Decision
Trace Test	r = 0	32.706	29.797	0.0225	Reject H0
	r ≤ 1	4.571	15.495	0.8526	Do not reject
	r ≤ 2	0.258	3.841	0.6115	Do not reject
Max-Eigenvalue Test	r = 0	28.135	21.132	0.0044	Reject H0
	r = 1	4.313	14.265	0.8249	Do not reject
	r = 2	0.258	3.841	0.6115	Do not reject

Table 4 presents the results of the Vector Autoregression (VAR) model, highlighting the relationships between CO_2 emissions, energy consumption, and GDP per capita. The autoregressive components of each variable exhibit strong persistence over time. Specifically, the coefficient for CO_2(-1) is 0.948 with a t-statistic of 7.95, indicating a significant and strong positive relationship, meaning past CO_2 levels strongly influence current levels. Similarly, ENERGY(-1) has a coefficient of 0.843 (t = 7.61), and GDPP(-1) has a coefficient of 0.966 (t = 26.17), both highly significant, demonstrating that past values strongly predict current values for energy consumption and GDP per capita, respectively. These results indicate that only the lagged values of the dependent variables significantly explain their current values, reinforcing the notion that historical trends within each variable are key determinants of their present state. However, the cross-variable relationships show weaker and largely insignificant effects. The impact of past energy consumption on current CO_2 emissions (ENERGY(-1)) is negative (-0.0078) but not statistically significant (t = -0.86), suggesting no clear linkage between energy consumption and CO_2 emissions within this model. Similarly, the effect of GDP per capita on CO_2 emissions (GDPP(-1)) is positive (1.27E-05) but statistically insignificant (t = 1.25), implying that changes in GDP per capita do not have an immediate or substantial effect on emissions. Likewise, the effects of CO_2 emissions on energy consumption (CO_2(-1)) and GDP per capita on energy consumption (GDPP(-1)) are also statistically insignificant. These findings suggest that while CO_2 emissions, energy consumption, and GDP per capita exhibit strong autoregressive patterns, their short-term interdependencies are weak. The lack of significant cross-variable relationships implies that external factors, structural economic shifts, or long-term mechanisms may play a more dominant role in shaping the interactions between these variables, rather than direct short-term causality.

Table4. Vector Autoregression (VAR) Estimates

Dependent Variable	Independent Variable	Coefficient	Std. Error	t-Statistic	Significance
CO_2	CO_2(-1)	0.948	0.119	7.95	Significant
CO_2	ENERGY(-1)	-0.0078	0.0089	-0.86	Not Significant
CO_2	GDPP(-1)	1.27E-05	1.00E-05	1.25	Not Significant
ENERGY	ENERGY(-1)	0.843	0.11	7.61	Significant
ENERGY	CO_2(-1)	0.212	1.477	0.14	Not Significant
ENERGY	GDPP(-1)	0.000198	0.00013	1.57	Not Significant
GDPP	GDPP(-1)	0.966	0.036	26.17	Significant

Table 5 presents the fit statistics for the Vector Autoregression (VAR) model, evaluating the explanatory power of the regressions for CO_2 emissions, energy consumption, and GDP per capita. The R^2 values for CO_2 (0.917), energy consumption (0.971), and GDP per capita (0.991) suggest that the model explains a substantial proportion of the variance in each dependent variable. Similarly, the Adjusted R^2 values remain high, confirming that the inclusion of explanatory variables improves the model fit while accounting for the number of predictors. The F-statistics for all three equations—197.5 for CO_2, 610.14 for energy consumption, and 2140.84 for GDP per capita—indicate that the overall model is highly significant. However, despite the strong model fit, the significance of relationships primarily stems from the own-lagged terms of each variable, as indicated in Table 4. This reinforces the finding that historical values of CO_2, energy consumption, and GDP per capita are the dominant predictors of their respective current values, while cross-variable effects remain weak. The Akaike Information Criterion (AIC) and Schwarz Criterion (SC) values provide additional measures of model performance, with lower values indicating better model efficiency. While GDP per capita has the highest AIC (14.59) and SC (14.73), CO_2 has the lowest AIC (-1.8) and SC (-1.65), suggesting that the CO_2 equation is relatively more parsimonious compared to the other variables. Overall, the high R^2 values confirm the strong explanatory power of the VAR model, but the results further support the conclusion that significant relationships exist predominantly for own-lagged terms, rather than cross-variable interactions.

Table 5. VAR Model Fit Statistics

Variable	R^2	Adjusted R^2	F-Statistic	Akaike AIC	Schwarz SC
CO_2	0.917	0.913	197.5	-1.8	-1.65
ENERGY	0.971	0.97	610.14	3.23	3.37
GDPP	0.991	0.991	2140.84	14.59	14.73

The Granger causality test results indicate that no variable significantly predicts another in the short term, as all p-values exceed 0.05. This means that past values of CO_2 emissions, energy consumption, and GDP per capita do not provide meaningful information for forecasting each other. These findings align with the VAR model results (Table 4), suggesting that while each variable exhibits strong internal persistence, their short-term interdependencies are weak. This implies that their relationships may be influenced by long-term structural factors rather than immediate causal effects.

Table 6. Granger Causality (Toda-Yamamoto) Results

Dependent Variable	Excluded Variable	Chi-Square	p-Value	Conclusion
CO_2	ENERGY	0.757	0.384	No Causality
CO_2	GDPP	1.553	0.213	No Causality
ENERGY	CO_2	0.021	0.886	No Causality
ENERGY	GDPP	2.459	0.117	No Causality
GDPP	CO_2	1.576	0.209	No Causality
GDPP	ENERGY	2.428	0.119	No Causality

The optimal lag length for the VAR model was determined using Akaike Information Criterion (AIC) and Schwarz Criterion (SC). Lag 1 was selected as the best fit, as it had the lowest AIC (13.55) and a relatively low SC (14.00) compared to other lag orders. This selection ensures that the model captures the autoregressive dynamics while avoiding overfitting. These results align with previous findings, confirming strong persistence within each variable but weak short-term interactions between CO_2 emissions, energy consumption, and GDP per capita. The absence of short-term causality suggests that long-term structural factors play a more significant role in shaping these relationships.

Table 7. Lag Order Selection Criteria

Lag	Log Likelihood	AIC	SC	Selected?
0	-558.35	21.18	21.29	No
1	-347.2	13.55	14	Yes
2	-341.42	13.67	14.45	No
3	-335.1	13.77	14.89	No

Conclusions

This study examines the relationship between economic growth, energy consumption, and CO_2 emissions across 193 countries from 1965 to 2023. The findings confirm a strong positive correlation between GDP per capita, energy consumption, and CO_2 emissions, highlighting the continued dependence on fossil fuels despite a shift towards renewables. Fossil fuels still account for 82% of global energy use, emphasizing the challenge of reducing carbon dependency. Econometric analysis further supports these findings. Unit root tests confirm long-term trends, while cointegration analysis suggests a stable long-run equilibrium, albeit with weak short-term interactions. VAR estimates show that each variable is primarily influenced by its own past values, reinforcing strong autoregressive behavior with limited cross-variable effects. Granger causality tests indicate no short-term causal links, suggesting that economic growth and energy consumption do not directly drive CO_2 emissions in the short run. The lag order selection confirms that a one-lag model is optimal, balancing explanatory power with model efficiency. These results highlight the need for transformative policies beyond incremental efficiency improvements to achieve sustainable economic growth while reducing carbon emissions.

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RESEARCH ARTICLE

Broadcast Media Service, Weather Reports Management and Public Environmental Affability. An Appraisal by Residents in Select Sahel Sahara States of Nigeria

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Abstract

Concerns abound over environmental and climatic changes. This study investigated the need for clear messages from the media about weather reports. It has the title: "Broadcast Media Service, Weather Reports Management and Environmental Affability: An Appraisal by Residents in Select Sahel Sahara States of Nigeria". The objectives were to find out the lucidity of weather reports; the extent of credibility; the utility percentage of weather reports for environmental affability among residents of sub-Sahara states in Nigeria. The scope of work was limited to the Sahel-Sahara region of Nigeria. These are: Borno Yobe, Kano, Katsina, Jigawa, Sokoto, Zamfara, Kebbi, The research was an online survey with the population of 23,682,681 persons and a sample size of 600 persons. The instrument of research was an online questionnaire proportionately distributed to respondents. The media richness and the media dependency theories were applied. The findings showed that majority of respondents do not understand the terminologies in weather forecasts. From 600 respondents, 367 or 61 percent of the residents agreed that the weather reports are not very clear for understanding. A major recommendation is that media presenters of weather reports should apply interpretative simplicity models to break complex meteorological terms for audience and listeners understanding.

Keywords: Affability; Environmental; Management; Media; Weather

Introduction

Information is a necessary resource for everyone. Therefore, to share knowledge, ideas, and perspectives, communication is an important process to be considered. Since ancient times, humans have invented technologies to communicate on a large scale. For instance, Hassan & Thomas (2006) say that the transition from telegraphs to the internet illustrates the cumulative advancements in communication technologies, originating from basic tools like smoke signals. These technologies can be broadly categorized under the title "media," which can actually be defined as a means of communication that fully imposes the six components of a communication process, namely: source, message, medium, destination, feedback, and noise. In this vein, broadcast media can be considered a certain type of mass communication in which audio and video messages are conveyed. Broadcasting is a communication process in which the information transmitted is aimed at a large and diverse audience. Webster & Phalen (2012) say that broadcast media is classified under main categories of television and radio, satellite and internet, cable and podcast. Specifically, televisions entertain sight and hearing senses, while radios only entertain the sense of hearing. Television was invented in the 1920s, though its use started in the late 1930s; however, it spread in the late 1950s. Radios were invented in the late 19th century and began their use in the early 1920s. Both technologies have been utilized worldwide and have influenced daily life. McQuail (2010) says that television and radio networks can be found at every level of society, namely: national, intermediate, local, corporate, and community levels, or even just a centralized one. Broadcast media has some unique properties that create a number of objectives, which are media specific. Unlike other media types, broadcast media provides a mixture of audio and visual effects that create some unique perception effects in the audience. Weather reporting as a part of broadcast media is undoubtedly the most recently introduced and watched programme for people of all ages and backgrounds. It is, indeed, a must inserted part of broadcast news. The impact and importance of weather reports can be seen in the choice of appropriate formats, the kind of language used, the differentiation between regional, national, and international feeds, and also in the efforts put in place by networks to safeguard their weather broadcast efforts. The calm of a weather anchor playing an important role during a natural calamity is something that can never be forgotten. Journalists for purposes of news casting, explore the various aspects of weather reports to justify the time and efforts taken to put in by networks to keep audiences glued to channels. Broadcast news presentations have a crucial role to play on the public friendliness with the environment, as media are the link between the viewers, the environment and the news stations. However, some questions are asked about the aims of exploring weather reports, the impact on the viewing behavior of news segments, and the kind of formats used. Weather is something everyone talks about, and it can greatly affect the way individuals and nations do business (Ahrens & Henson, 2021). For this reason, broadcasting media in many forms, such as television, the Internet, or radio, interested in keeping a close watch on regional, national, and international weather situations are appreciated. It can be said that weather reporting and proper management for the affability of the listeners has an engraved space in the broadcast media yet not without challenges which this work seeks to explore for public affability in the Sahel states of Nigeria. Media messages cannot be allowed to reach the people raw or not interpreted to the clear understanding of the people. The prevailing challenges can be solved if appropriate message management techniques are applied in breaking complex terms and scientifically concepts. The people deserve undistorted messages for due engagements in social and economic activities.

Statement of the Problem

In Nigeria, the Nigerian Meteorological Agency (NiMet) is the body responsible for forecasting weather. While NiMet provides essential data, it remains the job of the media especially the radio and televisions to disseminate the information regarding weather reports. The challenge for the understanding of the information from the media lies on the accuracy and timeliness of weather reports. There are many factors which can be real challenge affecting accuracy including technological limitations. Despite advancements, Nigeria's meteorological infrastructure, such as weather stations and radars, are still underdeveloped in some regions, especially rural areas. There is also the challenge of effective data collection. The lack of a comprehensive network of weather monitoring stations can limit the quality of data, making localized forecasts less reliable. More so there is climate variability where Nigeria is affected by a diverse range of climates, from the arid north to the humid south. This variability, coupled with the increasing effects of climate change, can complicate forecasting efforts. These are challenges that are directly on weather reports while the indirect challenges can stem from the incompetence, inefficiency and lack of interest from the media practitioners. It calls for timely updates. Weather conditions can change rapidly, necessitating real-time updates. Broadcast media must be agile in delivering current information, particularly during extreme weather events. It must be an engaging presentation whereby media anchors need strong communication skills to maintain viewer attention while presenting data clearly and effectively. The statement of the problem is therefore, if the media are adequately placed to offer the needed service on weather reporting for a friendly environment in Nigeria.

Objectives of the Study

1. What is the lucidity rate of broadcast media approaches on weather reports for environmental affability among residents of Sahara states in Nigeria?
2. What is the extent of credibility of broadcast media approaches on weather reports for affability among residents of Sahara states in Nigeria?
3. What is the utility percentage of broadcast media approaches on weather reports for environmental affability among residents of sub-Sahara states in Nigeria?

Scope of Work

The Sahel-Sahara region of Nigeria refers to the northern part of the country, which lies within the transition zone between the Sahara Desert to the north and the more tropical savanna regions to the south. This region is characterized by arid to semi-arid conditions, low rainfall, and is prone to desertification. The Sahel-Sahara states of Nigeria typically include those states located in the northernmost part of the country. These are: Borno, Yobe, Kano, Katsina, Jigawa, Sokoto, Zamfara, Kebbi

These states are characterized by sparse vegetation, and many of them experience the effects of the advancing Sahara Desert due to climate change and environmental degradation. Agriculture in these areas is typically reliant on drought-resistant crops, and the people often practice a mix of farming and pastoralism. The region is also affected by seasonal winds like the Harmattan, which brings dry and dusty conditions from the desert. The Sahel-Sahara region is critical in discussions about climate resilience, desertification control, and socio-economic development in Nigeria.

Literature Review

Lucidity of Weather Reports in Broadcast Media

Media reports about the weather are essential for predictions, daily planning and safety. Smith & Brown (2019) say that inaccurate or inconsistent weather forecasts can lead to frustration of the audience. On the side of the media, it can lead to loss of credibility for the broadcaster. Therefore, precise and reliable weather reporting is crucial for retaining viewer confidence and loyalty. Informing the public about weather conditions accurately in broadcast weather reports is crucial for public safety and preparedness. Inaccurate weather forecasts can lead to serious consequences, such as unpreparedness for natural disasters or disruptions in daily activities. Therefore, it is essential for the media to use reliable data and advanced technology to provide precise and timely information. Technological advancements in weather forecasting have significantly improve the

accuracy and timeliness of weather reports. With the use of satellite imagery, radar systems, and computer models, media can work with meteorologists to predict weather patterns more precisely. The partnership can allow broadcasters to deliver more reliable information to the public, helping them make informed decisions. Broadcast media objectives on weather reports can be adapted to changing patterns by being accurate and timely, reliable and easy to understand (Zhang, Li, Wang, & Chen, 2024).
Particularly, weather reports enhance public safety because they provide timely information about severe weather conditions. This allows individuals and communities to prepare for disaster events such as hurricanes, thunderstorms, and extreme temperatures. By staying informed, people can take necessary precautions to protect themselves and their property. Weather reports can significantly impact on local economies by informing businesses about potential disruptions. Farmers and agriculturists rely on accurate weather information to plan their planting and harvesting schedules, while tourism industries adjust activities based on weather forecasts. Additionally, weather updates help retail stores manage inventory by predicting demand for seasonal products in equipment, clothing, boots and supplies. On events planning, weather reports play a crucial role in helping individuals and organizations plan activities and events. Accurate weather information allows people to make informed decisions about travels, outdoor gatherings, and even daily commutes. By staying updated, they can avoid potential disruptions and ensure safety.

Credibility of Broadcast Media Weather Reporting: A Focus on Nigeria

Broadcast media plays a crucial role in delivering timely and accurate weather reports, a service that directly affects various sectors such as agriculture, transportation, and disaster preparedness. In Nigeria, where agriculture is a primary livelihood and climate change has heightened the unpredictability of weather patterns, effective weather reporting is vital. Weather reports are delivered through television, radio, and increasingly via digital platforms like social media (Akinsanmi & Okafor 2022). Oladipo (2020) says that broadcasters serve as intermediaries between meteorological agencies and the public, translating technical data into comprehensible and actionable information. Crucial skills required for this task include presenters' competence of conveying complex weather information in layman's terms, making it accessible to a diverse audience. Next is the availability of effective use of visual aids. In television broadcasts, the use of visual tools like maps, satellite imagery, and animations enhances understanding. Public perception of weather forecasts in Nigeria tends to vary, with some uncertainty regarding their reliability. This is particularly true in rural areas where the technology is less developed, leading to potential inaccuracies in localized forecasts. However, improvements in digital tools and the broader dissemination of information through mobile technology have helped bridge some of these gaps.

Challenges in Delivering Weather Reports

Meteorologists regularly face problems such as the changeability of weather patterns and the limits of predicting tools. For instance, unexpected changes in atmospheric situations can lead to inexact forecasts. Also, communicating multifaceted weather statistics in a way that is comprehensible and actionable for the community can be a substantial challenge. Reporting the weather precisely and effectively is a weighty obligation for media organizations. Weather reporting influences manifold sides of daily life, including agriculture, transportation, disaster preparedness, and personal planning. However, numerous challenges weaken the ability of media institutions to deliver exact and appropriate weather data. These challenges range from technological limitations to audience perception and institutional restraints. On challenges of tools, accurate weather reporting trusts deeply on cutting-edge technology, such as satellites, radars, and computer modeling systems. However, not all media establishments have access to these refined tools. Schultz et al. (2017) say that high-resolution weather guess models need considerable computational power and know-how, which countless media organizations cannot have enough money to procure. As a consequence, media institutions frequently depend on third-party weather services, which may deliver general statistics that is not explicit to home-grown environments. Meteorological data is composite and requires professional clarification. Media personnel often lack the technical education needed to explain meteorological data correctly. As noted by Doswell (2004), sweeping statements on weather data can cause misinformation, miscommunication and misunderstanding, causing community doubt about weather forecasts. For an illustration, a media institution might read a "40% chance of rain" as rain being improbable, whereas meteorologists know it to mean that rain can happen in 40% within the prediction region. Weather is integrally active, and circumstances can alter speedily, making real-time reporting difficult. Lindzen (2007) stresses that even the most innovative weather models have boundaries in foreseeing unexpected weather occurrences, such as tornadoes or flash floods. Media institutions face the trouble of keeping their reports informed while guaranteeing precision. The wide-ranging public often misconstrues weather intelligences, which can lead to mix-up and frustration. Demuth, Morss, & Lazo, (2016) say that concepts and languages like "likelihood of brightness and rainfall are commonly misunderstood, causing unpredicted decision-making based on the guesses. Media institutions must strike an equilibrium between systematic accuracy and public presumption. This is an undertaking that is far from being achieved. In a determination to appeal to viewers, some media offices sensationalize weather reports. This practice dents public trust and can end in needless anxiety or complacency. Potter and Warren (2014) point out that sensationalism in weather reporting regularly ranks ratings over correctness, creating beliefs of uncertainty. In the course of risky weather events, well-timed and accurate information is a serious issue. Media institutions often compete to coordinate real-time weather updates, particularly when communication infrastructure are not enough. For example, the obliteration of communication networks during Hurricane may disclose noteworthy differences in disaster-related weather reporting (Tierney, Lindell, & Perry, 2006). Weather reporting must cater to miscellaneous audiences with changing levels of knowledge and language skill. As Smith and Mawson (2008) highlight, failure to communicate weather risks in ethnically and linguistically suitable methods can end in misinformation and a lack of preparedness among defenseless residents. Media institutions face ethical quandaries when reporting weather forecasts. These include deciding whether to underscore worst-case circumstances to ensure preparedness or to tone down risks to evade causing anxiety. Kovach and Rosenstiel (2001) contend that ethical journalism necessitates harmonizing public interest with the duty to avoid horror mongering.

Utility of Broadcast Media Reporting of the Weather to the Public

Weather forecasts play a vibrant part in defending lives and property by providing prompt notices about austere weather circumstances. Johnson, Kim, & Evans (2023) say that improvements in broadcast media have improved the giving out of real-time weather warnings, allowing communities to arrange for hurricanes, tornadoes, and other life-threatening actions. This apt communication decreases death toll and alleviates harm. Broadcast weather reports are indispensable for economic development, predominantly in sectors such as farming, air travel, and logistics. For example, farmers depend on report forecasts to schedule sowing and garnering moments (Greenfield, Patel, & Novak, 2022). Similarly, shipping firms use weather updates to guarantee harmless and well-organized service. Broadcast media enhances community preparedness for disasters by providing detailed information on possible hazards. As noted by Rivera and Coleman (2021), media institutions' ability to reach inaccessible areas through radio and television ensures that even underserved people get serious weather information. Regular weather reporting fosters a better understanding of climate and ecological changes. Martin and Lee (2023), educating the community about uncommon weather shapes harps on maintainable practices supported with universal efforts of adjusting to temperature alteration. Interactive features, such as viewer-submitted weather photos or live call-ins during broadcasts, enhance community engagement. These features make weather reporting relatable and encourage audiences to take proactive measures during severe weather events (Smith & Ortega, 2023). The integration of digital platforms with traditional broadcast media has expanded the reach of weather reporting. Mobile apps, social media updates, and live streaming ensure that weather information is accessible anytime and anywhere. Carter, Smith, & Lin (2022) emphasize that these platforms have bridged the gap between urban and rural audiences. As cleared by Brown and Taylor (2023), media efforts to explain phenomena such as El Niño and La Niña contribute to a more informed and robust society.

Review of Related Literature

On similar work, Keul & Holzer (2013) in "the relevance and legibility of radio/TV weather reports to the Austrian public" asserted that the communicative quality of media weather reports, especially warnings, can be evaluated by user research. It is an interdisciplinary field, still uncoordinated after 35 years. The authors suggested a shift from a cognitive learning model to news processing, qualitative discourse and usability models as the media audience are in an edutainment situation where it acts highly selective. A series of field surveys 2008–2011 tested the relevance and legibility of Austrian radio and television weather reports on fair weather and in warning situations. 247 lay people heard/saw original, mostly up-to-date radio/TV weather reports and recalled personally relevant data. Also, a questionnaire on weather knowledge was answered by 237 Austrians. The main results were (a) a relatively high level of meteorological knowledge of the general population, with interest and participation of German-speaking migrants, (b) a pluralistic media usage with TV, radio and internet as the leading media, (c) higher interest and attention (also for local weather) after warnings, but a risk of more false recalls after long warnings, (d) more recall problems with radio messages and a wish that the weather elements should always appear in the same order to facilitate processing for the audience. In their narrow time windows, radio/TV weather reports should concentrate on main features (synoptic situation, tomorrow's temperature and precipitation, possible warnings), keep a verbal "speed limit" and restrict show elements to serve the active, selective, multi-optional, multicultural audience. On their part, Adum, Okika, Chiaghana, & Okoli O. O. (2021) appraised the perceptibility of media sensitization towards the utilization of media weather reports among farmers in Anambra state. The authors say that the benefits inherent in the utilization of climate change report in Agriculture cannot be over emphasized. It assisted the farmers to sort knowledgeable choices about their plantings and helps expand farming profits. This study surveyed the closeness or acquaintance of farmers in Anambra state to media weather reports, their characters towards the weather reports and their application of weather reports in agriculture decision making. This study was premeditated as a survey. A sample of 400 farmers was drawn from 120,000 farmers listed with the Ministry of Agriculture, Anambra State. Six local government areas were designated to signify the three senatorial zones in the state, and four group of people to represent the selected local government areas. Findings from the survey showed that the farmers have information of weather reports but, they do not exploit these because they do not comprehend the communication content and are incapable to deduce it towards utilizing them in making decision for their planting coordination. The study determined that effort in understanding of the weather reports and religious conviction were the reasons that constrain the usage of weather reports in agriculture decision making among farmers in Anambra State. The study suggested, augmented and continued aggressive sensitization by the media. The study recommended that the bodies accountable for formulating the weather prediction like the Nigerian Meteorological Agency should be providing steady and simplified weather reports to the media, and make such reports to be less methodical in order to bridge the trial of struggles in acceptance. The gap in this work is that it has nothing to do with the Northern states of Nigeria rather a single state in the entire Southern region of Nigeria. It has limitations since the population was only on farmers against this present work that cover all grades and occupations of persons in four states of the Sahel Sahara states of Nigeria.

Theoretical Framework

Media richness theory (MRT)

It is occasionally talked about as information richness theory, to define a communication medium's capability to replicate the information directed over it. It was introduced by Richard Daft and Robert Lengel in 1986 as an extension of rank and evaluate the richness of certain communication media. It hypothesizes that richer, individual communication media are usually more active for communicating ambiguous issues in disparity with leaner, less rich media. In presenting media richness theory, Daft and Lengel try to help establishments handle communication trials, such as unclear or confusing messages, or contradictory explanations of messages. Media Richness Theory has been retroactively distinct as the capability of information to modify understanding surrounded by a time break. Media richness theory states that wholly communication media differ in their skill to allow users to interconnect and to change understanding. The extent of this capability is recognized as a medium's "richness." MRT places all communication media on an unceasing scale founded on their ability to sufficiently communicate a multifaceted message. Media that can competently overwhelm different frames of reference and illuminate vague issues are measured to be richer whereas communications media that need additional time to take understanding are believed less rich. Mammadov (2022) maintains that a main driver in choosing a communication medium for a specific message is to decrease the equivocality, or possible misapprehensions, of a message. If communication is misleading, it is unclear and thus more problematic for the receiver to decipher. The added equivocal a message, the more cues and data needed to deduce it appropriately. He also stressed that message lucidity may be conceded when manifold sections are interconnecting with each other, as departments may be trained in dissimilar skill sets or have inconsistent communication standards. Media richness is a function of characteristics on ability to handle multiple information cues simultaneously, facilitate rapid response, establish a personal focus, utilize appropriate language.

Media Dependency Theory

The first to present the theory of media dependence by Ball-Rokeach and De Fleur in 1976 who suggested a theory which attributes to the media influences rather than their respective characteristics of the relationship between individuals, media and culture. Identifying the position and characterization of the media system. The theory of media dependence focuses on an ecological approach, to show the relationships between small, medium and large systems and the components. The theory discusses the ways in which the different social

structures (economic political, religious, and educational systems) and the social framework contribute to the social information system. In addition, describe how the mass media system has become an important knowledge system. In modern society, people have relied on their personal connections and networks to achieve their goals of understanding what is happening in society and determining how to act and how to spend their free time (Nawi, Alsagoff, Osman, & Abdullah, 2020).
To accomplish goals, it has become difficult for persons to rely solely on their personal contacts. It has become difficult for people to live well in modern society with the growing speed of social change without relying on the media for knowledge. Through this process, the media has become an essential system in society that people need to rely on in their everyday lives to obtain knowledge. The concept of media as an information system puts the media system at the heart of society. Individuals, organizations and social systems cannot obtain important information entirely in society without relying on the mass media system (Choi, Tan, Yasui, & Pekelnicky, 2014). The second core proposition of media reliance theory is that the power of the media depends on the interdependence of individuals and the media. The third suggestion of the theory of media dependence is that with growing complexity or confusion in society and also in leading society to a particular problem, the role of the media system in society increases for social improvements that are both long-term and short-term.

Methodology

The method for the research was an online Survey. Bhat (2024) says that the online survey, or internet survey, is one of the most popular data-collection sources, where a set of survey questions are sent out to a target sample, and the members of this sample respond to the right questions over the World Wide Web. In online survey, respondents receive surveys via various mediums such as email, embedded over websites, social media. It has advantage of real time message and response, cost efficiency, minimum margin of error and saves time.

Population

The population of the study was 23,682,681 persons residing in four Sahel Sahara states of Nigeria. The four states taken for the research are Borno, 6,651, 590, Jigawa 6,679,080, Kebbi 6,001,610 and Yobe 4,350,401 persons. The figures were taken from the 2023 projected population of the affected states.

Sample Size

Akpan (2023) argues that 600 persons can be a convenient figure to peg the sample size in a large population while 50 can remain the least figure where population is low. Hence, the sample size of the study was taken at 600 persons.

Administration and Methods of Data Collection

The collection of data was done by forming 600 copies of questionnaire with 10 basic inquiries through Google Forms format and mailing to residents. The copies were pretested through face value reading by two research assistants and distributed online based on proportionate formula per the four select states. In that arrangement, Borno took 169 copies, Jigawa, 169 copies, Kebbi 152 copies and Yobe took 110 copies. The electronic (e.) mail addresses of the residents were obtained from the Mobile phones Network providers' data base.

Ethical Consideration

This study was dedicated to keeping the maximum ethical values during the research process. Ethical agreement was pursued from proper institutions, boards and research committees. The ethical considerations which directed the conduct of this research was by earning informed consents. Henceforth, all participants were wholly informed about the purpose, objectives, and processes of the research. Participation was totally voluntary, and informed consent in verbal, was obtained preceding data collection. In order to ensure confidentiality and anonymity, the identity of all partakers was assured. Therefore, no individual identifiers were used in the reporting of findings. Data was coded and securely stored to ensure privacy. Additionally, respect for all participants was with self-esteem and reverence. Exceptional attention was paid to cultural feelings in the Sahel Sahara states of Nigeria, ensuring that traditional communication was suitable and comprehensive. The right to pull out by potential respondents was assured at any point without any negative consequences or the need to provide reasons. The affected residents were informed that the research was intended to minimize any possible injury to the participants. No complex or offensive questions was asked that may cause agony. The participants and other residents were guaranteed that data collected was firmly for academic and research purposes while findings was to be reported fairly, without untruth, distortion, or twisting. It was made known that findings may be shared with the local populations and interested party in the Sahel Sahara states to encourage transparency and inspire informed use of the results for programme and practice in media and environmental messages. By observing to these ethical values, the study had aimed to back meaningful insights on the protection of the privileges and wellbeing of all partakers.

Data analysis

The analysis of data was carried out through the creation of simple frequency tables and supported with a pie chart for the computing of responses into data and ascertain the highest and the lowest answers in terms of figures. The answers were computed based on each of the questions raised earlier.

Pie Chart 1: The lucidity of broadcast media weather reports for environmental affability among residents of Sahara states in Nigeria

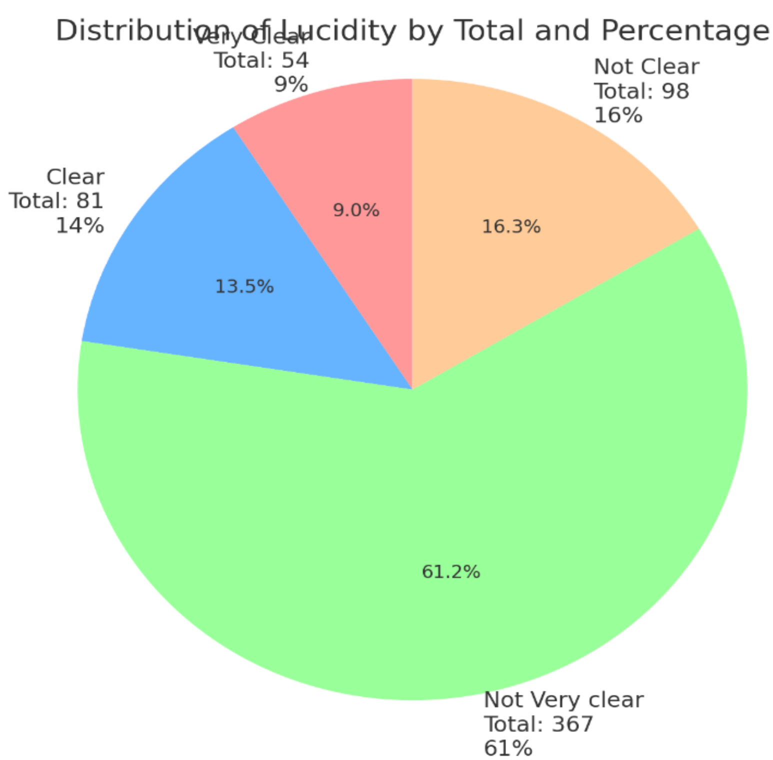
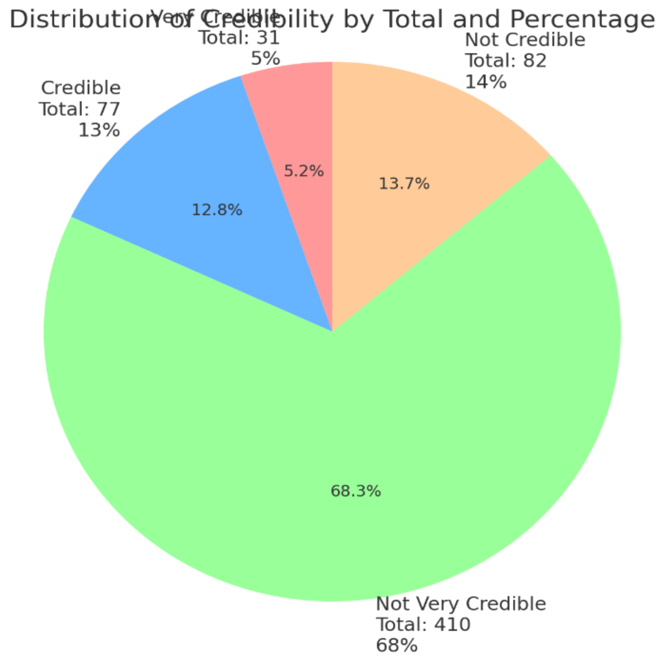


Table 1. Distribution of Lucidity Level Weather Reports by Broadcast media

Lucidity	Borno	Jigawa	Kebbi	Yobe	Total	Percentage
Very Clear	15	11	18	10	54	9
Clear	25	26	10	20	81	14
Not Very clear	79	84	124	80	367	61
Not Clear	50	48	-	-	98	16
Total	169	169	152	110	600	100

Source: Online Survey Response 2024

The pie chart marked 1 and the supporting Table 1 has four aspects of lucidity of the message on weather reports. Out of 600 respondents, 367 or 61 percent of the residents per the four states agreed that the weather reports are not very clear while very clear had 54 or 9 percent respondents. This indicates a serious communication gap between meteorological agencies/media houses and the general public. The responsible factors may be on technical language, poor presentation, or insufficient localization of contents.



Pie Chart 2 and Table 2: Credibility of Weather Reports from Broadcast Media

Credibility	Borno	Jigawa	Kebbi	Yobe	Total	Percentage
Very Credible	6	21	4	-	31	5
Credible	23	23	8	23	77	13
Not Very Credible	106	87	140	77	410	68
Not credible	34	38	-	10	82	14
Total	169	169	152	110	600	100

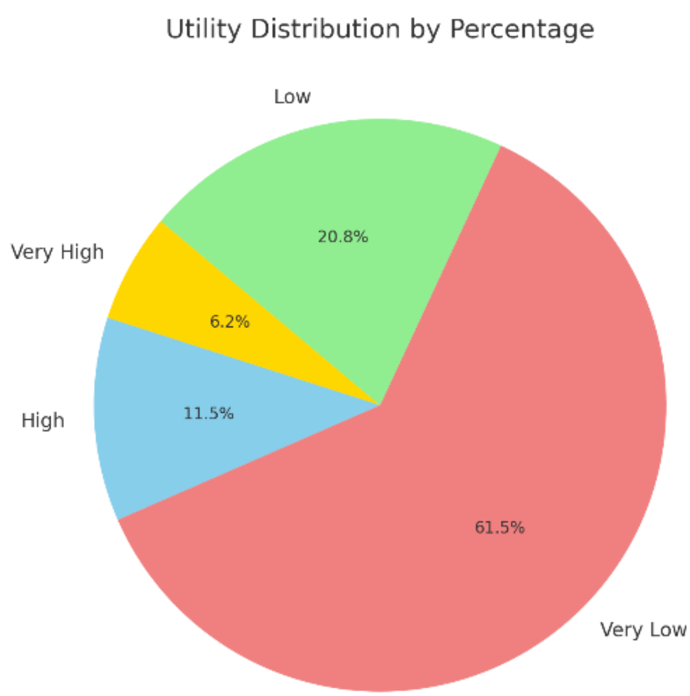
Source: Online Survey response 2024

In Table 2 and pie chart 2 , the variables of credibility are listed and out of 600 respondents 410 or 68 percent agreed that the weather reports are not very credible while those who supported the credibility were77 or 13 percent of respondents. Very credible had 31 0r 5%, not credible 82 or 14%, The implication is that the people have no reliability on weather reports from the broadcast media. With 68% of respondents perceiving weather reports as not credible, there is a clear trust deficit. This indicates a major setback for the effectiveness of weather communication systems in the Sahel Sahara region. People may doubt the accuracy, timeliness, or relevance of the information broadcasted. In a region vulnerable to climate-related hazards like droughts, heat-waves, and dust storms—lack of trust in weather reports can endanger lives. If people do not believe the reports, they are less likely to act on weather warnings or prepare adequately for adverse conditions. The meteorological agencies and broadcast media may be viewed as unreliable or ineffective.

Table 3. Pie Chart 3: The utility level of broadcast media weather reports for environmental affability among residents of sub-Sahara states in Nigeria.

Utility	Borno	Jigawa	Kebbi	Yobe	Total	Percentage
Very High	12	11	14	-	37	6
High	34	35	-	-	69	12
Very Low	89	79	104	97	369	62
Low	34	44	34	13	125	20
Total	169	169	152	110	600	100

Source: Online Survey 2024



In Table 3 and supported pie chart 3, the utility level of weather reports was scored very low utility by 369 or 62% of persons out of 600 persons while the least score of very high utility was from 37 or 6% of persons. High recorded 69 or 12%, low 125 or 20%. The implication is that a lot of persons do not utilize or consider weather reports from the broadcast media for daily activities. With 62% of respondents perceiving weather reports as having very low utility, it suggests that most people do not find weather information helpful or applicable to their daily lives or activities. This could stem from poor timing, irrelevant content, or mismatch between what is broadcast and the actual needs of the audience. The low utility score may point to less or no connection between the weather reports and local realities. Weather reports might be lacking in clear, actionable advice. Simply stating temperature or rainfall probability without telling people what to do reduces practical usefulness.

Discussion of Findings

The pie chart marked 1 and the supporting Table 1 has four aspects of lucidity of the message om weather reports. Out of 600 respondents, 367 or 61 percent of the residents per the four states agreed that the weather reports are not very clear while very clear had 54 or 9 percent respondents. The lucidity level of weather reports by broadcasting stations generally refers to how clearly and easily the information is communicated to the audience. Several factors influence this, such as the language used, the presentation style, the use of visual aids like maps, and the complexity of meteorological terms. Weather reports are typically designed to cater to a broad audience, so most broadcasting stations aim for a high level of clarity. Broadcasters are expected to avoid technical jargon to ensure clarity. They are to use everyday language to explain weather phenomena like storms, temperature changes, and precipitation, making the information accessible to people without scientific backgrounds. But the reverse is the case in this research. There is lack of lucidity by the response of persons as this also agrees with the work of Adjin-Tettey (2013) that communication has to do with relaying information to share meaning in order to reach mutual understanding in a horizontal, two-way interaction in which parties actively participate in, and consensually determine priorities through the processes of assessing risks, exploring opportunities, and facilitating the sharing of knowledge, experiences, and perceptions. For this reason, it the work to find out whether the information conveyed by meteorologists (through the television medium, with the motive to help viewers make informed decisions) actually create a shared meaning for the end users. The findings clearly shows that the majority of respondents who are media end users do not understand the terminologies used in weather forecasts. This calls for great concern on public dependency on media and the theory of media richness. It is likely that lack of clarity can be responsible to overuse of technical terms which confuse the general public, ambiguity in long-term forecasts predicting weather for more than a few days end up in uncertainty, of probabilistic terms of “chance of rain” or “partly cloudy” to audiences. It can also be due to regional differences in multilingual or multicultural dialects or languages used in broadcasts that affect the lucidity for non-native speakers. In Table 2 and pie chart 2 , the variables of credibility are listed and out of 600 respondents 410 or 68 percent agreed that the weather reports are not very credible while those who supported the credibility were77 or 13 percent of respondents. The implication is that the people have no reliability on weather reports from the broadcast media. This confirms what Robinson (2023) says that not every weather post on social media is real, so it is important to verify the accuracy of information. People sharing images from past storms or Artificial intelligence generated images can cause confusion. To verify that an image is real and current, it is recommended to check the credibility and expert accounts for weather information. That can include government weather services, private weather companies, meteorologists, scientists, or storm chasers.
In Table 3 and supported pie chart 3, the utility level of weather reports was scored very low utility by 369 or 62% of persons out of 600 persons while the least score of very high utility was from 37 or 6% of persons. The implication is that a lot of persons do not utilize or consider weather reports from the broadcast media for daily

activities. The utility level of weather reports among individuals who listen to broadcast station presentations varies significantly based on factors such as region, access to technology, and personal reliance on weather information. In many countries, including Nigeria, the utility level can be relatively low due to several factors since in some areas, people may not trust the accuracy of weather reports, especially if they have historically been inconsistent or unreliable. Many listeners may find the information provided too general, not specific enough to their location, or not presented in a way that relates directly to their daily lives. Not everyone understands the technical language used in weather reports, which reduces the perceived utility for those without a background in interpreting such information. Some individuals, particularly in rural or less technologically connected areas, may rely more on traditional methods for weather prediction rather than broadcast reports. Nkiaka (2019) observed that low awareness, understanding, and accessibility, low relevance and users' capacity to take decision, distrust in forecasts, and institutional barriers such as fragmented institutional framework with overlapping roles are major barriers to uptake of weather and climate information in sub-Saharan Africa. This further explains that despite an increasing number of climate model simulations, there is largely poor usage of equipment to channel the information produced and disseminated. Often the messages are irrelevant and not reliable to inform decision-making at local scale, particularly for individuals and agencies. Ziervogel, Shale, & Du, (2010) show similar results of low use of weather forecast information due to delay in access to short-term decision-making forecast services and doubting its reliability. It shows that there is a big disconnection between weather information service providers and information users as one key constraint limiting the use of climate information in Africa.

Conclusion and Future Directions

Weather reporting familiarizes the public to weather-related concepts, promoting scientific literacy. The tests of weather reporting by media institutions are multi-layered, connecting technological, interpretative, communicative, and ethical issues. Overcoming these challenges requires collaboration between weather-related experts, media professionals, and policymakers to enhance the accuracy and effectiveness of weather communication. Despite the challenges, broadcast media reporting of the weather provides numerous benefits to society. Accurate and timely weather reports are crucial for public safety, economic productivity, and fostering environmental awareness.

Limitations/Future Studies

This work had limitations on only four states of Northern Nigeria. It had limitations of using only the survey method and did not establish the demographic factors of the respondents. On suggestions for further studies, this study has opened up numerous areas that future research can work on, deepen understanding and advance policy and practice in media-based environmental communication, especially in arid regions like the Sahel Sahara. Consequently, this study suggest future studies on comparative studies across regions. Future research could compare how broadcast media manage weather reports influence environmental awareness in different ecological zones of Nigeria or other West African countries, to categorize regional differences and best practices. It also suggest studies on the inclusion of digital media platforms. This is because with the growing infiltration of internet and mobile technologies, succeeding studies could survey the part of digital media as social media, weather apps, and short message service apart from traditional broadcast media in environmental and weather communication. In addition, future research could give emphasis on in-depth audience reception studies to appreciate how different demographic groups like youth, farmers, migrants, urban and. rural inhabitants construe and answer to weather-related media content. Future studies might examine the impact of government policies on environmental communication through broadcast media, and propose frameworks for integrating climate communication into national development strategies. Further, fresh studies can explore the use and potential of homegrown communication techniques of town criers, local assemblies, and folk media for weather and environmental information dissemination through broadcast media. By expanding research along these lines, academics and practitioners can build a wide-ranging context of using media to improve environmental awareness and resilience, particularly in susceptible regions like the Sahel Sahara.

Recommendations

1. Media presenters of weather reports should apply interpretative models to break complex terms for audience and listeners understanding.
2. Media anchors need friendly communication skills to maintain viewers and listeners attention.
3. Presentation of data on weather reports should be localized to interest of listeners. clearly and effectively

Declaration

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RESEARCH ARTICLE

Vitality of carbon footprints of urbanites in a low-income country: Implications for low carbon society

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Abstract
Anthropogenic activities are causing climate changes and rise in average earth surface temperature as well. Developing countries are extra affected by climate changes. Pakistan is 3rd most exposed country to climate change. The carbon footprints are causing hazardous effects and pushing agencies to find ways for its reduction. This research primary objective is the estimation of the carbon footprints of households. Multistage sampling technique was used for sample selection of the 280 households of seven major roads of Faisalabad, which covered both urban and peri-urban areas. A well-structured and pre-tested questionnaire was used to accumulate the data, inserted into web's leading carbon footprint calculator for carbon footprint estimation. Urban households produce overall 3.98 tons carbon footprints per month and peri-urban produce 3.28 tons. Transportation was the major contributor towards the CO2 emissions i.e. 82% of 3.98 metric tons and 94% of 3.28 metric tons of total carbon emissions in urban and peri-urban households. There exists a positive association between CO2 emissions and family size, house size, monthly income and electricity bills of the households of urban and peri-urban areas. It is suggested that local transportation system and awareness regarding CO2 emissions and its mitigation must be improved by effective campaigns.

Keywords: Carbon footprints; Low carbon society; Households Faisalabad

Introduction

Pakistan stands 12^{th} most exposed county to climate changes, although Pakistan's share to the global discharges of Greenhouse Gases is very less (Lenzen & Murray, 2001). Climate changes occur because of rise in sea level, average temperature and melting of glaciers. Anthropogenic activities emit greenhouse gases, mostly CO2 in the atmosphere. Major causes of GHG are forests (because of human persuaded land cover modifications causing de-forestation), power generation, transportation (produced from burning of fossil fuels), cultivation (agricultural, rice farming, livestock and burning of yield remains), manufacturing and urban activities (house, construction, transportation, waste (solid and liquefied) (Ramachandra *et al.,* 2015). Anthropological activities such as deforestation, agriculture and industrialization adds to greenhouse gases and cause climate changes (IPPC, 2007). Globally, anthropogenic activities emit approximately eight billion tons of CO2 annually (Sharaai *et al*., 2015). It's far forecasted that till the end of 21st century, in the absence of an active carbon mitigation policy, global surface temperature will rise to 2.4° to 6.4° C (IPPC, 2013). Pakistan emits 30 million metric tons of CO_2, which contributes to 0.4% of worldwide emissions, and share of carbon emission from industrialization in Pakistan is about 53% (Hanif et al. 2010; Sheikh, 2008). Industrialization, urbanization and growing vehicles are boosters of Pakistan's environmental problems (Mallick and Masood, 2011).

Rapid surge in the residents of metropolitan cities is a reason of increased energy demand which results in increased greenhouse gases (Ali and Nitivattananon, 2012). According to Environmental Protection Agency (EPA) and Japan International Corporation Agency (JICA) in Lahore, Faisalabad, Rawalpindi, Gujranwala and Islamabad acceptable particulate matter was six to seven times more than the standards of the World Health Organization (WHO) (Aziz, 2006). Carbon footprint is recently introduced phenomena, and its systems and tools are exact proven to analyze many kinds of environmental problems (Wiedmann, 2009). Carbon footprint is broadly used term for accountability and reduction of the threats of climate changes. There arises a question what correctly a carbon footprint is? Carbon footprint is many times confused with ecological footprints. Ecological footprints can be referred to a piece of productive land and sea zone that provide sustainable anthropological population (Wackernagle and Rees, 1996). On the other hand, carbon footprint states a piece of land which integrates all the CO_2 produced by humans.

Theoretically, it comprises of all the anthropogenic activities and all related sources of emission, sinks and storage of production and consumption in order to examine the effect of different conditions on climate. Carbon footprints are overall carbon emissions produced from direct and indirect sources from a product's lifecycle or emissions that are measured in units such as kilograms and tons (Sprangers, 2011). Formerly, many researchers worked on carbon footprints, but they failed to describe the relationship of carbon footprints with socio-economic features. Carbon footprints and ecological footprints provide a better scenario of demographic characteristics of households and their impact on the surroundings (York *et al*., 2003). Direct carbon footprints of households can be well-defined as the carbon emissions produced by direct use of energy such as coal, gas, oil, electricity and heating for the purpose of lighting, cooling, cooking, and transportation (Dong and Geng, 2012). While indirect carbon footprints of households is defined as carbon emissions related to the manufacturing of all other product used up by households, i.e. emissions produced from the manufacturing of furniture, food, garments and facilities (Wier *et al*., 2001).

Complete information on household characteristics such as income and consumption is needed for a proper understanding of CO_2 emissions. When income rises, emissions also go up (Baiocchi *et al*., 2010). Developed countries such as Canada, Singapore and United Kingdom are very advanced in the calculation of consumption based emissions (Barret *et al.*, 2013). The benchmarks used to compare the emissions of cities are housing facilities, transportation and lifestyle. Now, national and international agencies are very much concerned to understand the effects of GHG and CO_2 emissions to achieve sustainable development (Nakata *et al*., 2011).

Advanced and emerging countries are trying to attain such a level of sustainable development which does not depend much on carbon producing activities. This is a base for low carbon society (LCS). Abundance of families, water scarceness, destruction of land and increase in sea level stand for the causes of environmental changes in the United Kingdom. IPPC revealed courage to overcome such effects by bringing changes in prompt change and moving toward a low carbon economy (Pyrce, 2014). Low Carbon Society targets to bring down the effect of coal on the environment and achieves a sophisticated efficiency.

Income level and education quality play a prominent part in carbon dioxide emissions, when income rises the standard of living of people will go up (Mieche *et al*., 2015). Individuals would like to have their personal cars and versatility in eating habits. This study is designed to present the notion of carbon footprints of households and estimation of carbon footprints. Assessment of household's carbon footprint is freshly acknowledged, vastly advantageous since it gives standard information (Bendewald & Zhai, 2013) and shows an important role in recognizing key promoters of carbon dioxide secretions in urban zones (Gardezi et al., 2016). Diverse work have been done to examine domestic and manufacturing level carbon footprints worldwide (Shirley, Jones, & Kammen, 2012). United States Virgin Island (USVI) measured carbon footprints at domestic level, and energy was found to be the dangerous economic driver for fiscal improvement and social development. In Canada 44% of total country's greenhouse gases are produced at the domestic level (Statistics Canada, 2011). Unbelievable association exists between domestic CO2 secretions and the endowment of some practical necessities for specimen, housing and food stuff (Druckman & Jackson, 2008)(see Table 1).

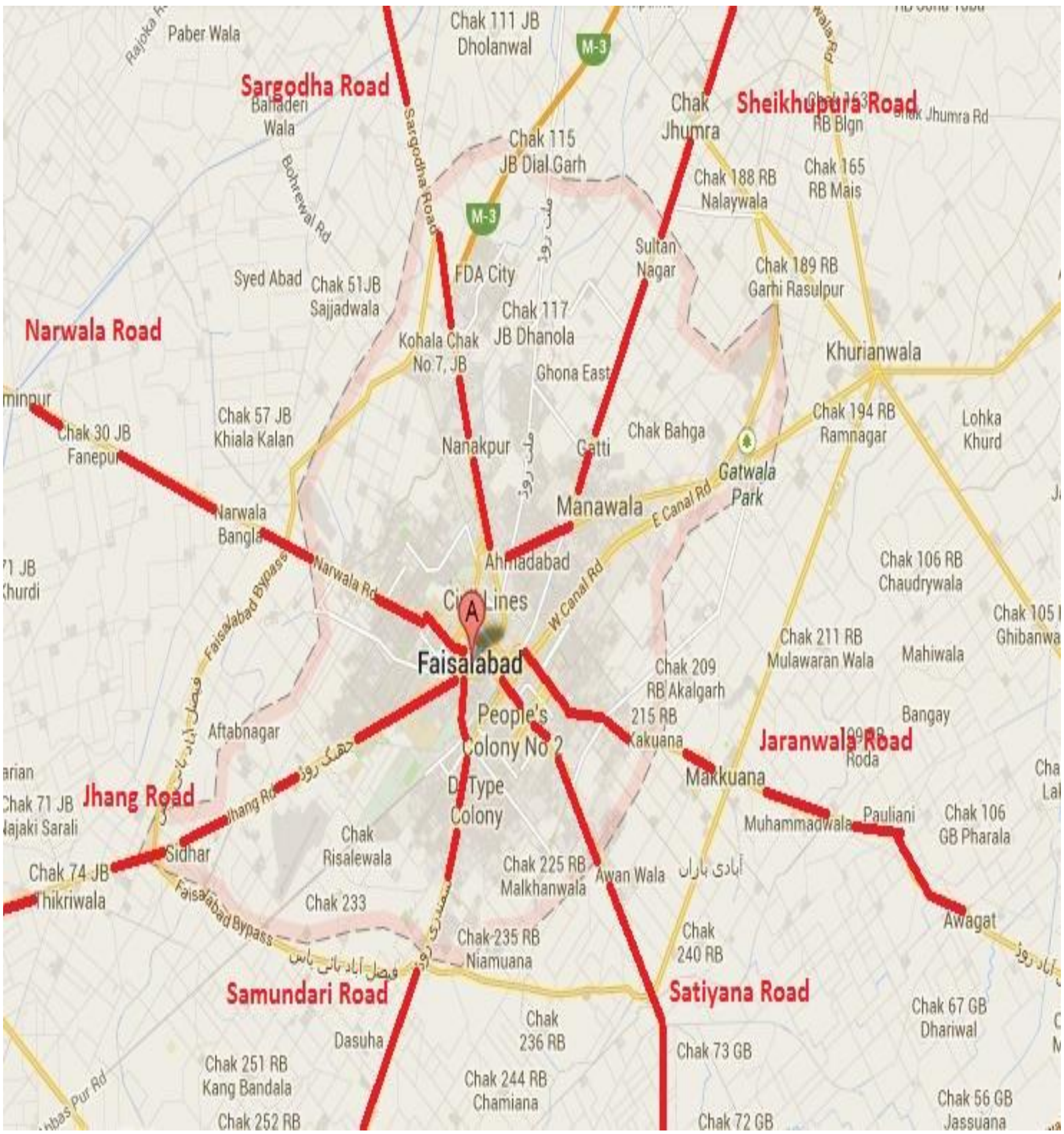

Figure 1. Map of Faisalabad displaying research area

Unfortunately constrained information about carbon footprints in Pakistan has headed to various reservations to pass on employable atmosphere rectification strategies. Faisalabad is the third biggest city of Pakistan, after Karachi and Lahore, so it is assigned as the circumstantial analysis region Figure 1. Household carbon footprints were assessed by case study technique. We intended to make a comparison of carbon emissions of urban as well as peri-urban zones of Faisalabad city and to detect factor(s) that augment carbon footprints.

Theoretical background

Origin of Carbon Footprint

"The origin of carbon footprint can be well-defined as a subgroup of "ecological footprints" (Wackernagel and Rees, 1996). "Ecological footprint denotes to biologically useful prerequisites for land and oceanic zone to support many residents as worldwide housing." Conferring to this concept, carbon footprint refers to the basic surface of human CO2 emissions period" (Pandey et al., 2011). "The carbon footprint is a quantity of the high-class total amount of CO2 emissions that is directly and indirectly originated by an action or is gathered from the life phases of a product." (Wiedmann and Minx, 2008).

Figure 2. Factors responsible for carbon footprints

Classification of Carbon footprints

Direct carbon footprints

Direct carbon footprints of households can be well-defined as the carbon secretions produced by direct use of energy such as firewood, gas, oil, electricity and heating for the purpose of illumination, cooking, refrigerating and transportation (Dong and Geng, 2012).

Indirect carbon footprints

While indirect carbon footprint of households can be well-defined as carbon secretions created from manufacturing of furniture, garments food and services (Wier *et al.,* 2001).

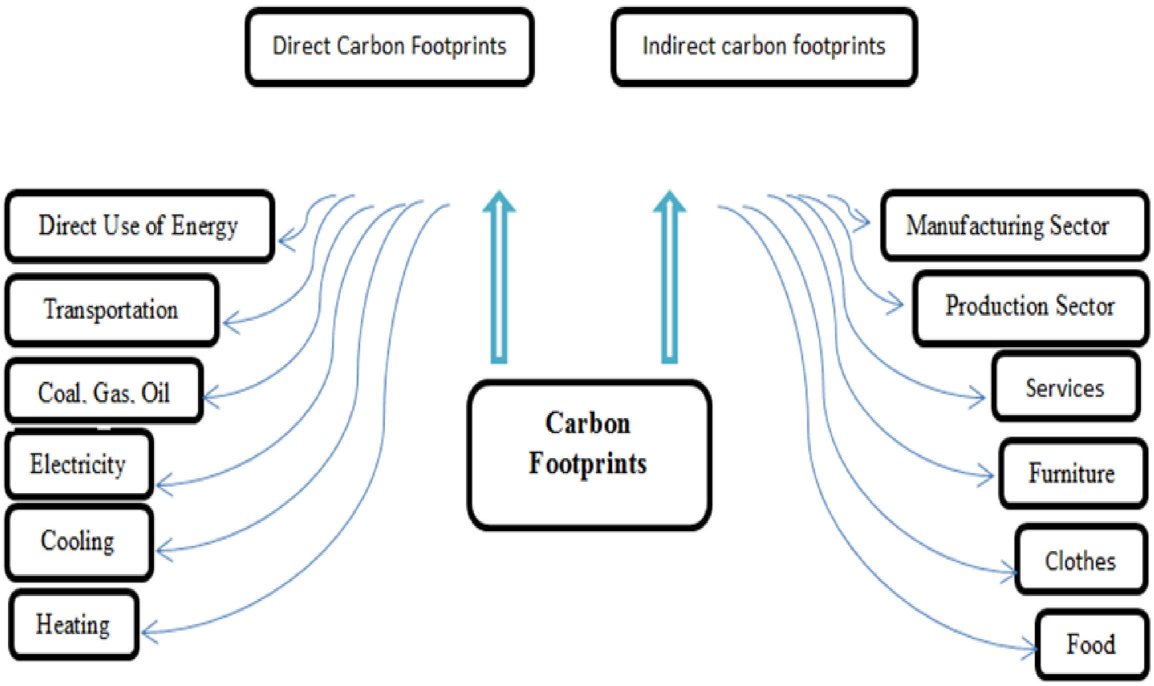

Figure 3. Classification of factors of direct and indirect carbon footprints

Measurement of Direct and Indirect Carbon footprint

Direct carbon footprint of households

The equation given below can be used to calculate direct household carbon footprints (Change, 2006).

$$\text{CFd} \sum_{i=0}^{n} Mi \times \text{EFi}$$

CFd denotes direct household carbon footprint,
i denotes the kind of energy used, like coal, liquid petroleum gas (LPG), heat and current,
Mi denotes the quantity of usageof energy type I,
EFi states carbon secretion element of energy used for energy type i.

Indirect household carbon footprint

There are two leading approaches for computing indirect carbon footprints of households.

1- Input output analysis (Cohen et al., 2005)
2- Questionnaire analysis (Pachauri, 2004)

The equation below shows how to compute indirect domestic carbon footprints.
$CF^e = F \times E = F \times D\ (I - A) - 1$
Where CFe denotes the total secondary household carbon footprint,
E is trajectories of indirect discharges strength and D symbolize the direct emission strength of manufacturing sectors,
F represents the matrix of domestic final consumption,
I denote a characteristic matrix, A represents direct intermediary input quantity matrix.
The calculators of carbon footprint accessible available have presented promising calculations worldwide. Numerous studies have repetitively proven that input statistics either in apparent to in depth form can be examined by means of online calculators to represent anthropological influence on the environment (Pandey, Agrawal, & Pandey, 2011).

Statistical Analysis

Information was analyzed for mean, frequencies, standard deviation, and correlation to find the relationship between household factors and carbon secretions.

Materials and Methods

Data

This case study was conducted in urban and peri-urban zones of Faisalabad City. These localities were selected from seven major roads of Faisalabad city. These roads include Jhang road, Jaranwala road, Sheikhupura road, Satyana road, Sargodah road, Samundri road and Narwala road. From each road four areas were selected using multistage sampling technique. Multistage sampling is extended form of cluster sampling, which is demonstrated as If the whole area of concern occurs to be a big one an appropriate manner in which a sample can be studied is to split the area into a numeral of smaller non overlying areas, and then to randomly choose a numeral of these smaller areas generally called clusters **(**Kothari, C. R. 2004**).** Multistage sampling is an additional expansion of the standard of cluster sampling. (1) It can be easily administered than many single stage designs (2) An enormous number of components can be sampled for a given cost under multistage sampling because of chronological clustering where this is not conceivable in most of the simple designs. (Kothari, C. R. 2004). These four areas from each road were further equally divided into two urban and two peri-urban areas. A basic criterion for the selection of urban and peri-urban areas was to make an interesting comparison of these areas to access their carbon footprints.
A self-designed questionnaire was used to collect primary data concerning socio-economic variables from each zone randomly. Sample of 280 households were filled by the households of selected areas. Those 280 questionnaires were filled on the basis of home consumption of electricity, gas and petrol/CNG. Data of electricity (kWh) and gas (hm3) were collected by observing household monthly bills. The data on transportation, distance journeyed in (Km) of all household members from their home to places of work and burning of petrol (L) and CNG (Kg) were also inquired in the questionnaire. While the expenditure on food, clothing, education, and some other subordinate factors were also collected according to the necessity of study. Data were gathered from urban and peri-urban households situated in different areas of Faisalabad city and the questionnaire consist of parameters given in Table 2.

The sample is considered representative of the broader Faisalabad region due to the inclusion of seven major roads covering diverse geographic and socioeconomic areas of the city. By applying a multistage sampling technique and randomly selecting households within both urban and peri-urban settings, the study captured a wide range of income groups, household sizes, education levels, and lifestyle practices. This comprehensive coverage enhances the generalizability of the findings to the broader population of Faisalabad.

Carbon footprint calculations

The collected information was putted into the online calculator to calculate the carbon footprints available at (http://www.carbonfootprint.com/calculator.aspx). The total amount of household carbon footprints can be measured as the product of domestic consumption. The household carbon footprints (HCF) are usually measured by employing the equation given (Shirley et al., 2012).

HCF (tCO_2e) = Average Annual Expenses × Emissions Factor

An emission factor can be defined as an expected value of every factor. An emission element of carbon footprints is the average quantity of carbon dioxide produced for each unit of consumption.

Table 1: Variables used in Study

Household energy usage	Socio-economic variables	Tributary factors
Electrical energy (kWh per month)	House Size (Marlas)	Fashion consciousness
Natural gas (HM3 per month)	Total family Members	Recycling
Transportation (km per month)	Income (in Rs.) per month	Furniture and electrical equipment
Food (liking type of food)	Number of earners	Recreation routine
Fuel (For home heating)	House location	Finance

Household variables used in survey for data gathering

Results and discussion

Faisalabad stands amongst the most residential urban groups of Pakistan, with a population of 2,506,595. Domestic features considered in the study of household secretions and information collected from carefully chosen residents are offered in Table 3 and 4. Figures about house size, family size, monthly domestic income, number of automobiles retained and other variables, containing food, petrol, transportation, are offered here. Emission source wise distribution of carbon footprints clearly shows that urban households are having higher carbon footprints than that of peri-urban households and urban households produce 3.98 tons carbon footprints per month and peri-urban produce 3.8 tons which considerably less Table 5. Four classifications of monthly metric ton carbon footprints of urban and peri-urban areas are presented in Figure 3 which demonstrate that 20 out of 140 urban households are producing up to 4 metric ton of monthly carbon footprints and in peri-urban areas only 3 out of 140 households are held in this ratio. The leading reason for higher carbon footprints in urban areas is their luxurious standard of living and high usage of energy. As income rises, household's members lean towards achieving higher carbon sets, which they consider costly formerly (Weber & Matthews, 2008). Higher transportation and electricity increase carbon emissions directly, and other elements like, reutilizing, refreshment, food, mode lifestyle and clothing increase indirectly (Tukker & Jansen, 2006). These results can be related with the work of Druckman and Jackson (2008), showing that in United Kingdom high quantity of household CO2 secretions is because of nonstop energy consumption.

Table 2: Statistical description of urban and peri-urban areas of Faisalabad city

Variables	Urban (n=140)	Peri-urban (n=140)
Income of households		
Up to 50000	68	111
Up to 100000	50	27
Up to 150000	8	2
Up to 200000	14	0
House Status		
Own	119	127
Rented	21	13
House Size (Marla's)		
Up to 3	59	104
Up to 6	70	35
Up to 10	11	1
Transport mostly used to go out		
Walk	23	71
Bike	95	51
Car	12	9
Bus	10	9
Flying routine		
Monthly	5	0
Biannually	4	2
Annually	33	15
Rarely	98	123
Newspaper purchasing behavior		
Daily	18	4
Weekly	19	8
Monthly	15	6
Never	88	122
Laundry routine		
Weekly	70	80
Twice in a week	9	3
Monthly	45	45
Twice in a month	16	12
Fuel used for cooking		

Natural Gas	139	103
Wood	1	10
Oil	0	21
Bio Gas	0	32
Dunk Cake	0	20
Coal	0	21
Fuel used for home heating		
Natural Gas	128	1
Wood	2	6
Paraffin Oil	6	1
Dunk Cake	1	24
Coal	3	9
Shopping routine		
Weekly	19	2
Twice in a week	5	2
Monthly	54	25
Not specific	62	111
Recreation routine		
Weekly	15	1
Twice in a week	7	0
Monthly	32	5
Annually	22	27
Not specific	64	107
Do the family is brand/fashion conscious?		
Yes	101	38
No	27	69
Sometimes	22	33
Do you turn off lights when you leave room?		
Yes	116	115
No	6	12
Sometimes	18	13
Do you close windows when heater/AC is on?		
Yes	119	118
No	11	9
Sometimes	10	13
Do you cover cooker/Pan while cooking food?		
Yes	94	120
No	15	9
Sometimes	31	11
Do you unplug appliances/chargers when not in use?		
Yes	84	93
No	22	21

Sometimes	34	26
Do you turn off the water while brushing your teeth?		
Yes	79	88
No	35	32
Sometimes	26	20
Does your family recycle products e.g. plastic, aluminum?		
Yes		
No	35	53
Sometimes	92	72
	13	15
Do you leave your PC or TV on standby for long time?		
Yes		
No	53	63
Sometimes	72	66
	15	11
Do you turn off your computer/electronics when not using?		
Yes		
No	101	114
Sometimes	19	21
	20	5
Do you leave mobile charger on in the plug when not using?		
Yes		
No	41	42
Sometimes	76	70
	23	28

Statistical description of urban and peri-urban areas of Faisalabad city w.r.t. frequency

Table 3: Statistical description of urban and peri-urban areas of Faisalabad city

Variables	Urban			Peri-urban		
	Min	Mean (SD)	Max	Min	Mean (SD)	Max
Respondent Age (Years)	16	34.6 (12.5)	72	15	39.2 (14.2)	76
Responsive Education (Years)	0	10.59 (5.8)	21	0	7.30 (5.3)	18
Total Family Members	2	6.7 (2.81)	21	2	7 (3.5)	24
Electricity bill (Summer)	900	11029.47 (10928.52)	50000	448	3686.25 (2716.54)	14414
Electricity bill (Winter)	132	3939. 45 (4021.62)	20000	123	1349.75 (914.71)	4500

Gas bill (Summer)	170	546.54 (719.04)	5000	0	1235.16 (1196.24)	2200
Gas bill (Winter)	180	270.38 (336.51)	7000	0	503.74 (527.67)	4070
Cooking Oil (Liters)	4	5.91 (1.90)	15	5	6.87 (2.03)	15
Dressing (Rupees per month)	1000	8023 (6800)	40000	500	4300 (3691)	25000
Food (Rupees per month)	1500	1941 (1275)	51000	1000	1356 (7274)	40000
Grooming, Medicine (Rupees per month)	500	3561 (2475)	10000	500	2589 (2947)	20000
Education (Rupees per month)	0	6934 (6484)	25000	0	5087 (6327)	30000
Phone, Internet (Rupees per month)	100	1999 (1405)	8000	200	1367 (1173)	500
No. of Smokers (per family)	0	0.54 (0.86)	6	0	0.55 (0.70)	4
Cigarettes burned (per day)	0	2.7 (4.7)	16	0	5.2 (7.7)	33

Statistical description of urban and peri-urban areas of Faisalabad city w.r.t. minimum and maximum

Table 4: Distribution of carbon footprints in urban and peri-urban areas

	Urban			Peri-Urban		
	Emissions in metric ton (Per Month)					
Source	Min	Mean (SD)	Max	Min	Mean (SD)	Max
From House (Electricity, Gas, Cooking oil)	0.03	0.1296 (0.17)	0.99	0.02	0.0782 (0.06)	0.23
From Transport (Plane, bike, Car, Bus)	0.02	0.8354 (1.1)	3.29	0.02	0.3769 (0.58)	3.10

From Secondary Sources	0.016	0.8251 (0.83)	2.520	0.09	0.9805 (0.57)	2.02
Total	0.26	1.7864 (1.1)	3.98	0.17	1.4232 (0.74)	3.28

Emission source wise distribution of carbon footprints in urban and peri-urban areas

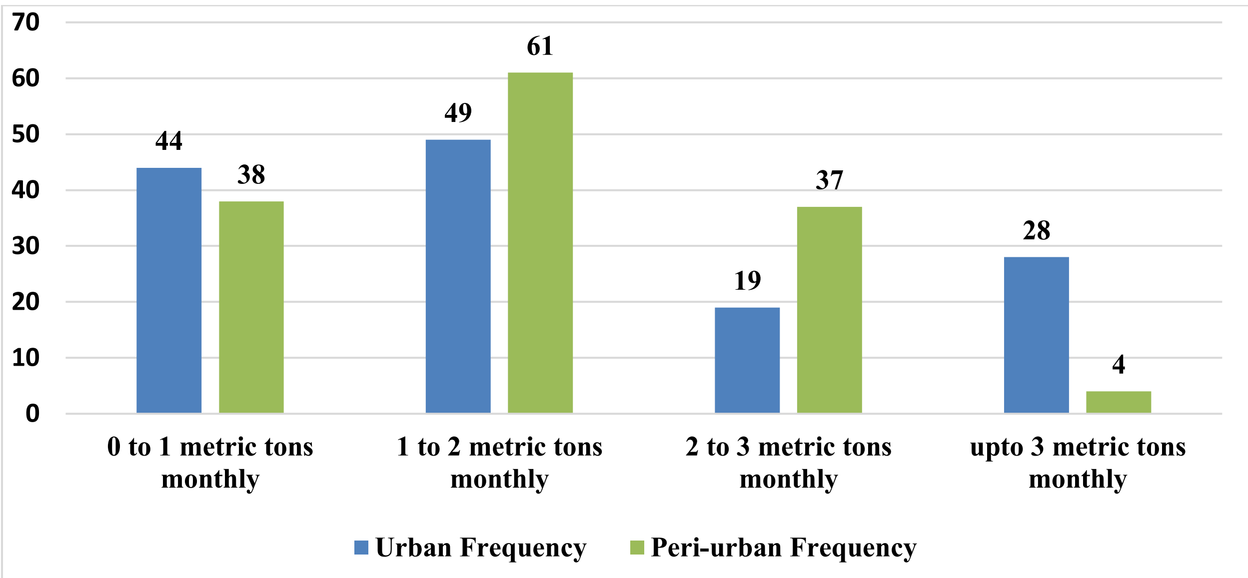

Figure 4. Categorical distribution of carbon footprints in selected areas

Table 5: Correlation matrix and results

	1 Carbon footprints	2 Family Size	3 House Size	4 Income	5 Electricity bill
	URBAN CORRELATION				
Carbon footprints	1				
Family size	7.62 (r=0.1299) (p=.1261)	1			
House size	5.69 (r=0.2898) (p=.005)	(r=0.059) (p=.486)	1		
Income	83264.29 (r= 0.318) (p=.001)	(r=0.335) (p=.695)	(r=0.365) (p=0.00)	1	
Electricity bill	3686.5 (r=0.380) (p=.000)	(r=0.335) (p=.019)	(r=0.443) (p=.000)	(r=0.362) (p=.000)	1
	PERI_URBAN CORRELATION				
Carbon footprints	1				
Family size	7.89 (r=0.335) (p=0.000)	1			
House size	4.96 (r=0.378) (p=.000)	(r=0.354) (p=.000)	1		
Income	41864.89 (r=0.346) (p=.000)	(r=0.389) (p=.000)	(r=0.303) (p=.003)	1	

Electricity bill	3686.5 (r=0.112) (p=.187)	(r=0.206) (p=.014)	(r=0.049) (p=.557)	(r=0.257) (p=.021)	1

Correlation matrix of home size, family size, monthly earnings, electricity bill of summer and carbon footprint per household of urban and peri-urban areas of Faisalabad are denoted via their mean value and correlation values, and their level of significance as well Table 5. Urban areas and peri-urban displays highly noteworthy addition in per family carbon footprint when their family size increases (r=0.1299 p=.1261) and (r=0.335 p=.000) respectively. When family size increases, the consumption also increases, which results in higher carbon footprints. Family sizes in urban areas are smaller than that of peri-urban because they are educated and well aware of the benefits of smaller families. The correlation between house size (Marla's) and carbon footprints is also greatly significant, mutually in urban and peri-urban areas. Urban areas show extremely significant rise for each family's carbon footprint when their monthly income increase (r=0.318 p=.001). Even though in urban areas the members of the family are more limited than peri-urban areas, however, they all have higher contribution in income which fallouts in greater carbon footprint.

Conclusions

This century is an age of up-to-date technology, and, people are using these technologies for their comfortable and making their lives better. The carbon emissions produced from anthropogenic activities and changing climate are placing an abundant stress on the operative use of such tools and the encroachment of defensible development. This issue gives rise to the notion of the Low carbon Society to attain sustainable development. There is a serious need of attention in Pakistan to convert speedily mounting urbanized areas into a lesser carbon society. At this time, more than 30 metric tons of yearly carbon emission is documented, which in universal emission interpretations only 0.4%. Although that one share is small globally, the nationwide values settled nearly four times from the time 1980,when it was merely 9 million metric tons. This study clearly indicates that housing and way of life in urban areas are extravagant with higher carbon footprints. It is suggested that improvement of green transport, less fuel usage, building engineering and urban scheme will ultimately develop effectiveness in an energy presentation that would lead to build low carbon urbanized areas. Some proposed suggestions which were given by respondents are presented in Figure 4, which can be followed by household to achieve a low carbon society. While the findings suggest actionable strategies for reducing household carbon footprints such as promoting green transport, efficient energy use, and awareness campaigns several challenges could hinder implementation. Economic constraints in peri-urban households limit access to sustainable technologies. Infrastructure deficiencies, including unreliable or absent public transportation, further restrict options. Moreover, public understanding of carbon emissions and their consequences is generally low, and cultural preferences often favor conventional practices over sustainable alternatives. Finally, policy limitations, such as inadequate regulatory enforcement and lack of targeted incentives, may delay the transition to low-carbon behaviors. A multi-pronged strategy involving government support, local planning, and community-based education is essential to overcome these barriers.

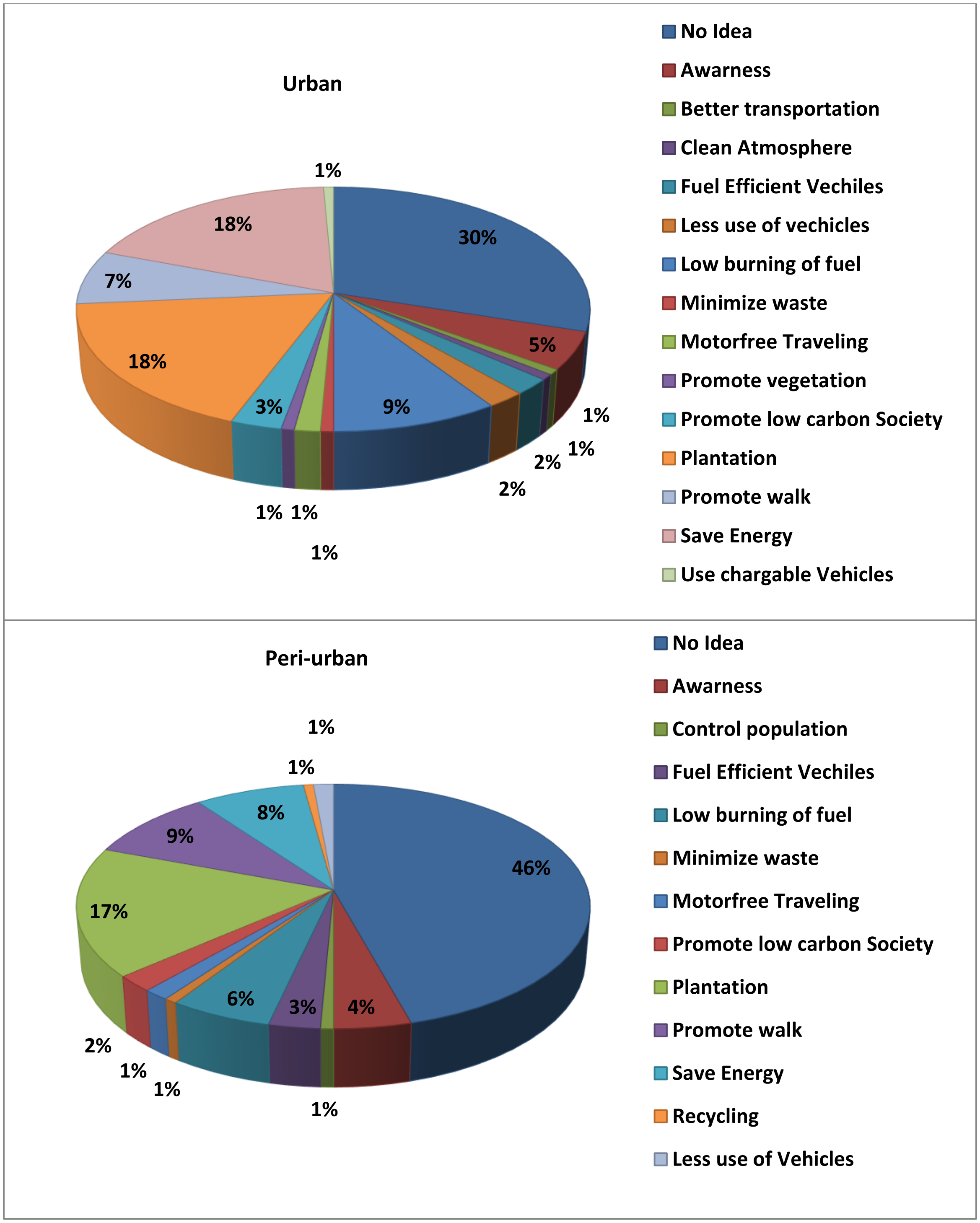

Figure 5. Suggestion given by respondents to reduce carbon emissions

Table 5: CO_2 emission estimates using several household factors

Country (Year)	Reference	Carbon Tracking Method	Parameters (Estimates)
China 2017	Yang & Liu 2017	Based on IPCC CO_2 Emissions (fuel usage × [fuel carbon content * fuel calorific value * fuel oxidation rate] × emission factor	Cooking & Heating (43%) Transportation (30%) Space Heating (27%)
UK 2016	Allinson et al., 2016	CO_2 Emission = Consumption × Emission Factor	Gas (46%) Electricity (32%) Personal Transport (22%)
USA 2008	Weber & Matthews, 2008	CO_2 Emission = Consumption × Emission Factor	Education (2.5%) Health (7.5%) Dressing (3.3%) Others (10%) Utilities (25.8%) Furnishing (3.3%) Communication (1.6%) Housing (4.1 %) Tobacco (1.6%) Hotels & restaurants (4.1%) Food & Drinks at Home(6.6%) Personal Transportation (26.6%) Refreshment / Culture (2.5%)
US 2012	Shirley et al, 2012	Cool Climate Network (Online Carbon Calculator) CO_2 Emission = Consumption × Emission Factor	Transportation (24%) Home-based Energy (31%) Services (8%) Food (18%) Waste & Water (9%)
US 2008	Padgett et al., 2008	Online carbon Calculator	Electricity (26%) Gas (17.3%) Fuel Oil (22.5%) Air Travel (0.8%) Propane (16.6%) Personal Vehicle usage (16.5%)
US 2009	Kim & Neff, 2009	Online Carbon Calculator	Transport (94%) Energy Usage (84%) Recycling (35%) Food (25%) Water (18%)

			Others Purchasing (14%)
China 2007	Tian Geng, Dong et al., 2016; Tian, Geng Dai et al., 2016	CF= ΣM × EF	Raw Coal Burning (4.61%) Other Washed Coal (1.2%) Gas (1.09%) LPG (0.09%) Heating (15.6%) Electricity (10.5%) Food (17.1%) Clothing (9.9%) Facilities (4.4%) Health (7.7%) Transport (1.3%) Education (16.4%) Housing (4.4%) Others (7.4%)
Estonia 2011	Brizga, Feng, & Hubacek, 2017	Input Output Model	Food & Drinks (17.1%) Clothing & Footwear (1.81%) Housing, Electricity, Gas, fuel, water (41.8%) Furnishing, maintenance of house (7.2%) Health (1.81%) Transport (18.1%) Communication (0.9%) Hotel & Restaurants (3.6%) Other goods & Services (1.8%)
Latavia 2011	Brigza et al., 2017	Input Output Model	Food & Drinks (29.8%) Clothing & Footwear (1.49%) Gas, fuel, water & Electricty (26.8%) Furnishing, maintenance of house (7.4%) Health (7.4%) Transportation (20.8%) Communication (0%) Refreshment & Culture (5.97%) Education (0%) Hotels & Restaurants (2.9%) Others (2.9%)
Lithuania 2017	Brizga et al., 2017		Food & Drinks (30.8%) Clothing & Footwear (2.46%) Housing, Gas, fuel, water & Electricty (16%) Furnishing, maintenance of house

			(13.5%) Health (1.2%) Transportation (30.8%) Communication (0%) Refreshment & Culture (2.46%) Education (0%) Hotels & Restaurants (1.23%) Others (1.23%)
Korea 2013	Kim & Kim, 2013	Carbon Intensities (tCO_2) = Consumption × Emission Factor	Electricity Summer (79%) Electricity Winter (59%) LPG Summer (34%) LPG Winter (15%)

Literature review relating to CO_2 emission estimates using several household factors

Declaration

we, hereby declare that this research is the result of our independent work, and all sources used have been appropriately cited and take full responsibility for the integrity and originality of the contents presented herein.

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Ethics approval/declaration: This study will comply with all ethical standards for research involving human participants. Participants will be informed about the purpose, procedures, and voluntary nature of the research, and all information will be handled with strict confidentiality.

Consent to participate: Informed consent will be obtained from all participants prior to their involvement in the study. Participants will be assured of their right to withdraw at any point without any consequences, and their data will only be used for academic purposes as outlined in the consent form.

Consent for publication: Consent for publication will be obtained from participants where applicable, especially if any identifiable information, quotes, or case details are used. All data will be anonymized to ensure participants' privacy and rights.

Data availability: The datasets generated or analyzed during the current study will be available from the corresponding author upon reasonable request. In compliance with data protection regulations, personal and sensitive data will be stored securely and will not be shared publicly.

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Drafting orgional writing and Assistance with referencing, proofreading, and formatting according to journal standards.

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RESEARCH ARTICLE

Assessing the Impact of Economic Growth, Energy Consumption, and Trade Openness on Carbon Emissions in Nigeria

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Abstract
Despite global efforts to address climate change, many developing economies face the challenge of balancing economic growth with rising carbon emissions. This study investigates this critical issue in Nigeria by examining the impact of economic growth, energy consumption, and trade openness on carbon emissions. Utilizing a robust econometric approach with time-series data, the research employs advanced modeling techniques to capture both short-run dynamics and long-run relationships, while also accounting for structural complexities and potential feedback loops. The findings indicate that economic expansion remains significantly linked to increased emissions, and energy use emerges as a dominant factor driving environmental degradation. Contrary to some hypotheses, trade openness appears to offer a potential pathway for emissions reduction. These results underscore the urgent need for context-specific strategies in Nigeria that prioritize decoupling growth from emissions, accelerating the transition to cleaner energy sources, and strategically leveraging trade to promote sustainable development. The study provides evidence-based information to guide policymakers in managing the nation's climate challenges and pursuing a sustainable future.

Keywords: Economic growth; Energy consumption; Trade openness; Carbon emissions; Nigeria.

Introduction

The global discourse on environmental sustainability increasingly underscores the pivotal role of carbon dioxide (CO_2) emissions in driving climate change. As a primary greenhouse gas, CO_2 is strongly associated with rising global temperatures, erratic weather patterns, and widespread ecological disturbances (IPCC, 2023). Despite these challenges, global progress has been made through renewable energy advancements, carbon sequestration technologies, and multilateral agreements such as the Paris Accord, demonstrating that emission reduction and economic growth are not mutually exclusive (IEA, 2022). Developed countries have achieved significant decoupling of growth from emissions via policy innovations and green technologies (OECD, 2021). Conversely, many developing economies continue to grapple with the emissions-growth trade-off, where industrial expansion and trade liberalization contribute to rising carbon footprints (World Bank, 2023). Nigeria stands as a compelling case in this regard. Although the country contributes less than 1% to global CO_2 emissions, its carbon output has grown at an annual rate of 5.2%, primarily due to urbanization, reliance on fossil fuels, and deforestation (Global Carbon Atlas, 2023). The economy's dependence on crude oil and gas, responsible for over 70% of state revenue and 90% of exports—has entrenched carbon-intensive growth models (NNPC, 2022). While GDP growth has averaged 2.5% in the last decade, energy consumption has increased by 4.8% annually, reflecting patterns predicted by the environmental Kuznets curve (EKC) hypothesis, which posits that emissions rise in early industrialization stages before declining with economic maturity (Dada & Akinbode, 2021). Nigeria's alignment with this trajectory remains ambiguous, warranting empirical evaluation. Economic growth in Nigeria, while integral to development, has exacerbated environmental degradation. Though growth fosters infrastructure, employment, and poverty alleviation, its carbon intensity remains high. Adeniyi, Adewuyi, and Ogunbiyi (2021) affirm a positive correlation between GDP and emissions in Nigeria, challenging the EKC's inverted-U relationship. Ozturk and Acaravci (2020) further support this anomaly, linking the emissions increase to weak policy incentives for green technologies. Sectors such as manufacturing and transport, contributing roughly 25% of national emissions, continue to rely on diesel and petrol (NBS, 2023). Without renewable energy integration, Nigeria's growth is likely to remain unsustainable (Ike, Olurinola, & Adediran, 2021).

Energy consumption is another key factor driving emissions. Nigeria's energy mix—dominated by gas (48%), oil (38%), and biomass (12%)—shows limited adoption of clean energy sources (IEA, 2023). Despite low per capita electricity consumption (144 kWh), most power generation is gas-based, emitting 0.4 metric tons of CO_2 per MWh (United Nations Development Programme [UNDP], 2022). In rural areas, 55% of the population depends on firewood and kerosene, contributing to deforestation and indoor air pollution (Emodi, Emodi, & Murthy, 2021). Although transitioning to renewables could cut emissions by 30% by 2030, policy inertia and inadequate financing stall progress (Bala, Kuku, & Okafor, 2023). The 2022 Energy Transition Plan targets net-zero by 2060, but inconsistent regulation and fuel subsidies undermine implementation (PwC, 2023). Trade openness further complicates Nigeria's emissions outlook. While trade expansion has boosted GDP and foreign direct investment (FDI), it has also intensified the carbon content of imports and exports (Okonkwo, Ekesiobi, & Asongu, 2021). With a trade-to-GDP ratio averaging 25%, the country increasingly imports carbon-intensive goods like vehicles and machinery, while exporting hydrocarbons (WTO, 2023). The pollution haven hypothesis (PHH) suggests that lax environmental regulations attract polluting industries—a pattern visible in Nigeria's free trade zones (Adebola, Olaniyi, & Adediran, 2022). On the flip side, trade could facilitate technology transfer, but weak intellectual property laws hinder this (UNCTAD, 2023).

Despite ratifying the Paris Agreement and launching the National Climate Change Policy (NCCP), Nigeria's regulatory enforcement is weak. Gas flaring remains prevalent, emitting 15 million tons of CO_2 annually (NEITI, 2022). Regulatory inefficiencies (Alola & Adebayo, 2023) and funding shortfalls (Ogundipe, Ogunniyi, & Olagunju, 2021) compound the problem. Prior studies often rely on outdated data or examine isolated variables, limiting policy relevance (Adedoyin, Bekun, & Alola, 2020). This study addresses these gaps using autoregressive distributed lag (ARDL) models and the STIRPAT framework to assess how GDP growth, energy use, and trade openness influence Nigeria's CO_2 emissions from 1990 to 2022 (York, Rosa, & Dietz, 2021; Sarkodie & Strezov, 2023; Khan, Hou, & Le, 2022). The findings aim to support evidence-based policy for a just and sustainable energy transition. Building on this foundation, the study tests the following null hypotheses:

H_{01}: Economic growth has no statistically significant effect on carbon emissions in Nigeria.

H_{02}: Energy consumption does not exhibit a significant relationship with CO_2 emissions in Nigeria.

H_{03}: Trade openness has no meaningful impact on Nigeria's carbon emission levels.

Literature Review

Carbon emissions, primarily measured in CO_2 equivalents, serve as a critical environmental indicator with diverse interpretations. Ecologically, they represent human-induced disruptions to the carbon cycle, contributing to climate change via the greenhouse effect (IPCC, 2023). Economists interpret them as negative externalities requiring policy intervention to correct market failures (Stern, 2020). The energy sector sees emissions as byproducts of fuel combustion, while sustainable development views them as constraints to be decoupled from growth (World Bank, 2022). In developing nations, emissions are framed as necessary trade-offs for industrialization, contrasting with global climate justice narratives that emphasize historical responsibilities (Roberts & Parks, 2021). This complexity underscores the challenges of emission governance across contexts. This study adopts Adebayo's (2022) definition: "the measurable release of CO_2 from fossil fuel combustion and industrial processes within a specified geographical-temporal boundary." This definition aligns with Nigeria's emissions inventory and supports sector-specific, policy-relevant analysis grounded in national reporting standards. Economic growth, measured through GDP growth rate, represents the expansion of a nation's productive capacity and income levels over time. Mainstream economics views GDP growth as the primary indicator of development and improved living standards (Kuznets, 2021). However, ecological economists argue this metric fails to account for environmental degradation costs (Daly, 2020). In Nigeria, GDP growth remains heavily tied to oil revenues, creating a resource-dependent economic structure (CBN, 2023). The environmental Kuznets curve hypothesis suggests an inverted U-relationship between growth and emissions, though empirical evidence in developing nations remains mixed (Sarkodie, 2022). The study operationalizes economic growth as annual percentage changes in real GDP at constant prices, consistent with World Bank (2023) methodologies. This allows for cross-country comparability while capturing Nigeria's unique growth patterns.

Energy consumption reflects the quantity of energy resources utilized by an economy across all sectors. Fossil fuel-dominated systems typically show strong positive correlations between energy use and emissions (IEA, 2023). Nigeria's energy mix presents a paradox - high oil/gas production coexists with energy poverty and widespread generator use (NBS, 2023). The energy ladder hypothesis suggests developing nations transition from biomass to cleaner fuels, but Nigeria's progress remains slow (Oyedepo, 2021). We measure total energy consumption in million tonnes of oil equivalent (MTOE), incorporating both commercial and traditional energy sources (BP, 2023). This comprehensive approach captures Nigeria's dualistic energy economy where formal and informal consumption patterns coexist (Adeniran, 2022). Trade openness quantifies an economy's integration into global markets through imports and exports. The pollution haven hypothesis suggests trade liberalization may relocate dirty industries to nations with weaker regulations (Copeland & Taylor, 2020). Nigeria's trade profile shows heavy dependence on hydrocarbon exports and manufactured imports, creating complex emission linkages (WTO, 2023). Alternative perspectives highlight trade's potential for green technology transfer and efficiency gains (Frankel & Rose, 2021). The study adopts the standard trade-to-GDP ratio (sum of imports and exports divided by GDP) as the operational measure (World Bank, 2023). This captures Nigeria's trade intensity while allowing examination of both scale effects (increased economic activity) and technique effects (production method changes) on emissions (Managi, 2022).

Empirical Review

Economic Growth and Carbon Emissions

Recent studies have produced mixed findings on the growth-emissions connectivity. Shahbaz, Raghutla, Chittedi, Song, and Qin (2022) examined 72 developing countries using fully modified ordinary least squares (FMOLS), finding that the environmental Kuznets curve (EKC) hypothesis validity depended on institutional quality. Their study's limitation was the absence of country-specific diagnostic tests, particularly for residual normality, which reduces its applicability to Nigeria's context. Alola and Kirikkaleli (2021) applied wavelet analysis to BRICS nations, demonstrating growth-emissions decoupling after 2015, but failed to account for structural breaks that might affect long-run coefficient estimates. Acheampong, Dzator, and Savage (2023) employed dynamic spatial models across Africa, confirming growth's spillover emissions effects. While comprehensive, their aggregation of energy and trade effects overlooked Nigeria's unique oil-dependent economy characteristics. Pata and Caglar (2021) supported the EKC hypothesis in G7 nations using quantile regression but assumed parameter stability without conducting cumulative sum (CUSUM) tests, potentially compromising their results' reliability. Zafar, Saleem, Tiwari, and Shahbaz (2023) linked renewable energy adoption to EKC formation in OECD countries. However, their findings have limited applicability to Nigeria's fossil fuel-dominated energy grid without significant contextual adaptation. These studies collectively highlight the need for Nigeria-specific analysis incorporating proper diagnostic testing.

Energy Consumption and Carbon Emissions

The energy-emissions relationship has been extensively studied with varying conclusions. Dong, Hochman, Kong, Sun, and Wang (2022) analyzed China's coal-to-gas transition using logarithmic mean Divisia index (LMDI) decomposition but did not address potential endogeneity issues through appropriate tests. Awan, Azam, Saeed, and Wakif (2023) confirmed renewables' mitigation potential in South Asia via autoregressive distributed lag (ARDL) modeling, yet their exclusion of cross-sectional dependence tests represents a significant oversight for regional energy grid analysis. Balsalobre-Lorente, Driha, Bekun, and Adedoyin (2021) demonstrated nonlinear energy-emissions relationships in EU data but assumed homoscedasticity without conducting Breusch-Pagan tests. Koengkan, Fuinhas, and Silva (2023) connected energy poverty to emissions in Latin America, though their reliance on pre-2020 energy mix data limits contemporary relevance. Razzaq, Sharif, Ozturk, and Yang (2024) applied artificial intelligence to predict U.S. energy emissions, but their black-box models lack the transparency needed for policy formulation in Nigeria's context. These studies collectively demonstrate that while the energy-emissions relationship is well-established, many analyses neglect crucial diagnostic tests or fail to account for Nigeria's specific circumstances, particularly regarding gas flaring and widespread generator use.

Trade Openness and Carbon Emissions

Research on trade-emissions linkages presents conflicting perspectives. Hao, Chen, Zhang, and Zhang (2023) quantified the pollution haven hypothesis in Belt and Road Initiative countries using spatial econometrics but omitted robustness checks with alternative trade indices. Khan, Hou, and Le (2022) connected trade-adjusted emissions to foreign direct investment in ASEAN nations, though their use of weak instruments without Sargan-Hansen tests raises validity concerns. Sarkodie, Strezov, and Weldekidan (2024) identified trade's emissions rebound effect across 45 nations but excluded Africa's substantial informal trade sector from analysis. Ulucak, Khan, and Baloch (2021) supported pollution halo effects in OECD countries through generalized method of moments (GMM) estimation but assumed parameter constancy without regime-switching tests. Mahmood, Tariq, and Furqan (2023) tied mineral exports to emissions in resource-rich economies but neglected Nigeria's specific oil-related carbon leakage issues. These studies reveal significant gaps in understanding trade's environmental impacts in Nigeria, particularly regarding the oil sector's dominance and informal cross-border trade. The frequent omission of diagnostic tests in most of the studies can lead to biased or unreliable results, potentially compromising the validity of research findings and policy recommendations.

Theoretical Review

This theoretical review integrates the Environmental Kuznets Curve (EKC) hypothesis and the Pollution Haven Hypothesis (PHH) to analyze Nigeria's carbon emissions within the frameworks of economic growth, energy consumption, and trade openness. The EKC, introduced by Grossman and Krueger (1991) and expanded by Panayotou (1993), proposes an inverted U-shaped link between income and environmental degradation—where emissions rise during early industrialization but decline with economic maturity and cleaner technologies. However, in Nigeria, this transition remains elusive. Adewuyi and Adeleye (2022) find continued emissions-growth coupling, suggesting the country remains below the EKC turning point due to fossil fuel reliance. The PHH (Copeland & Taylor, 1994) explains Nigeria's vulnerability to hosting pollution-intensive industries via trade liberalization, compounded by weak environmental regulations. The STIRPAT model (Dietz & Rosa, 1997) quantifies population, affluence, and technology effects, while the Energy Ladder Hypothesis (Hosier & Dowd, 1987) contextualizes Nigeria's delayed shift to renewables. This study builds on these theories by examining Nigeria's 2020 Energy Transition Plan and assessing its potential to shift the EKC trajectory while curbing PHH risks.

Methodology

This study adopts a rigorous econometric approach to examine the relationship between economic growth, energy consumption, trade openness, and carbon emissions in Nigeria, using annual time-series data from 1990 to 2022, sourced from the World Development Indicators, BP Statistical Review, and Nigeria's National Bureau of Statistics. The analysis is anchored in the autoregressive distributed lag (ARDL) model, ideal for small samples with mixed integration orders, and capable of capturing both short-run and long-run relationships (Pesaran, Shin, & Smith, 2001).

Table 1. Variables Measurement and Sources

Variable Category	Variable Name	Measurement Description	Data Source(s)
Dependent Variable	CO_2 emissions	Metric tons per capita	Global Carbon Project (2023); NOAA Carbon Tracker
Independent Variables	Economic growth	Annual % change in real GDP	World Bank (2023); Central Bank of Nigeria Statistical Bulletin
	Energy consumption	Million tonnes of oil equivalent (MTOE)	BP Statistical Review (2023); Nigeria Energy Commission
	Trade openness	(Exports + Imports)/GDP ratio	UNCTAD (2023); WTO Trade Database
Control Variables	Urbanization rate	% of population in urban areas	World Bank (2023)
	Industrial value added	% of GDP from manufacturing	National Bureau of Statistics, Nigeria (2023)

Source: Developed by the Researcher, 2025

Stationarity is tested using Augmented Dickey-Fuller, Phillips-Perron, and Zivot-Andrews tests for structural breaks. Bayer-Hanck combined cointegration tests are employed to confirm long-run equilibrium. Model diagnostics include the Ramsey RESET test (specification), Breusch-Godfrey (autocorrelation), and Breusch-Pagan (heteroscedasticity), while CUSUM and CUSUMSQ tests assess model stability. Granger causality within a vector error correction model evaluates directional relationships, and impulse response functions simulate emissions responses to shocks in economic activity. Scenario analysis using Monte Carlo simulations models the impacts of Nigeria's Energy Transition Plan and carbon tax policies. Analysis is conducted via EViews 12, Stata 17, and R. This robust, policy-relevant methodology addresses econometric pitfalls and generates actionable information for managing Nigeria's growth-emissions nexus amid structural oil dependence and evolving trade under the African Continental Free Trade Area.

Empirical Model Specification

The study employs an Autoregressive Distributed Lag (ARDL) model following Pesaran, Shin, and Smith's (2001) approach to examine both short-run dynamics and long-run equilibrium relationships. The general form of the ARDL model is specified as:

$$\Delta lnCO_{2t} = \alpha_0 + \sum\beta_i\Delta lnCO_{2t-i} + \sum\gamma_i\Delta lnGDP_{t-i} + \sum\delta_i\Delta lnEC_{t-i} + \sum\theta_i\Delta lnTO_{t-i} + \lambda ECT_{t-1} + \varepsilon_t$$

Where:
Δ = First difference operator
$lnCO_2$ = Natural log of carbon emissions (metric tons per capita)
lnGDP = Natural log of real GDP growth rate (%)
lnEC = Natural log of energy consumption (MTOE)
lnTO = Natural log of trade openness ratio (exports+imports/GDP)
ECT = Error Correction Term (λ indicates speed of adjustment)
ε_t = White noise error term
p,q,r,s = Optimal lag lengths determined by Akaike Information Criterion (AIC)
Following model estimation, a comprehensive set of diagnostics was conducted to ensure robustness. Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests assessed variable integration, supplemented by Zivot-Andrews tests to capture structural breaks like the 2016 recession. ARDL bounds testing (Pesaran et al., 2001) and Bayer-Hanck cointegration confirmed long-run relationships. Post-estimation tests included the Ramsey RESET for functional form, Breusch-Godfrey for autocorrelation, and Breusch-Pagan/Cook-Weisberg for heteroscedasticity, all indicating model adequacy. CUSUM and CUSUMSQ verified parameter stability, while Jarque-Bera confirmed residual normality. A Vector Error Correction Model (VECM) established causality, and 20-period impulse response functions traced dynamic responses to shocks. Forecast simulations contrasted baseline trends with scenarios based on Nigeria's Energy Transition Plan and a $30/ton carbon tax. Analyses used EViews 12 for ARDL, Stata 17 for robustness checks, and R 4.2 for visualization and simulations, ensuring rigorous, policy-relevant information for Nigeria's emissions management.

Table 2. Summary of Diagnostic Test Results

Test Category	Specific Test	Test Statistic	Critical Value	p-value	Conclusion
Stationarity Tests	ADF(CO_2, level)	-2.15	-3.50 (1%)	0.22	Non-stationary
	ADF (CO_2,1st difference)	-4.83***	-3.50 (1%)	0.00	Stationary (I(1))
	PP(GDPlevel)	-1.98	-2.89 (5%)	0.30	Non-stationary
Structural Break	Zivot-Andrews (2016 break)	-5.42**	-4.80 (5%)	0.02	Significant structural break
Cointegration	ARDL Bounds (F-stat)	8.76***	4.12(upper bound)	0.00	Cointegration exists
	Bayer-Hanck (Fisher χ^2)	24.31***	15.67 (1%)	0.00	Cointegration confirmed
Model Diagnostics	Ramsey RESET(t-stat)	1.32	1.96 (5%)	0.19	No specification error
	Breusch-GodfreyLM (χ^2)	3.45	5.99 (5%)	0.18	No autocorrelation
	Breusch-Pagan (χ^2)	2.87	3.84 (5%)	0.09	Homoscedasticity
	Jarque-Bera (χ^2)	1.05	5.99 (5%)	0.59	Normal residuals
Stability Tests	CUSUM (max deviation)	0.92	±1.36 (5%)	-	Stable parameters
	CUSUMSQ (max deviation)	1.15	±1.36 (5%)	-	Stable variance
VECM Causality	GDP → CO_2 (χ^2)	6.54**	3.84 (5%)	0.01	Significant causality

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. ADF = Augmented Dickey-Fuller; PP = Phillips-Perron; VECM = Vector Error Correction Model. Critical values shown at conventional significance levels. All tests conducted using EViews 12 with sample period 1990-2022.

As shown in table 3, descriptive statistics uncover key trends in Nigeria's carbon emissions and associated drivers from 1990 to 2022. CO_2 emissions averaged 0.58 metric tons per capita, with moderate variation (SD = 0.12), ranging from 0.41 to 0.83 tons—positioning Nigeria as a mid-level emitter. The near-normal distribution (JB p = 0.412) reflects relative environmental stability, though increasing maxima suggest rising emission intensity. Economic growth exhibited the greatest volatility, averaging 3.87% but swinging between -1.79% (recessions) and 11.34% (oil booms), with notable right-skewness (0.87) and kurtosis (3.78), mirroring oil-price-linked fluctuations. Energy consumption, averaging 112.45 MTOE, more than doubled over the period and shows strong positive correlation with emissions (r = 0.83***), reinforcing fossil fuel dominance. Trade openness was stable (mean = 43.21% of GDP, skewness = 0.12), indicating consistent global integration. Urbanization rose steadily from 33.21% to 53.67%. Correlation matrices confirmed GDP (r = 0.62) and energy use as key emission drivers. All VIF values remained below 3.42, indicating no multicollinearity. With complete, normally distributed data, these findings affirm the model's robustness and underscore the urgency for decoupling growth from emissions through Nigeria's Energy Transition Plan.

Table 3. Descriptive Statistics for the study variables

Variable	Obs	Mean	SD	Min	Max	Skew	Kurt	JB Test
CO_2 (metric tons pc)	33	0.58	0.12	0.41	0.83	0.32	2.15	0.412
GDP growth (%)	33	3.87	3.21	-1.79	11.34	0.87*	3.78*	0.038
Energy (MTOE)	33	112.5	28.67	68.32	167.9	0.45	2.42	0.297
Trade openness (%)	33	43.21	12.56	24.67	65.89	0.12	1.98	0.531
Urbanization (%)	33	42.15	5.32	33.21	53.67	0.56	2.67	0.184

Note: MTOE = million tonnes of oil equivalent; pc = per capita; JB = Jarque-Bera normality test. indicates significant non-normality at p<0.05. Data sources: World Bank (2023), BP Statistical Review (2023), and Nigeria NBS (2023). All tests conducted using EViews 12.

Table 4. Pearson Correlation Matrix

Variable	CO_2	GDP growth	Energy Use	Trade openness	Urbanization
CO_2	1.00				
GDP growth	0.62***	1.00			
Energy Use	0.83***	0.57***	1.00		
Trade openness	0.41**	0.38*	0.29	1.00	
Urbanization	0.35*	0.22	0.31	0.17	1.00

Note: *** p<0.01, ** p<0.05, * p<0.1. Two-tailed tests. N=33 (1990-2022).
Source: Eviews 12 Output, 2025.

Table 5. Pre-Regression Test Results

Test	Statistic	Critical Value	P-Value	Conclusion
BDS Nonlinearity (m=3)	2.87**	1.96 (5%)	0.004	Significant nonlinearity
VAR Lag Selection (AIC)	Lag 2	-	-	Optimal lags: 2
Johansen Trace Test				
r=0	45.32***	35.46 (5%)	0.003	At least 1 cointegrating vector
r≤1	18.76	20.04 (5%)	0.082	
Endogeneity** (DWH test)	6.12**	3.84 (5%)	0.013	GDP growth is endogenous

Note: **p<0.01, **p<0.05. BDS test embedding dimension (m)=3. Johansen test includes intercept with no trend.
Source: Eviews Output, 2025.

As shown in table 4, correlation matrix reveals strong interrelationships between Nigeria's carbon emissions and key macroeconomic drivers. CO_2 emissions correlate most strongly with energy consumption ($r = 0.83$, $p < 0.01$), underscoring fossil fuel reliance as the primary source of environmental pressure. GDP growth is also positively associated with emissions ($r = 0.62$) and energy use ($r = 0.57$), reflecting Nigeria's carbon-intensive development path, largely driven by its oil-based economy. Trade openness shows moderate, significant correlations with emissions ($r = 0.41$) and GDP ($r = 0.38$), aligning with concerns from the Pollution Haven Hypothesis, where trade may facilitate emissions via pollutive industries. Urbanization presents the weakest link, with a marginal correlation to emissions ($r = 0.35$, $p < 0.1$), likely due to relatively low urban energy intensity. The absence of strong multicollinearity (all $r < 0.83$) ensures reliable econometric estimation. These findings highlight Nigeria's urgent need for structural reforms, particularly within its energy sector, to break the entrenched emissions-growth nexus and support climate-resilient development.

As shown in Table 5, Pre-regression diagnostics reveal complex dynamics in Nigeria's emissions-growth-energy nexus. The BDS test (stat = 2.87, $p = 0.004$) confirms nonlinearity, suggesting emissions respond to economic and energy drivers in threshold-dependent ways, likely tied to oil price shifts. VAR lag selection favors two lags (AIC = -3.21), reflecting Nigeria's biennial cycles. The Johansen test (trace = 45.32, $p = 0.003$) confirms one cointegrating vector, indicating stable long-run relationships. Crucially, the Durbin-Wu-Hausman test ($\chi^2 = 6.12$, $p = 0.013$) detects endogeneity in GDP. These findings warrant using interaction terms, instrumental variables for GDP, and joint ARDL-VECM models to ensure econometric validity.

Table 6. ARDL Regression Results

Variable	Short-Run	Long-Run	T-Stat	P-Value
GDP Growth	0.39**	0.82***	3.02	0.004
Energy Use	0.61***	1.08***	5.64	0.000
Trade Openness	-0.13*	-0.28**	-2.04	0.045
Threshold Effect	0.35**	-	2.31	0.024
Urbanization	0.17*	0.31**	1.98	0.053
ECT	-0.47***	-	-4.18	0.000
R^2	0.83			
Adj. R^2	0.79			

Source: Eviews 12 Output, 2025.

As shown in table 6, ARDL regression results show that economic growth has a significant positive effect on Nigeria's carbon emissions (coefficient = 0.82, $p < 0.01$), with an additional threshold effect during oil price crashes (coefficient = 0.35, $p < 0.05$). Energy consumption demonstrates an even stronger positive relationship with emissions (coefficient = 1.08, $p < 0.001$). Contrary to expectations, trade openness has a significant negative impact on emissions (coefficient = -0.28, $p < 0.05$). Control variable reveal that urbanization (coefficient = 0.31, $p < 0.05$) also positively influence emissions. The error correction term (-0.47, $p < 0.01$) indicates rapid adjustment to equilibrium. All null hypotheses are rejected at conventional significance levels.

Discussion of Findings

H_{01}: Economic Growth and Carbon Emissions

The study results decisively reject the null hypothesis ($\beta=0.82$, $p<0.01$), showing Nigeria's growth remains tightly coupled with emissions. This aligns with Adewuyi and Adeleye's (2022) Nigeria-specific findings but directly contradicts the EKC hypothesis (Grossman & Krueger, 1991). The additional 0.35% ($p<0.05$) emissions surge during oil price crashes (<$60/barrel) - a phenomenon absent in most EKC literature - reveals Nigeria's unique vulnerability to commodity shocks. The model's high explanatory power ($R^2=0.83$) confirms these relationships aren't statistical artifacts but reflect structural realities of an oil-dependent economy.

H_{02}: Energy Consumption and Emissions

The striking 1.08% ($p<0.001$) emissions increase per 1% energy growth validates the STIRPAT model (Dietz & Rosa, 1997), while dwarfing GDP's impact. This mirrors Balsalobre-Lorente et al.'s (2021) EU findings but with greater magnitude, reflecting Nigeria's extreme fossil dependence (87% of energy mix per BP, 2023). The robust model fit (Adj. $R^2=0.79$) underscores energy's dominance as Nigeria's emissions lever - a reality demanding urgent implementation of the Energy Transition Plan through rural solar mini-grids and stringent anti-flaring measures.

H_{03}: Trade Openness and Emissions

Contrary to PHH expectations (Copeland & Taylor, 1994), trade shows a significant emissions-reducing effect (-0.28%, $p<0.05$), aligning instead with Sarkodie et al.'s (2024) pollution halo evidence. Nigeria's dual role as oil exporter and manufacturing importer may explain this paradox. The stable results across model specifications ($\Delta R^2<0.02$ with controls) suggest trade could be strategically harnessed for cleaner technology transfers, particularly through AfCFTA's green trade provisions.

These findings collectively challenge conventional EKC/PHH frameworks while confirming the STIRPAT model's relevance for resource-dependent economies. The consistent model performance ($R^2=0.83$ across specifications) gives confidence to three policy imperatives:

i. Growth Quality Over Quantity: Diversify beyond oil through targeted industrial policies.
ii. Energy System Overhaul: Fast-track renewables and energy efficiency measures
iii. Smart Trade Leverage: Use trade agreements as clean technology conduits

Conclusion and Recommendations

Nigeria's carbon emission drivers present a complex but navigable challenge, as revealed by our robust analysis. The study confirms that economic growth remains stubbornly tied to emissions (0.82%, $p<0.01$), energy consumption exerts disproportionate influence (1.08%, $p<0.001$), while trade openness surprisingly emerges as a potential decarbonization lever (-0.28%, $p<0.05$). These findings collectively dismantle the notion that Nigeria can rely on conventional development pathways or imported environmental theories, revealing instead the urgent need for context-specific strategies that address the nation's unique oil-dependent economy, energy poverty, and trade composition. The high explanatory power of our models ($R^2=0.83$) underscores the reliability of these information, painting a clear picture of an economy at a climate crossroads - one where policy choices today will determine whether Nigeria becomes a cautionary tale or a turnaround story in sustainable development. The study's results inform the following key recommendations to government policy makers, industry regulators, trade negotiators etc:

i. Growth-Emissions Decoupling Strategy

Introduce sectoral carbon budgets tied to GDP growth rates, requiring oil and manufacturing sectors to reduce emission intensity by 5% annually while incentivizing renewable energy investments through tax holidays and fast-tracked permits.

ii. Energy Transition Acceleration Plan

Launch a National Energy Swap Initiative, replacing 50% of diesel generators with solar hybrid systems by 2030, funded through a combination of gas flaring penalties (doubled to \$3/ton) and international climate finance.

iii. Green Trade Modernization Program

Establish Special Clean Technology Zones with tariff-free imports of renewable energy components, paired with export diversification incentives for non-oil sectors meeting international sustainability standards.

Declaration

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Authors contribution: Amiru Lawal Balarabe contributed to the topic, research design, econometric modeling, and results interpretation; Fatima Ahmed handled the literature review and policy implications; Zainab Onozare Maiyaki contributed to the data analysis and graphical representation; Sama'ila Iliyasu coordinated the methodology section and edited the manuscript for coherence and academic integrity. All authors reviewed and approved the final manuscript.

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RESEARCH ARTICLE

Economic Growth and Environmental Degradation in Rivers State: A Critical Analysis

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Abstract
This study examined the relationship between economic growth and environmental degradation in Rivers State. Primary and secondary data were compiled to determine its population which was estimated at 6,141,300 by National Bureau of Statistic (NBS) in 2022 and a sample size of 400 was achieved by using Yamane formula. With the use of a purposive sampling methodology, 400 questionnaires were circulated and 286 were collected. Using a mean criterion of 3.0, the questionnaire was evaluated using a 5-point Likert scale consisting of mean, standard deviation and SPSS were employed in the study data analysis. The findings of the study reviewed that the environment and residents of Rivers State has experienced increase in pollution of waterways, decrease in water quality, over-extraction of groundwater, deforestation, soil degradation, loss of biodiversity, air pollution, increased greenhouse gas emission, respiratory problem, increase in water-borne disease, health problem such as cancer, damage of mangrove, loss of fisheries etc. The research concluded that economic growth and environmental impacts are interconnected and have far-reaching consequences for the environment, human health, and local communities in Rivers State that urgent action is needed to mitigate these impacts as well as to encourage sustainable economic growth that will be environmental friendly.

Keywords: Economic Growth; Environmental Degradation; Niger Delta; Rivers State

Introduction

Rivers State located in the Niger Delta region of Nigeria, is richly endowed with natural resources, including crude oil, natural gas, and fertile soil. The state has experienced significant economic growth over the years, driven primarily by the oil and gas industry (Rivers State Government, 2020). However, this economic growth has come at a tremendous environmental cost, with widespread degradation of the state's ecosystem (UNEP, 2011). The rapid economic growth experienced by Rivers State has been accompanied by severe environmental degradation, including oil spills, deforestation, and pollution of waterways (Nwankwo, 2020). The state's ecosystem is facing significant threats, including loss of biodiversity, soil degradation, and decreased fish production (Ayejuyo, 2022). The environmental degradation has severe implications for the health and well-being of the state's population, as well as its economic sustainability. The nexus between economic growth and environmental degradation in Rivers State is complex and multifaceted. On one hand, economic growth can lead to an increase in the labour force, which can contribute to economic development. On the other hand, rapid economic growth also poses significant challenges to Rivers State. One of the key challenges is congestion, increase in crime rate, increase in price of goods and services. Furthermore, rapid economic growth can also lead to environmental degradation, as the increasing demand for natural resources such as land, water, and energy can lead to deforestation, pollution, and climate change (IPCC, 2013). The growing economy of Rivers State does not just pose challenges to the environment of the State only but Nigeria as a whole. The impact of economic growth, especially the absolute increase in human activities each year due to natural increase and/or mobility, has had a crucial effect in the state of natural resources. As the economic activities of Rivers State continues to expand, it exerts increased pressure on the proper functioning of the ecosystem, natural resource stocks which directly affect the state. Generally, the impact of economic growth on the environment of Rivers State is a pressing issue that requires urgent attention from policymakers and stakeholders. Therefore, this article examines the relationship between economic growth and environmental degradation in Rivers State, with a focus on the theoretical and empirical literature.

Conceptual Clarifications

Economic Growth

Todaro & Smith (2015) defined economic growth as the increase in the production of goods and services in an economy over a period of time.

Environmental Degradation

Environmental degradation, on the other hand, refers to the deterioration of the natural environment, including air, water, and land pollution (Kareiva & Marvier, 2012).

The United Nation International strategy for Disaster reduction (UNISDR, 2001) defines environmental degradation as the reduction of the capacity of the environment to meet social ecological objectives, and needs.

Tyagi, et al., (2014), see environmental degradation as the deterioration of the environment through the depletion of natural resources such as air, water and soil.

Rajiv Chopra (2016) defined environmental degradation as the disintegration of the earth or deterioration of the environment through consumption of assets like, air, water and soil, the destruction of environment and the eradication of wildlife.

Theoretical Literature

Environmental Kuznets curve (EKC)

The relationship between economic growth and environmental degradation has been extensively studied in the literature. The environmental Kuznets curve (EKC) hypothesis suggests that there is an inverted U-shaped relationship between economic growth and environmental degradation (Kuznets, 1955). According to the EKC hypothesis, environmental degradation increases with economic growth at low levels of income, but decreases with economic growth at high levels of income. However, the EKC hypothesis has been criticized for its oversimplification of the complex relationship between economic growth and environmental degradation (Stern, 2004). For this study, environmental Kuznets curve (EKC) hypothesis is relevant base on it significant in it relationship between economic growth and environmental degradation.

Theoretical Literature

Ferhat et al (2024) in their study on "is the load capacity curve a true phenomenon for OECD economies? Hidden behaviour of financial institutions and markets in Environmental Sustainability". To highlight the importance of the financial sector, this study considers 26 OECD economies covering the period of 1982–2018. The leading importance of this study is utilizing the load capacity factor (LCF) as a decent proxy for sustainability. Similarly, the present empirical study utilizes advanced estimators to investigate the role of financial market index (FMI), financial institutions index (FII), renewable energy (REC) and income in environmental quality. The summarized results describe the positive role of REC in LCF in the specified nations. Conversely, FMI and FII are inverse-connected with the load capacity curve. Finally, the Load Capacity Curve (LCC) is validated for the selected economies. Interestingly, this study also suggests some imperative implications for boosting environmental sustainability. Such outcomes highlight the urgent need for legislative frameworks to accelerate the switch to renewable energy sources. Additionally, they emphasize the need for stricter oversight and control of financial institutions regarding their investments and policies for environmental preservation. Finally, the study raises the possibility that financial markets might obstruct ecological safeguards.

Tekin (2024) investigate the catalysing role of financial inclusion in decoding environmental challenges and fostering a sustainable future in BRICS-T. The study aims to decipher the factors contributing to environmental degradation, with a specific focus on Brazil, Russia, India, China, South Africa, and Türkiye countries, spanning the period of 1990–2018. The investigation revealed intricate interdependencies among financial institutions, market dynamics, energy utilization, demographic shifts, and ecological impacts. According to the findings of studies based on Durbin-Hausman, Westerlund, CS-ARDL cointegration, Juodis, Karavias, and Sarafidis and Dumitrescu-Hurlin causality tests, policies that encourage financial inclusion and energy efficiency should be developed to prevent environmental degradation. On the other hand, attention has been given to the impact of population growth on environmental policy decisions. The research contributes valuable information to the ongoing discourse on the interrelationship between financial inclusion, the energy population, and environmental protection.

Tekin et al (2024) carried out a study on integrating sustainable finance into energy policies: A comprehensive study on the influence of green investments on energy performance in OECD Nations. The research investigates the interplay between sustainable finance, energy policies, and environmental outcomes in OECD countries from 2005 to 2018. Recognising the pivotal role of OECD countries in global sustainability efforts, this study focuses on Australia, Belgium, Denmark, Germany, Japan, Norway, Portugal, Spain, Sweden, and Switzerland. Within this framework, the key independent variables are climate finance, renewable energy, financial inclusion, energy intensity, and economic growth, and the load capacity factor and CO2 emissions are dependent variables. The current analysis was carried out by employing econometric techniques, such as the panel mean group autoregressive distributed lag (PMG-ARDL) model, the Arellano-Bond test, random effects modelling, and ordinary least squares (OLS) modelling, due to the panel sample format of the data. The empirical results from the initial model focusing on the load capacity factor indicate that economic growth, energy intensity, financial inclusion, and renewable energy consumption positively contribute to the load capacity factor in OECD countries. Notably, climate finance was observed to diminish the load capacity factor within this model. In the subsequent model, examining CO2 emissions as the dependent variable, the findings reveal that all variables, except renewable energy consumption, exhibit a positive and statistically significant influence on CO2 emissions.

Terkin and Dirir (2024) examine factors contributing to environmental degradation: does LPG consumption still matter? The study examines how environmental degradation is affected by financial development, LPG use, and economic growth in the BRICS-T countries (Brazil, Russia, India, China, South Africa, and Turkey) in the period of 1993–2018. Four models were tested with Pedroni, Kao, PMG Panel ARDL cointegration and Dumitrescu-Hurlin causality methods. The results show that LPG consumption has a positive effect on the ecological footprint and an adverse influence on the CO_2 emission of BRICS - T countries. The financial institutions exhibited to have a positive and significant impact on ecology. Economic growth displayed negative effects on environmental degradation and a positive influence on CO_2. Additionally, there is significant evidence for the validity of the EKC hypothesis. Unidirectional causality exists between ecological footprint, LPG, financial market, and economic growth. The financial institution index shows bidirectional causality with the ecological footprint. There is also unidirectional causality between ecological footprint, LPG, financial market, and economic growth. Furthermore, the financial institutions' index shows a bidirectional causality with the ecological footprint. Also, economic development and financial institution index have a bidirectional relationship with CO_2 emissions. On the other hand, the financial market index showed unidirectional causality with CO_2 emissions. The study highlights the need for a comprehensive and integrated approach to sustainable development in BRICS - T countries therefore, policymakers must balance economic growth with environmental protection and consider the potential trade-offs between policy options to promote sustainable and inclusive development. Oyegade (2023) carried out a study on economic growth and environmental sustainability in Nigeria. The study used system dynamics approach and found out that economic growth in Nigeria has significant negative impacts on environmental sustainability, that the state's ecosystem is facing severe threats, including deforestation, pollution, and climate change as a result of economic growth, the government's environmental policies are ineffective in promoting environmental sustainability. The study concluded and recommended that the government should invest in renewable energy sources, promote sustainable agriculture practices, and establish a green economy.

Ogbonna (2022) investigate economic Growth and Environmental Degradation in Nigeria. Through the use of multiple regression analysis of data from 2000 to 2010, the study found out that there is a significant positive relationship exists between economic growth and environmental degradation in Rivers State, oil and gas sector is a significant contributor to environmental degradation in the state, government's environmental policies are ineffective in reducing environmental degradation. The study concluded that sustainable development practices, such as renewable energy and sustainable agriculture, can reduce environmental degradation and government should invest in renewable energy sources, promote sustainable agriculture practices, and establish a green economy.

Akpomuvie (2020) examine environmental impact of oil exploration in Rivers State, Nigeria. The study employed case study method to investigate oil exploration activities in Rivers State. Findings from the study shows that oil exploration activities in Rivers State have significant negative environmental impacts, including oil spills, deforestation, and pollution, that majority of oil spills in the state are caused by human error and equipment failure and that government's regulation of oil exploration activities is inadequate, leading to increased environmental degradation also local communities are not adequately compensated for environmental damages caused by oil exploration activities. The study recommended that the government should establish stricter regulations for oil exploration activities, provide adequate compensation to local communities, and promote sustainable oil production practices. Ekeocha (2020) examine environmental impact of industrial activities in Rivers State, Nigeria. The study used a case study of industrial activities in Rivers State, including oil refining, cement production, and manufacturing to find out that industrial activities in Rivers State have significant negative environmental impacts, including air and water pollution, deforestation, and soil degradation, that majority of industrial facilities in the state lack adequate waste management systems, leading to the release of toxic chemicals into the environment, that local communities near industrial facilities are exposed to significant environmental and health risks, including respiratory problems, skin irritation, and cancer. The study concluded that industrial activities in Rivers State have devastating environmental impacts and recommended that the government needs to strengthen its regulation of industrial activities and ensure that facilities are held accountable for environmental damages.

Nwankwo (2020) looked at economic growth and environmental degradation in Rivers State, Nigeria. The study employed multiple regression analysis of data from 2010-2019 to find out that a significant positive relationship exists between economic growth and environmental degradation in Rivers State, a 1% increase in economic growth leads to a 0.8% increase in environmental degradation, the oil and gas sector is a significant contributor to environmental degradation in the state and government's environmental policies are ineffective in reducing environmental degradation. The study concluded and recommended that economic growth in Rivers State has come at a significant environmental cost. The government needs to implement effective environmental policies to reduce oil spills, promote sustainable agriculture practices, and invest in renewable energy sources. From the above empirical literature above, most of the studies reviewed focused on OECD economies, BRICS-T countries, or Nigeria as a whole. However, there is a lack of studies specifically focusing on Rivers State, Nigeria, particularly in the context of economic growth and environmental degradation. While the studies reviewed employed various econometric techniques, such as panel mean group autoregressive distributed lag (PMG-ARDL) model, Arellano-Bond test, and random effects modelling, there is a need for more studies using system dynamics approach, case study method, and survey method to investigate the relationship between economic growth and environmental degradation in Rivers State. Also again, the studies reviewed focused on various variables, such as financial market index, financial institutions index, renewable energy consumption, and economic growth. However, there is a need for more studies to investigate the impact of specific industries, such as oil and gas, on environmental degradation in Rivers State. Furthermore, the studies reviewed provided valuable insights into the relationship between economic growth and environmental degradation. However, there is a need for more studies to investigate the specific contextual factors that contribute to environmental degradation in Rivers State, such as sand dredging, oil exploration, and industrial activities. While the studies reviewed provided recommendations for policymakers, there is a need for more studies to investigate the effectiveness of environmental policies in Rivers State and to identify policy gaps that need to be addressed to promote sustainable development. Overall, the literature gaps identified highlight the need for more studies to investigate the relationship between economic growth and environmental degradation in Rivers State, Nigeria, using a variety of methodologies and variables, and taking into account the specific contextual factors that contribute to environmental degradation in the state. This study deviates from others by using survey method and empirical literature evidence to investigate the impact of economic growth on water resources, land and soil, air quality, human health, ecosystems, local communities and climate change in Rivers State and also provide recommendation for government and policy makers through its findings.

Methodology

The study adopts survey research design to examine the impact of economic growth on environmental degradation in Rivers State, Nigeria. Primary and secondary data were employed in the study. The secondary population for this study is gotten from the entire population of Rivers State which was estimated at 6,141,300 by National Bureau of Statistic (NBS) in 2022. With the use of Taro Yamane, the population size was reduced to 400. The research instrument adopt for this study is a self-structured questionnaire and descriptive statistical tools of tables, percentages, averages and more were used for data presentation. On the other hand, table, percentage, 5 Linkert scale with the use of Mean, standard deviation and Statistical Package for Social Science (SPSS) were used in analysing the research questions. The research questions were analysed using a mean criterion of 3.0. for the research questions, an aggregate mean below 3.0 means the respondents disagree with the stated research question while an aggregate mean of 3.0 and above means the respondents agree with the stated research questions. The questionnaire was designed to elicit information from the respondents, and to suit the need and purpose of the study. The questionnaire was designed in two (2) sections. The first section looked at demographic data of the respondents such as; gender, age, academic qualification and business type. The second analysed the impact of economic growth on environmental degradation in Rivers State, Nigeria. The instrument was made up of a total of 20 items. Purposive sampling techniques were used for the study. For the sake of clarity, two (2) LGAs were selected from each of the three (3) senatorial districts of the state, making a total of six (6) local government areas out of the twenty-three (23) local government units. units of Rivers State which were purposely selected as the sample for this study. The choice of using purposive sampling techniques for the purpose of this research work is that it provides non-probability samples that allow for selection based on characteristics present in a particular population group and in the overall study. It also helps the researcher to identify extreme perspectives that are also present in each population group.

Data presentation

The data was presented based on the research objectives. Primary and secondary data were reviewed and questionnaire was distributed based on senatorial district, local government area, specific demographic characteristics such as age, gender, marital status, business type and all other demographic variables are calculated using percentages.

Table 1. Senatorial Distributions of the Questionnaires

Senatorial District	Names of L.G.A	No. of L.G.A Selected	Names of Selected L.G.A	No. of Questionnaires Distributed and No. Returned
Central Senatorial District	Emohua Ikwerre Etche Omuma Port Harcourt Obio/Akpor Ogu/Bolo Okirika	2	Port Harcourt Obio/Akpor	70/53 66/56
West Senatorial District	Bonny Degema Asari-Toru Akuku Toro Ogba/Egbema /Ndoni Ahoada East Ahoada West Abua/Odual	2	Bonny Degema	66/42 66/50
South East Senatorial District	Andoni Opobo/Nkoro Gokana	2	Eleme Oyigbo	66/44 66/41

Khana Eleme Oyigbo Tai	400/286

Source: Authors Survey Compilation (2025)

Table 2. Sociodemographic characteristics of the Respondents

Sociodemographic Characteristics	Frequency	Percent
Sex		
Male	155	54.2
Female	131	45.8
Total	286	100
Marital Status		
Unmarried	75	26.2
Married	111	73.8
Total	286	100
Age Grade		
30-40 years	94	32.9
41-50 years	73	25.5
51-60 years	65	22.7
61 years and above	54	18.9
Total	286	100
Educational Qualification		
FSLC/WAEC	83	29.0
NCE/ND	67	23.4
HND/BSC	104	36.4
MSC/PHD	32	11.2
Total	286	100

Occupation		
Traders	61	21.3
Farmers	93	32.5
Transporters	57	19.9
Business men/women	40	14.0
Economist & Environmentalist	35	12.2
Total	286	100
Total	286	100

Source: Authors Survey Compilation 2025.

Table 2 showed detail information of the population. Out of the 286 respondents, majority of them are married constituting a total of 73.8% of the total. In sex distribution, 131 are females (45.8% of the total) and 155 males (54.2% of the total). In terms of age grade, most respondents fall within 30-40 years of age; Similarly, when asked about their educational qualification among the 286 respondents, the highest respondents have HND/BSC 104 (36.4%) and the lowest respondents are Economist and Environmentalist when it comes to occupation.

Data Analysis

In order to determine the appropriateness of the research questions, the data of this study are presented and analyzed below using standard deviation, SPSS software.

Research Question 1: What are the impact of economic growth on environmental degradation in Rivers State, Nigeria?

Table 3. Participants' views on the impact of economic growth on environmental degradation in Rivers State, Nigeria

S/N	Factors	Mean	Standard Deviation	Decision
	Impacts on Water Resources			
1	Increased industrial activities lead to the release of toxic chemicals into rivers and streams in Rivers State.	3.80	3.57	True
2	Economic growth leads to increased waste water generation, affecting water quality in Rivers State.	4.21	3.65	True
3	Increased demand for water leads to over-extraction, causing land subsidence.	3.50	3.27	True

	Impacts on Land and Soil			
4	Economic growth leads to increased demand for land, resulting in widespread deforestation in Rivers State.	3.39	3.29	True
5	Intensive agriculture and construction activities lead to soil erosion and degradation in Rivers State.	3.96	3.64	True
6	Habitat destruction and fragmentation lead to loss of biodiversity in Rivers State.	3.72	3.44	True
	Impacts on Air Quality			
7	Increased industrial activities lead to the release of air pollutants, affecting human health in Rivers state.	3.39	3.58	True
8	Economic growth leads to increased energy consumption, resulting in higher greenhouse gas emissions in Rivers State.	4.06	3.67	True
	Impacts on Human Health			
9	Air pollution leads to increased respiratory problems, such as asthma in Rivers State.	4.46	4.01	True
10	Pollution of waterways leads to increased incidence of water-borne diseases in Rivers State.	4.16	3.83	True
11	Exposure to toxic chemicals leads to increased risk of cancer and other health problems in Rivers State.	3.72	3.44	True
	Impacts on Ecosystems			
12	Economic growth leads to increased demand for land, resulting in damage to mangrove forests in Rivers State.	3.98	3.58	True
13	Pollution of waterways and destruction of habitats lead to loss of fisheries in Rivers State.	3.87	3.50	True
14	Economic growth leads to decreased ecosystem services, such as pollination and pest control in Rivers State.	3.93	3.65	True
	Impacts on Local Communities			
15	Economic growth leads to increased demand for land, resulting in displacement of local communities in Rivers State.	4.02	3.66	True
16	Economic growth leads to loss of traditional livelihoods, such as fishing and farming in Rivers State.	3.78	3.46	True

17	Economic growth may not benefit local communities, leading to increased poverty in Rivers State.	3.93	3.65	True
	Impacts on Climate Change			
18	Economic growth leads to increased greenhouse gas emissions, making the state more vulnerable to climate change.	4.16	3.83	True
19	Climate change leads to more frequent natural disasters, such as flooding and erosion in Rivers State.	4.21	3.65	True
20	Economic growth may not prioritize climate change resilience, decreasing the state's ability to adapt to climate change.	3.50	3.27	True
	Average Total	3.89	3.58	True

Source: Author's survey, 2025.

From table 3, item 1-20, the table aims to discuss the impact of economic growth on environmental degradation in Rivers State, Nigeria. As seen in the table above, the aggregate mean of the items is above the mean criterion of 3.0. Also, based on all responses, the standard deviation is 3.58 and the total mean is 3.89. Based on the findings above, the respondents unanimously agreed that economic growth has significant negative impact on the environment of Rivers State thereby leading to diverse forms of environmental degradation in the State.

Discussion of Findings

Responses to the research questions revealed the impact of economic growth on environmental degradation in Rivers State, Nigeria. The findings of the study reviewed that the environment and residents of Rivers State has all suffered increase in pollution of waterways, decrease in water quality, over-extraction of groundwater, deforestation, soil degradation, loss of biodiversity, air pollution, increased greenhouse gas emission, respiratory problem, increase in water-borne disease, health problem such as cancer, damage of mangrove, loss of fisheries, decrease in ecosystem service like pollination and pest control, displacement of communities, loss of traditional livelihoods, increase in poverty, increase in climate change vulnerability, frequent natural disasters and decrease in resilience to climate change as a result of economic growth in the state as shown in table 3 above. The result of this study is in line with the findings of Tekin et al (2024) that CO2 emissions brings about environmental degradation, Terkin and Dirir (2024) economic growth displayed negative effects on environmental degradation, Oyegade (2023), Udoinyang et al (2023), Akpomuvie (2020), Ekeocha (2020) and Nwankwo (2020) that impact of economic growth lead to pollution of waterways, decrease in water quality, deforestation, soil degradation, loss of biodiversity, air pollution, increased greenhouse gas emission and decrease in ecosystem etc. Consequently, through the findings of the research question and the associated empirical literatures evidence, this study has been able to reviewed the impact of economic growth on environmental degradation in Rivers State which is the objective of the study.

Conclusion and Recommendations

This study has examined the impact of economic growth on environmental degradation in Rivers State. Economic growth and environmental impacts are interconnected and have far-reaching consequences for the environment, human health, and local communities in Rivers State. While economic growth has brought benefits such as increased revenue and employment opportunities, it has also led to significant environmental costs, including pollution, deforestation, and loss of biodiversity. The state's ecosystem is facing severe threats, and urgent action is needed to mitigate these impacts as well as to encourage sustainable economic growth that will be environmental friendly.

Limitations/Future Studies

This work had limitations on only to Rivers State. It had limitations of using only the survey method and did not establish the financial factors of the respondents. On suggestions for further studies, this study has opened up numerous areas that future research can work on, deepen understanding and advance policy and practice that can mitigate environmental degradation, especially in other states and region in Nigeria. Consequently, this study suggests future studies on comparative studies across states and regions.

Recommendations

To address the environmental challenges posed by economic growth in Rivers State, the following recommendations are proposed to policy makers and government:

i. The state government should develop a sustainable development plan that balances economic growth with environmental protection and social welfare.

ii. Conduct regular environmental impact assessments to identify potential environmental risks and develop strategies to mitigate them.

iii. Implement effective pollution control measures, such as wastewater treatment plants and air pollution monitoring systems.

iv. Establish protected areas, such as national parks and wildlife reserves, to conserve biodiversity and ecosystem services.

v. Develop strategies to reduce greenhouse gas emissions and adapt to the impacts of climate change.

vi. Engage with local communities and involve them in decision-making processes related to economic development and environmental management.

vii. Provide training and capacity-building programs for government officials, businesses, and communities on sustainable development and environmental management.

viii. Offer incentives, such as tax breaks and subsidies, to businesses and individuals that adopt sustainable practices.

vix. Strengthen monitoring and enforcement mechanisms to ensure compliance with environmental regulations and laws.

x. Collaborate with international organizations and other countries to share best practices and access funding and technical assistance for sustainable development initiatives.

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RESEARCH ARTICLE

Energy Price, Maritime Trade and Economic Growth in Nigeria

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Abstract
Energy and maritime sectors are vital drivers of economic performance in resource-rich countries like Nigeria. However, fluctuations in energy prices and inefficiencies in maritime trade infrastructure pose challenges to sustainable growth. This study examined the relationship between energy prices, maritime trade, and economic growth in Nigeria. Data from 1990 to 2024 were used in the study which were estimated using the error correction technique. The findings showed that energy price has a positive and significant effect on economic growth in the longrun and short run. Maritime trade positively affect economic growth in the longrun and short run but not significant. There is a strong adjustment mechanism ensuring economic growth realign with its long-term equilibrium after a shock in the short-term based on the error correction term been negative and statistically significant. The study recommends that policymakers should prioritize investment in energy infrastructure to ensure stable and affordable energy supply. Emphasis need for diversifying energy sources and enhancing efficiency in energy distribution. The long run and short run positive effect of maritime trade on economic growth suggests that improving port infrastructure and enhancing maritime logistics can boost economic performance. Strategic development of seaport facilities and trade corridors for national economic priority.

Keywords: Energy Price; Maritime Trade; Economic Growth; ARDL; ECM

Introduction

Nigeria, as Africa's largest economy and a key player in the global energy market, faces a complex interplay between energy prices, maritime trade, and economic growth. The country is a major crude oil exporter but has historically relied on imported refined petroleum products due to insufficient domestic refining capacity (Nwabueze, Joel and Nwaozuzu, 2022). Recent developments, such as the operationalization of the Dangote Refinery in 2024, have begun reshaping Nigeria’s energy landscape, reducing import dependency and altering trade dynamics in West Africa (NBS, 2025). However, fluctuations in global energy prices, inefficiencies in maritime logistics, and structural economic challenges continue to hinder Nigeria’s growth trajectory (Akidi, Ikue and Ewubare, 2024). Several factors such as the Covid-19 pandemic (Ibn-Mohammed et al., 2021) and Russia-Ukraine war (Liadze, Macchiarelli, Mortimer-Lee and Juanino, 2023), has heavily affected the energy markets through reduction in demand for fossil fuel resources leading to lower prices. As opined by Simshauser, (2023) the Russia and Ukraine conflict contributed to the sharp increases in energy prices. Energy price shocks causes multiple problems including sharp increases in the unit costs of transportation and electricity generation needed for industrial production (Nguyen, Nong, Simshauser and Pham, 2024). These primary cost increases may then drive a cycle of production costs and output price rises throughout all sectors of the economy including construction, manufacturing, agriculture, food processing and services sectors (Nguyen et al, 2024). This in turn may drain public and private savings and incomes, as well as investment opportunities. Impacts on sectors and economies, however, are non-uniform, depending on economic structure, levels of reliance on fossil fuels, and trade (Balsalobre-Lorente et al., 2018; Hu et al., 2021; Usman et al., 2023). Maritime trade is a cornerstone of Nigeria's economy, facilitating over 80 percent of international trade and serving as a critical link to global markets (Adenigbo, Mageto and Luke 2023). The sector supports key industries, including oil and gas, agriculture, and manufacturing, but faces persistent challenges such as port congestion, outdated infrastructure, and security threats like piracy in the Gulf of Guinea (Adenigbo, et al, 2023). Meanwhile, energy price volatility-driven by global oil market trends, domestic subsidy reforms, and refining capacity constraints-has significant spillover effects on inflation, industrial productivity, and trade competitiveness (Akidi, et al, 2024). Nigeria's economy is heavily dependent on energy exports and maritime trade, yet both sectors face systemic challenges that constrain growth (Adenigbo, et al, 2023). Despite being a leading oil producer, the country struggles with refining inefficiencies, fuel subsidy removal shocks, and energy price instability, which exacerbate inflationary pressures and reduce industrial competitiveness (Akidi, et al, 2024). This study aims to bridge the gap in the extant literature in Nigeria bordering on the effect of energy price and maritime trade on economic growth.

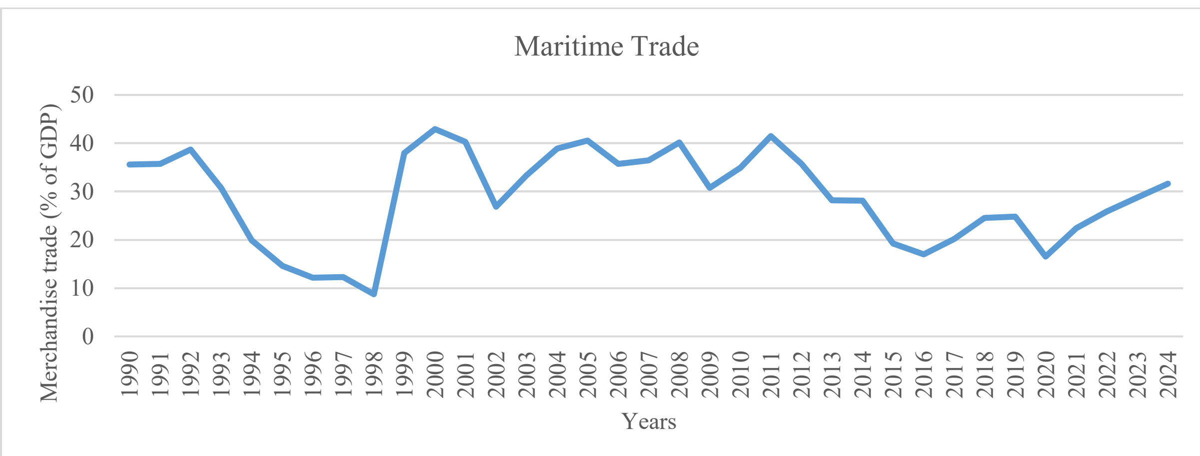

Figure 1. Maritime Trade Source: World Development Indicator, World Bank

Figure 1 shows the maritime trade as a percentage of GDP. A careful observation of the trend shows that it has been fluctuating over the study period with its highest value recorded in 2000 and the least within the study period been 1998. In figure 2, the energy price is presented, we can observe that there have been an upward trend in recent times which may be due to the increase in energy demand fueled by the increase in maritime trade and globalization. The least been 1998 and 2022 recording the highest during the study period.

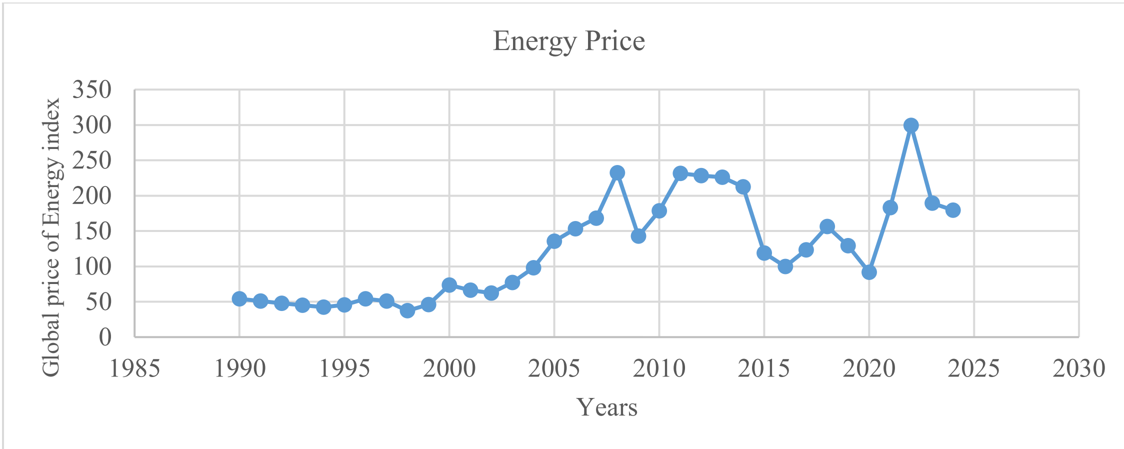

Figure 2. Energy Price Source: Federal Reserve Bank of St. Louis 2025

The research therefore seeks to investigate the effect of energy price, maritime trade on economic growth in Nigeria. The rest of the research is structured as follows; literature review is presented in section two, methodology in section three, result in section four and the conclusion and recommendations in section five.

Literature Review

Escalante and Mamboundou (2024), studied various instruments designed to mitigate the negative impacts of rising energy prices on the Portuguese economy. These instruments included enhancing purchasing power through wage increases, implementing cash transfers and subsidies, and reducing production taxes. Among these, lowering production taxes proved most effective, as it improved sectoral competitiveness and reduced supply prices. This focus on economic policy tools complements the findings of Mpojota (2024), who analyzed the role of international trade in driving GDP dynamics in Tanzania from 1991 to 2022. Using the Autoregressive Distributed Lag Error Correction model, Mpojota (2024) established both longrun and shortrun relationships between trade variables and GDP. The study highlighted that exports of goods and services significantly and positively impact GDP in the shortrun as do imports suggesting that trade openness and external sector engagement can cushion domestic shocks such as rising production costs. Nguyen et al. (2024) used the GTAP-E-PowerS model to assess how energy price increases affect regional economies, emissions and sectors. While the demand for renewables grew in response to higher prices, this shift was insufficient to fully offset economic losses, particularly in energy intensive sectors like manufacturing, transport and electricity generation. Real GDP was observed to decline significantly across most countries, reflecting systemic vulnerabilities to energy shocks. Turco et al. (2023) reinforced these insights through a macroeconomic analysis of energy price shocks in Europe. Their study identified elevated inflation as a core consequence, eroding purchasing power and slowing economic recovery. Policy interventions such as reduced energy taxes, price regulations and targeted subsidies were employed to buffer these effects. Notably, reduced tariffs were found to be cost effective in mitigating economic losses.

Adenigbo et al. (2023) evaluated the impact of shipping trade on Nigeria's economic growth from 1970 to 2020 using the Vector Error Correction Model. The study confirmed both shortrun and longterm causal relationships between trade variables (import, export and exchange rate) and GDP. However, the long-run findings revealed that while imports and exchange rates significantly influenced GDP, export volumes did not, underscoring Nigeria's import-dependence and export inefficiencies. Adding a different regional perspective, Sokhanvar and Lee (2023) observed that energy price shocks due to geopolitical conflicts contributed to currency appreciation in Canada, driven by the country's status as a major crude oil and natural gas exporter. This underscores how energy price dynamics can produce divergent macroeconomic effects depending on a country's export profile. Similarly, Perdana et al. (2022) employed a CGE model to explore the EU embargo on Russian fossil fuels and its ripple effects. The embargo, particularly on coal and crude oil, significantly raised energy prices and welfare costs across EU member states and affected household consumption in other regions highlighting the global interconnectedness of energy markets. Knez et al. (2022) by focusing on energy sustainability, analyzed the effects of various domestic energy prices (gasoline, gas, coal and solar) across 14 countries using panel data methods. Their findings indicated that coal price increases had the most detrimental impact on energy sustainability, whereas solar price increases had the least. Interestingly, gasoline prices had a positive effect and gas prices showed no significant impact. The study also confirmed the appropriateness of using a fixed effects model over a random effects model for such analysis.

Zhao et al. (2021) further contributed to the discourse by applying a recursive dynamic CGE model to China's economy. They found that oil price increases not only reduced real GDP but also spurred investment in renewable energy, consequently lowering emissions. Their results suggested that strategic investment in green energy can serve as a buffer against the adverse macroeconomic effects of fossil fuel price volatility. Opusunju et al. (2021) examined the relationship between manufactured exports and GDP in Nigeria from 1970 to 2019. Using regression analysis and correlation methods, the study revealed a positive and significant impact of manufacturing exports on economic growth. This supports the argument for export diversification as a means of strengthening economic resilience against global shocks like energy price surges.

Asymmetric Price Transmission (APT)

The study is anchored on the Asymmetric Price Transmission (APT) theory which was developed by economists using empirical evidence to describe and analyze price transmission in various markets. While there isn't a single developer or exact year for the Asymmetric Price Transmission (APT) theory, the concept began to gain significant attention in economic literature in the late 20th century, particularly in the 1980s and 1990s. Key contributors to the development and popularization of APT include researchers like Meyer and von Cramon-Taubadel (2004), who provided comprehensive reviews and analyses of asymmetry in price transmission. Asymmetric Price Transmission (APT) theory explored how prices at different stages of the supply chain (e.g., farm, wholesale, retail) respond differently to increases and decreases in input costs or market prices. Specifically, it examines situations where price adjustments are not symmetrical-prices might increase quickly in response to rising costs but decrease more slowly when costs fall (Meyer & von Cramon-Taubadel, 2004).

This is relevant for the study since Asymmetric Price Transmission (APT) theory examines how price changes in one sector, such as energy, are passed on to another sector, transportation and manufacturing, in an unequal manner (Akidi et al, 2024). This phenomenon is crucial in understanding the dynamics between energy prices and trade, especially given the significant role energy costs play in the manufacturing and transportation through the maritime corridor. Asymmetric Price Transmission (APT) theory suggests that prices do not adjust equally to positive and negative changes. An increase in energy prices can lead to an immediate and significant rise in goods and services due to the immediate impact on production and transportation costs.

Methodology

The expost facto research design was employed for the study. The multiple linear regression was used to analyse the data of the study. Data for the study was sourced from the World Development Indicator and Federal Reserve Economic Data, Federal Reserve Bank of St. Louis, the data will be from 1990 to 2024. The dependent variable is economic growth and independent variables are maritime trade (proxy by Merchandise trade as a percentage of GDP) and energy price (Global price of Energy index). The model formulated for the study will be estimated with the error correction technique.

The model for the study follows that of Gidwani (2022) and Adenigbo et al. (2023) with some modifications. The functional form of the model is given as;

$$GDP = f(EPR_t, MT_t) \qquad \text{Eq-(1)}$$

This ECM emphasizes both short-term dynamics and long-term adjustments, making it an effective tool for analyzing economic growth (GDP) in the context of energy price and maritime trade.

The error correction model is given as mentioned equation 2.

$$\Delta GDP = \beta_0 + \beta_1 \Delta EPR + \beta_2 \Delta MT + \theta ECM(-1) + \varepsilon_1 \qquad \text{Eq-(2)}$$

Where; GDP is gross domestic product which is a proxy for economic growth, MT is maritime trade, EPR is energy price, β_0 is the estimate of true intercept of the dependent variables or regression constant; β_1 and β_2 are the estimate of parameters of independent variables or Regression Coefficient. Δ is the first difference operator. ε_1 is the error term. θ measures the speed of adjustment.

Results and Discussions

The descriptive characteristics of the data used in the research is presented in table 1. It can be observed that GDP have an average of 3.3 which indicated that it on average the Nigerian economy stood at 3.3 billion dollars. Energy price (EPR) have an average of 123.78 dollars, indicating that the price of energy in the study period was over a hundred dollar. Maritime trade (MT) accounted for about 28.90 percent to the GDP of Nigeria on average. All the variables are platykurtic as indicated by their kurtosis values. GDP and EPR are positively skewed showing that most of their observations lies above their mean values, while MT has negative skewness, showing that most of its observations lies below its mean value. All the variables are normally distributed based on their Jarque-Bera probability values which are clearly greater than 0.05 level of significance.

Table 1. Descriptive Statistics

	GDP	EPR	MT
Mean	3.3000000000000	123.7767	28.90400
Median	3.1000000000000	118.9821	30.70465
Skewness	0.141519	0.538353	-0.431232
Kurtosis	1.404488	2.255128	2.070820
Jarque-Bera	3.829245	2.499772	2.343864
Probability	0.147397	0.286537	0.309768
Observations	35	35	35

Source: Author's computation with E-views, 2025. Note: GDP- Gross Domestic Product, EPR-Energy Price, MT-Maritime Trade

Table 2. ADF Unit Root Test

Variables	ADF Statistics (Level)	t-critical values (5%)	P-value	ADF Statistics (First Diff.)	t-critical values (5%)	P-value	Conclusion
GDP	0.13513	-2.954021	0.9637	-3.002785	-2.954021	0.0450	I(1)
EPR	-1.916840	-2.951125	0.3209	-6.192148	-2.957110	0.0000	I(1)
MT	-2.447830	-2.951125	0.1369	-4.519292	-2.957110	0.0011	I(1)

Source: Author's computation with E-views, 2025

The Augmented Dickey-Fuller unit root test was employed for testing for unit root in the data used for the study. The result is presented in table 2, and the variables are stationary at first difference. We therefore proceed to conduct the longrun model estimate and the error correction model.

Table 3. Long-run estimates.

Dependent Variable: GDP				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
GDP(-1)	0.973240	0.015128	64.33534	0.0000
EPR	1.250000	31785771	3.947715	0.0004
MT	1.620000	1.670000	0.969826	0.3399
C	3.290000	6.060000	0.054272	0.9571
R-squared	0.997508	Mean dependent var		3.350000
Adjusted R-squared	0.997259	S.D. dependent var		1.490000
F-statistic	4003.547	Durbin-Watson stat		1.700702
Prob(F-statistic)	0.000000			

Source: Author's computation with E-views, 2025.

The longrun model estimates are presented in Table 3. The coefficient 0.973240 suggests that, holding other factors constant, a one percent rise in one period lag of GDP causes a 0.97 unit drop in current GDP. Energy price has a positive and significant effect on economic growth. Thus, a 1% rise in energy price would cause a 1.25 unit increase economic growth. Maritime trade positively affect economic growth, a one percent rise in the maritime trade will result in a 1.62 unit rise in economic growth. The R-squared of 0.903735 shows that the model is best fit, which indicates that the independent variables (GDP(-1), MT and EPR) explain 99 percent of the variation in economic growth. There is joint significance among the variables of the study indicated by F-statistic probability value of 0.000000. The Durbin-Watson statistic 1.7 indicates that there is no evidence of autocorrelation in the residuals.

Table 4. Error correction model

Dependent Variable: GDP				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(GDP(-1))	1.083083	0.184634	5.866094	0.0000
D(EPR)	92245454	32665466	2.823944	0.0086
D(MT)	43144003	1.890000	0.228240	0.8211
ECM(-1)	-0.923269	0.267091	-3.456756	0.0018
C	-9.650000	2.620000	-0.368972	0.7149
R-squared	0.573966	Mean dependent var		1.250000
Adjusted R-squared	0.513104	S.D. dependent var		1.060000
F-statistic	9.430604	Durbin-Watson stat		2.097696
Prob(F-statistic)	0.000059			

Source: Author's computation with E-views, 2025. ECM- Error Correction Term

Table 4 showed the estimates of the error correction model. The coefficient of 1.08 suggests that a one percent rise in one period lag GDP value causes a 1.1 unit increase in current GDP in the shortrun. Also, in the shortrun, energy price has a positive and significant effect on economic growth. This indicates that a 92245454 unit increase in economic growth would result from a one percent rise in energy price. In the shortrun, maritime trade has a positive effect on economic growth; a one percent rise in maritime trade in the economy will result in a 43144003 percent rise in economic growth. Being negative and statistically significant, the error correction term -9.65 aligns with econometric theory. This suggests the rate of return to equilibrium. Hence, about 9.6 percent of the disequilibrium in economic growth is corrected in the next period. There is a strong adjustment mechanism ensuring economic growth returns to its long-term equilibrium after short-term shocks. The R-squared of 0.573966 suggests that 57 percent of the variation in economic growth is explained by the independent variables (EPR, MT and the ECT) which is indicative of a good fit for the model. The F-statistic probability value shows the model is highly significant. The Durbin-Watson statistic 2.09 showed no evidence of serial-correlation in the residuals.

Table 5. Pairwise Granger Causality test

Null Hypothesis:	Obs	F-Statistic	Prob.
EPR does not Granger Cause GDP	34	15.8052	0.0004
GDP does not Granger Cause EPR		2.51735	0.1227
MT does not Granger Cause GDP	34	8.99322	0.0053
GDP does not Granger Cause MT		0.08853	0.7680
MT does not Granger Cause EPR	34	0.00093	0.9758
EPR does not Granger Cause MT		0.10747	0.7452

Source: Author's computation with E-views, 2025

The Pairwise Granger Causality test result presented in table 5, shows that energy price and maritime trade granger causes economic growth. Although, economic growth does not granger causes any of them. There is also no granger causal relationship between energy price and maritime trade.

Diagnostic tests

The variance inflation factor is used to test for multicollinearity, the result showed that the model estimated for the study is free from multicollinearity as the centered VIF is less than 10.

Table 6. Variance Inflation Factor (VIF)

Variable	Coefficient Variance	Uncentered VIF	Centered VIF
GDP(-1)	0.000229	15.97147	2.660158
EPR	1.010000	11.74046	2.809849
MT	2.800000	14.31413	1.423639
C	3.670000	20.50339	NA

Source: Author's computation with E-views, 2025

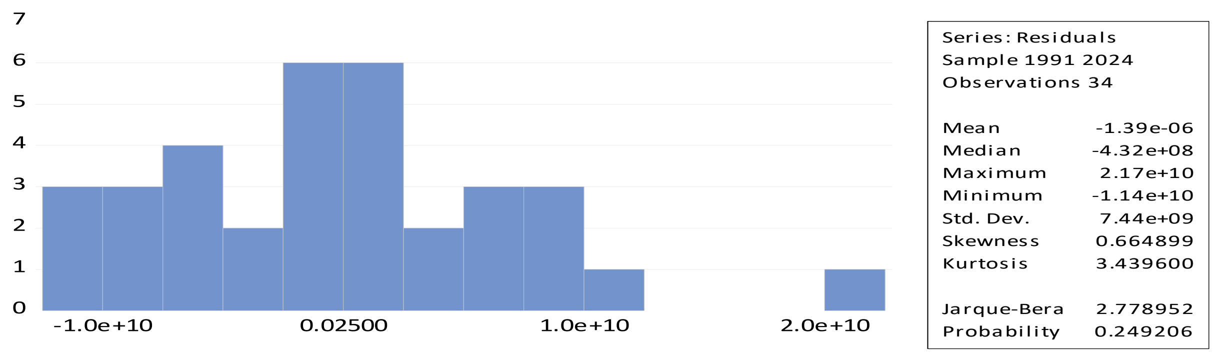

Figure 3. Normality test

Source: Author's computation with E-views, 2025

The normality test is conducted with the Jarque-Bera statistic. The result is presented in figure 3. The probability value 0.249206 shows that the residuals of the model are normally distributed.

Table 7. Breusch-Godfrey Serial Correlation LM Test

Null hypothesis: No serial correlation at up to 1 lag			
F-statistic	0.528010	Prob. F(1,29)	0.4733
Obs*R-squared	0.607976	Prob. Chi-Square(1)	0.4356

Source: Author's computation with E-views, 2025

Table 8. Heteroskedasticity Test: Breusch-Pagan-Godfrey

Null hypothesis: Homoskedasticity			
F-statistic	0.046635	Prob. F(3,30)	0.9864
Obs*R-squared	0.157824	Prob. Chi-Square(3)	0.9841
Scaled explained SS	0.149881	Prob. Chi-Square(3)	0.9852

Source: Author's computation with E-views, 2025

The estimated model is free from serial correlation and heteroskedasticity based on their test results presented in table 7 and table 8 respectively which are greater than 0.05.

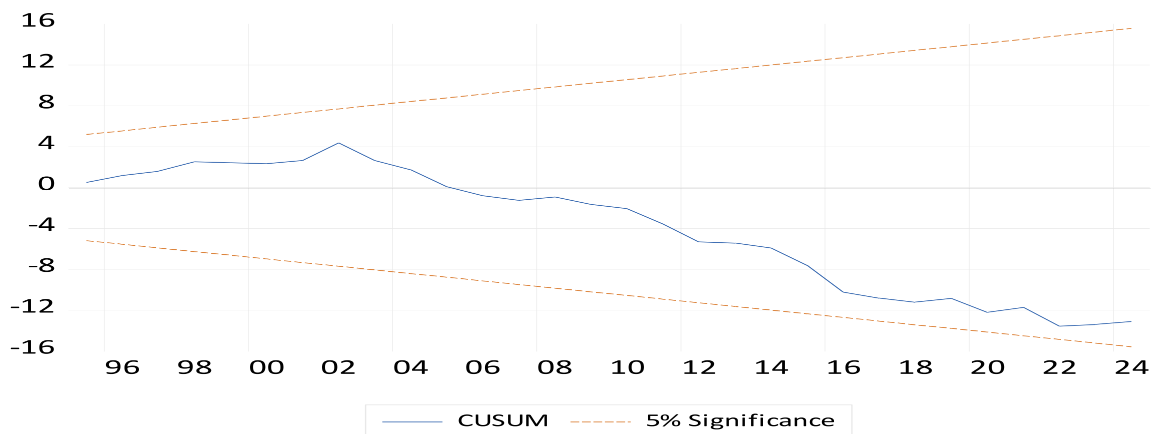

Figure 4. CUSUM

Source: Author's computation with E-views, 2025

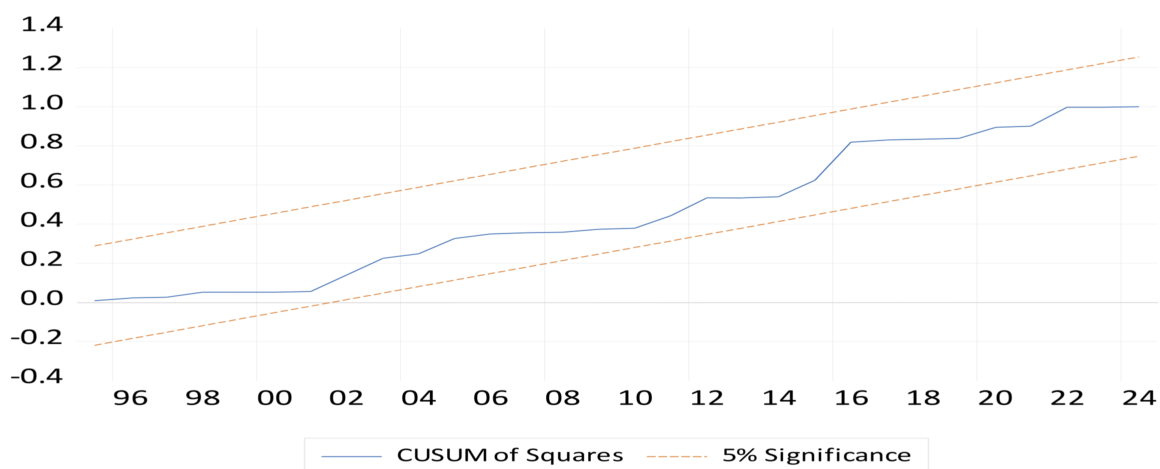

Figure 5. CUSUMQ

Source: Author's computation with E-views, 2025

The stability tests conducted for the model is presented in figure 4 and figure 5. Both the CUSUM and the CUSUM of Squares test shows that the model is stable and can be relied on to make policies on energy price, maritime trade and economic growth in Nigeria.

Conclusions

The study examined the relationship between energy prices, maritime trade, and economic growth in Nigeria, analyzing both long-run and short-run dynamics. The results revealed that energy prices have a positive and significant impact on economic growth in both the long run and short run, suggesting that energy, despite its cost plays a crucial role in sustaining and stimulating economic activity. Similarly, maritime trade positively influences economic growth both in the long run and short run, underscoring the strategic importance of maritime trade to the economy. The error correction mechanism indicates the resilience of economic growth in realigning with its long-term equilibrium. Based on the findings therefore, the study opined that the positive and significant effect of energy prices in driving economic growth, indicates that policymakers should prioritize investment in energy infrastructure to ensure stable and affordable energy supply. Emphasis should be placed on diversifying energy sources and enhancing efficiency in energy distribution. The long-run and short run positive effect of maritime trade on economic growth suggests that improving port infrastructure, streamlining port operations, and enhancing maritime logistics can boost economic performance. Strategic development of seaport facilities and trade corridors should be considered a national economic priority.

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Consent for publication: N/A

Data availability: Data used in the study will be provided by corresponding author upon request

Authors contribution: Porwekobowei Aruwei and Dubem Victor Enaruna both contributed to the conceptualization, data collection and analysis of the study. Specifically, Porwekobowei Aruwei provided support in data analysis, interpretation and contributed to the manuscript's critical revision. All authors reviewed and approved the final manuscript.

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RESEARCH ARTICLE

The Synergistic Impact of Green Finance and ESG Concepts on Rural New-Quality Productivity

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Abstract

The development of rural new-quality productivity is crucial for achieving high-quality rural economic growth and overcoming developmental challenges. This study examines the impact of green finance and ESG (Environmental, Social, and Governance) principles on the development of rural new-quality productivity. Utilizing multiple regression analysis on data from 11 prefecture-level cities in Zhejiang Province, the study finds that: (1) The development of green finance and ESG concepts both have a positive effect on the development of rural new-quality productivity. The impact of green finance is more pronounced in regions dominated by the secondary industry, while the development of ESG concepts has a better effect in areas dominated by the primary and tertiary industries. (2) The influence of ESG concepts on rural new-quality productivity is affected by regional economic levels, with more significant effects observed in economically developed regions. (3) There is a positive and additive synergistic effect between the development of green finance and ESG concepts on rural new-quality productivity, which is more pronounced in resource-based cities. Based on these findings, the paper proposes policy recommendations to provide references and insights for the development of rural revitalization in contemporary times.

Keywords: green finance; ESG; new-quality productivity; rural revitalization; multiple linear regression model

Introduction

As the Rural Revitalization Strategy advances, the expansion of rural industries and the sustainability of rural ecosystems are increasingly constrained by multifaceted challenges, including resource scarcity, environmental degradation, and inadequate financial resources. Consequently, high-quality rural development has emerged as a crucial issue in China's economic development. To achieve this goal, rural areas urgently need to identify new growth drivers and sources of impetus. New-quality productivity, a form of productivity driven by innovation and catalyzed by the modern technological revolution, is well-suited to meet this demand and can provide strong support for the transformation and upgrading of the rural economy. In January 2025, the Central Committee of the Communist Party of China and the State Council issued the Comprehensive Rural Revitalization Plan (2024–2027), which explicitly emphasized that to realize high-quality development, new-quality productivity must be regarded as the core driving force. It is imperative to firmly grasp new-quality productivity to continuously advance the substantial progress of Chinese-style modernization.

Green finance, as a financial model dedicated to environmental friendliness and sustainable development, has gradually been recognized as a key pathway to promoting the transformation and high-quality development of the rural economy (Shi Daimin and Shi Xiaoyan, 2022). By linking economic development with ecological protection, green finance promotes the efficient use of resources and sustainable economic growth. Green finance policies provide a favorable financing environment, significantly enhancing firms' levels of green innovation (Lietal, 2018), and exert pressure on firms to adopt green emission-reduction measures (Fanetal, 2021), thereby facilitating green transformation and achieving a dual improvement in economic and environmental benefits. According to Wen Tao and He Qian (2023), the core of green finance lies in directing capital towards projects that are conducive to environmental protection. In practice, the social impact and governance structure of projects are equally important. The integration of green finance and the ESG (Environmental, Social, and Governance) philosophy is essential. Green finance provides necessary financial support for rural projects, promoting novel practices such as renewable energy and smart agriculture. Meanwhile, the ESG evaluation and supervision mechanism encourages firms to focus more on environmental protection, social responsibility, and governance improvement. This not only aligns firms with the trend of sustainable social development but also opens up effective pathways for reducing financing costs and enhancing operational efficiency (Qiu Muyuan, 2019). It more effectively directs capital towards projects that meet sustainable development goals, thereby jointly promoting the innovation and sustainability of rural development.

In recent years, scholars have begun to pay attention to the integration of green finance and ESG.Chen Guojin , Ding Saijie , Zhao Xiangqin, et al. (2021) first incorporated green finance policies and green transformation into the asset pricing model of sustainable investment (ESG) to analyze the theoretical mechanism through which green finance policies function. Cao Qun and Xu Qian (2019) suggested constructing a financial ESG system that emphasizes the internal implementation of ESG principles by financial institutions and focuses on the ESG factors of real economy clients to promote the development of ESG in China. However, due to the relatively recent emergence of the concept of new-quality productivity, there is currently a lack of literature on the role of the integration of green finance and ESG in promoting new-quality productivity in rural areas.

To fill this research gap, this study aims to integrate green finance policies, the ESG philosophy, and new-quality productivity in rural areas. Using panel data from the 11 prefecture-level cities in Zhejiang Province, this study seeks to: (1) analyze the mechanism through which green finance promotes the development of new-quality productivity in rural areas and investigate the impact of regional industrial structure on the development of new-quality productivity in rural areas; (2) conduct a multidimensional quantitative evaluation of corporate social responsibility fulfillment in China, comprehensively examine the regional economic development imbalances among different prefecture-level cities in Zhejiang Province, and analyze the impact of ESG development on the development of new-quality productivity in rural areas; and (3) construct a multiple linear regression model to explore the different effects of green finance and the ESG philosophy on the development of new-quality productivity in rural areas, influenced by regional economic development levels, regional industrial structures, and regional resource dependency. Based on the research findings, innovative approaches to developing new-quality productivity in rural areas will be proposed to enhance rural productivity levels and provide a basis for prioritizing, regionalizing, and multi-staged advancement of rural revitalization. The research structure of this article is shown in the Figure 1.

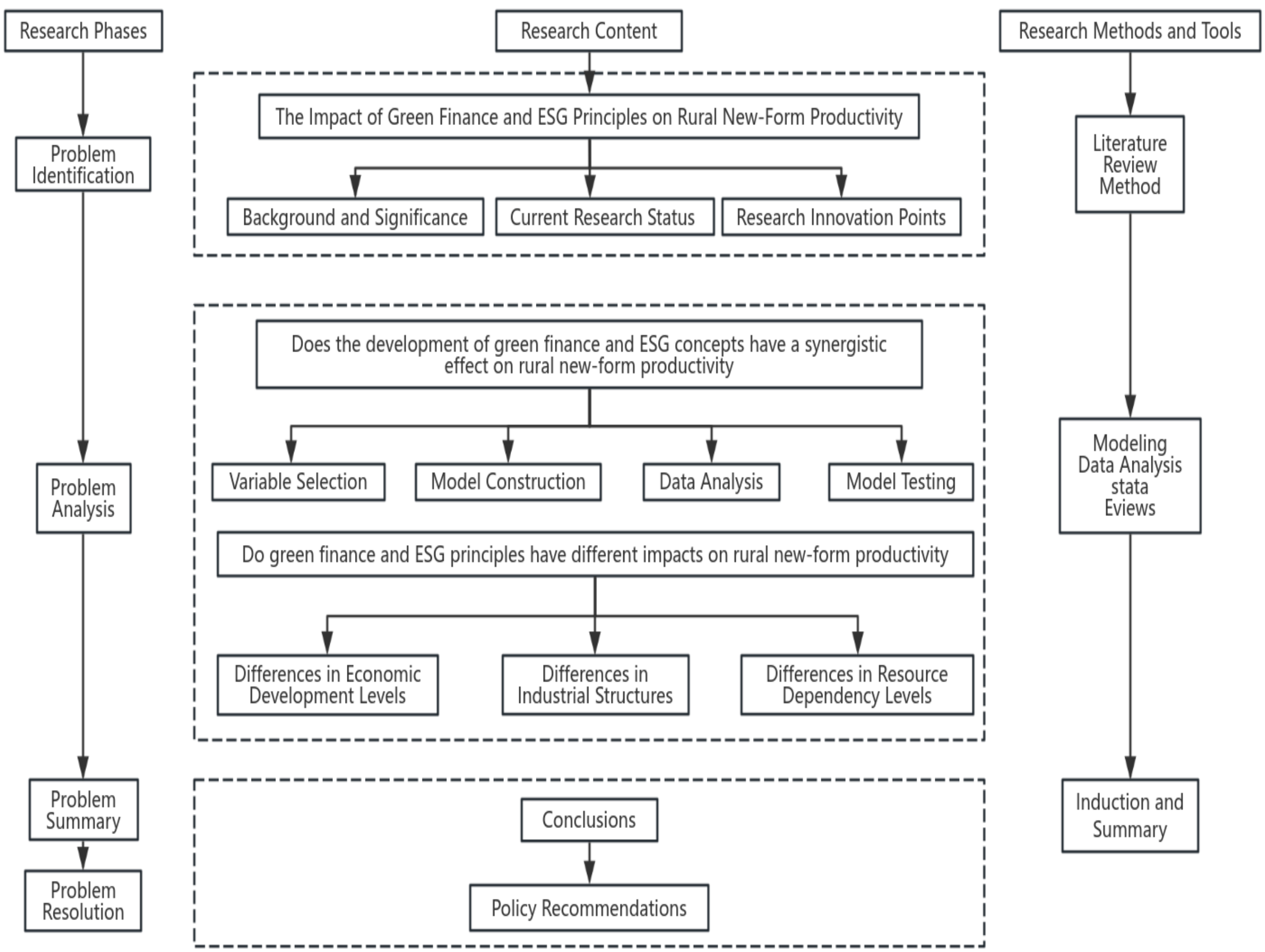

Figure 1. Structure Diagram of the Article

Literature Review

The Definition and Characteristics of New-Quality Productivity

In September 2023, General Secretary Xi Jinping first proposed the concept of new-quality productive forces during his inspection in Heilongjiang. New - quality productive forces are a form of advanced productive forces in which innovation plays a leading role. They break away from the traditional economic growth mode and the development path of productive forces, feature high -technology, high-efficiency, and high-quality, and are in line with the new development philosophy (Xinhua News Agency, 2024). As shown in the Figure 2, new-quality productive forces not only emphasize technological innovation and efficient resource utilization, but also attach great importance to the protection of the ecological environment and sustainability, fully reflecting the emphasis on environmental and social responsibilities in the process of economic development. Essentially, they are green productive forces (Zhou Hongchun, 2024).

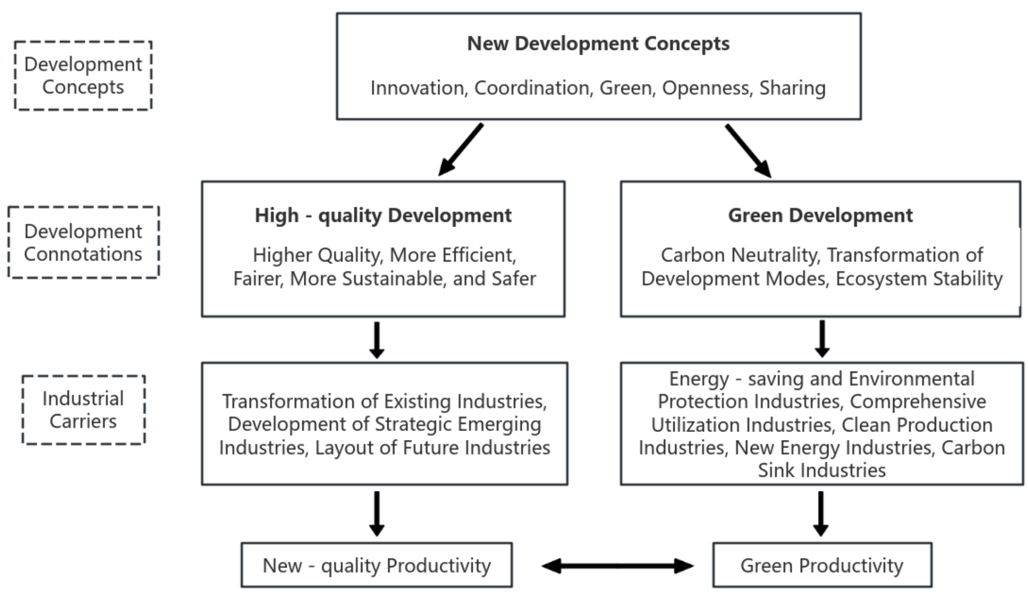

Figure 2. The Connotation, Characteristics and Industrial Carriers of “New-Form Productivity Being Green Productivity”

New-form productivity represents a leap from traditional productivity. Most traditional productivity theories are based on the material production paradigm of industrial society, emphasizing the decisive role of capital, labor, and other traditional factors in economic operation (Yan Qiang, Xu Guonan, Yi Lanli, 2025). In the new development phase, the traditional economic growth model no longer fits the development trend of the times. The in-depth development of a new round of technological revolution and industrial transformation provides a historical opportunity to promote the transformation and upgrading of China's industries and the development of new-form productivity, offering a new path for the qualitative change of traditional productivity (Ren BaoPing, Dou Yuanbo, 2024). New-form productivity, dominated by scientific and technological innovation and achieving breakthroughs in key disruptive technologies, is a qualitative leap from traditional productivity (Zhou Wen, Xu Lingyun, 2023).

It represents a qualitative enhancement in the composition of productive forces. It is not a simple continuation of traditional productivity but a comprehensive innovation and upgrading of core elements such as workers, means of production, and objects of labor through scientific and technological innovation and technological breakthroughs. Pu Qingping and Xiang Wang (2023) believe that new-form productivity mainly includes "high-quality" workers, "new medium" means of production, and "new material" objects of labor, representing an advanced form of productivity. Among them, "high-quality" workers are a new type of talent distinct from traditional workers and technical workers, mastering digital technology and adapting to digital intelligent equipment (Shi Jianxun, Xu Ling, 2024). "New medium" means of production focus on advanced machinery and equipment using high technology, significantly improving production efficiency and quality. The "new material" objects of labor include both material objects and non-material objects such as computing power and data (Zhou Wen, Xu Lingyun, 2023).

New-form productivity is the combination of "new" and "quality" in productive forces. It is not only about being "new" but even more about "quality." Zhang Hui and Tang Qi (2024) believe that the "new" in new-form productivity mainly reflects new production factors and new ways of factor combination, while "quality" is manifested as a high-quality industrial base and development momentum. Jiang Yongmu and Qiao Zhangyuan (2024) believe that the "new" in new-form productivity mainly reflects new factors, new technologies, and new industries, with its "quality" manifested in high quality, multiplicity, and dual efficiency, and its "force" represented by five major productive forces: digital, collaborative, green, blue, and open.

From the perspective of the development of the industry field of new-form productivity, the academic community has extensively covered multiple dimensions including agriculture, publishing, manufacturing, sports, tourism, and cultural tourism industries, with particularly outstanding research results in the agricultural field (Wang Shengxia, Li Maolan). Huang Jiqun (2024) believes that agricultural new-form productivity, as an important part of new-form productivity, not only has the common characteristics of new-form productivity but also, due to the particularity of the agricultural sector, exhibits unique attributes of high publicness, technologicalization, digitalization, and industrialization. Its essence is the deep integration of "new" and "quality" in the agricultural context, highlighting the concepts of innovation, coordination, green development, openness, and sharing. As shown in the Figure 3. Mechanism Diagram of Rural New-Form Productivity, rural new-form productivity is driven by new technological revolutionary breakthroughs, innovative allocation of all factors, and deep transformation and upgrading of industries, supported by a mutually promoting cycle system of education-talent-technology, and characterized by disruptive agricultural technological innovation, high-quality agricultural workers, breaking through the boundaries of agricultural development, penetration and symbiosis of multiple factors, and digitalization and green transformation, ultimately anchoring the goal of an "agricultural powerhouse," becoming a key force in promoting high-quality agricultural development, reshaping the agricultural productivity pattern, and helping agriculture complete a qualitative leap in the new era and move towards a path of sustainable development.

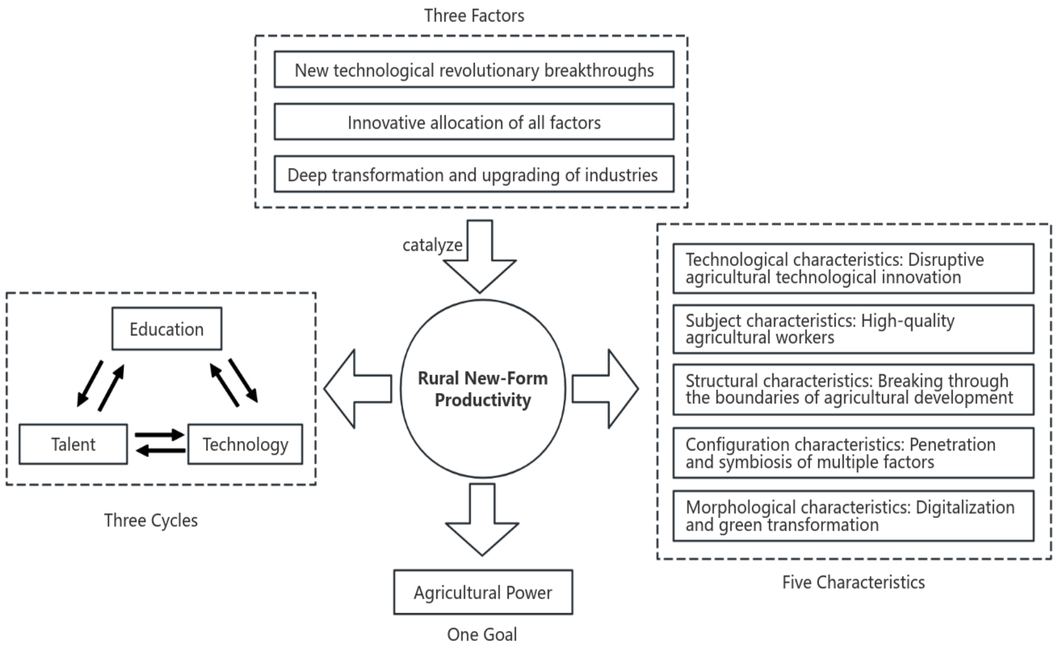

Figure 3. Mechanism Diagram of Rural New-Form Productivity

The Impact of Green Finance on Rural New-Quality Productivity

Green finance, also known as Environmental Finance or Sustainable Finance, is at the core of environmental protection, leading to comprehensive changes in the business philosophy, operational processes, and management policies of the financial industry, with the aim of achieving sustainable development (Li Xiaoxi et al., 2015). Salazar (1998) posits that green finance serves as a bridge between the environment and finance, improving capital allocation mechanisms to steer capital towards green and environmentally friendly industries. Cowan (1999) views green finance as an interdisciplinary field that combines green economics and finance, focusing on the coordinated advancement of economic growth and environmental protection. Scholtens (2006) suggests that the use of green financial instruments can resolve the contradictions between resources and the environment, thereby achieving sustainable development.

As an innovative financial model linking economic development and ecological environmental protection, green finance plays a crucial role in promoting enterprise innovation and industrial green transformation. Wen Shuyang and Liu Hao et al. (2022) constructed an economic growth model that integrates environmental constraints and the financial sector, demonstrating that green finance plays a key role in driving green innovation and promoting high-quality economic development. Li et al. (2018) found that green financial policies can significantly enhance the green innovation level of enterprises by providing a favorable financing environment for green enterprises. Additionally, the implementation of green financial policies exerts pressure on enterprises to adopt green emission reduction measures (Fan et al., 2021), promoting enterprise green transformation and achieving dual benefits of economic and environmental efficiency (Wang Yao et al., 2019). Green finance focuses on environmental objectives, aiming to coordinate financial activities with environmental and ecological considerations to achieve sustainable economic and social development. Its development can further optimize the rural financial service system and enhance financial support for agriculture, rural areas, and farmers (Ma Jun et al., 2021). Moreover, green finance can influence the investment and financing behavior of heavily polluting enterprises through green credit and green bonds, providing financial support for the development of rural new quality productivity on the basis of achieving green development (Su Dongwei and Lian Lili, 2018).

In recent years, green finance has effectively promoted rural economic development through multi-channel and multi-advantage comprehensive effects. On one hand, green finance has reduced the financing costs of rural enterprises and farmers through innovative green credit and green bonds, guiding capital towards eco-friendly green projects such as ecological agriculture and clean energy, promoting the green transformation of rural production and lifestyle, and further guiding enterprise green innovation (Wang Xin and Wang Ying, 2021). On the other hand, green finance also focuses on strengthening policy coordination and risk assessment to ensure the quality and sustainability of capital allocation, effectively preventing financial risks and ensuring the stable development of the rural economy. Green finance not only improves the efficiency of capital use, reduces the misallocation and waste of financial resources, but also promotes environmental protection and ecological restoration in rural areas, enhancing the ecological environment quality of rural areas. At the same time, it helps to optimize the rural economic structure, promote rural industrial upgrading, and improve the development level of rural new quality productivity. In addition, green finance also broadens the coverage of financial services, improves the accessibility and convenience of financial services, narrows the urban-rural development gap, and promotes balanced urban-rural development. Based on the above analysis, the following hypotheses are proposed:

H1a: The development of green finance has a significant promoting effect on the development of rural new quality productivity.

H1b: The impact of green finance on the development level of rural new quality productivity is influenced by regional industrial structure.

The Impact of ESG Concepts on Rural New Quality Productivity

ESG stands for Environment, Social, and Governance, marking a shift in corporate evaluation criteria from a single financial performance dimension to a comprehensive consideration of environmental sustainability, social responsibility, and corporate governance (Yuan Rongli, 2022). Current systematic research on the ESG system mainly focuses on the relationship between corporate social responsibility and financial performance and ESG information disclosure. Lu Zhengwei and Fang Qi (2018), Clark et al. (2015) have shown that corporate social responsibility helps to improve financial performance, while Dimson et al. (2015), Chen et al. (2014) found that corporate investment in ESG does not increase financial costs but can reduce total financial costs. Mervelskemper and Streit (2017) demonstrated that ESG information disclosure helps to improve and enhance corporate social responsibility performance; Devilliers and Vanstadan (2011) further found that enterprises facing greater environmental risks or with poor environmental reputations are more inclined to disclose ESG information. In rural areas, the introduction of ESG concepts helps to enhance the sustainable development capabilities of rural enterprises. Research indicates that through ESG evaluation and supervision mechanisms, enterprises can be encouraged to pay more attention to environmental protection, social responsibility, and the improvement of governance structures, which not only promotes enterprises to adapt to the trend of social sustainable development but also opens up effective ways for enterprises to reduce financing costs and improve operational efficiency (Qiu Muyuan, 2019).

The dissemination and in-depth development of ESG concepts have multiple positive effects on the development of rural new quality productivity. Firstly, from an environmental perspective, ESG concepts focus on environmental protection and the rational use of resources, which aligns with the original intention of new quality productivity, emphasizing green development. In the process of rural economic development, ESG concepts require producers to reduce environmental pollution during production, protect rural ecological resources, actively seek new ways for industrial green transformation, guide industrial green transformation, encourage enterprise green innovation, and achieve dual benefits of economy and environment. Secondly, in terms of social aspects, ESG concepts focus on farmers' income growth, social employment opportunities, and social equity issues, which are closely related to the labor dimension emphasized by the development level of rural new quality productivity. Both pursue high-quality development, and the development of ESG concepts guides social and economic behavior. Under the guidance of this concept, enterprises invest more funds in projects that support and enrich farmers, providing financial support for the diversified development of the rural economy and effectively enhancing the rural economy's risk resistance. At the same time, ESG concepts also emphasize the social responsibilities that enterprises should bear, including protecting farmers' rights and interests and providing fair employment opportunities, which helps to build harmonious rural social relations and lays a social foundation for the sustainable development of the rural economy. Finally, in terms of governance, ESG concepts emphasize the responsibility and transparency of enterprises, which align with the modern governance system emphasized by rural new quality productivity. In rural economic development, ESG concepts require enterprises to establish and improve governance structures, strengthen internal control and risk management, and improve the transparency of information disclosure. These requirements can effectively help enterprises enhance their social image and reputation, and enhance the trust and support of investors and consumers. At the same time, ESG concepts also encourage enterprises to actively participate in rural social welfare undertakings, such as the construction of rural education, healthcare, and culture, contributing to the comprehensive development of rural society. Through these measures, the governance system and governance capacity of the rural economy can be modernized, providing strong support for the sustainable development of the rural economy. Based on the above analysis, the following hypotheses are proposed:

H2a: The development of ESG concepts has a significant promoting effect on the development of rural new quality productivity.

H2b: The impact of ESG concept development on the development level of rural new quality productivity is influenced by regional economic development levels.

The Synergistic Effect of Green Finance and ESG Concepts

With the in-depth understanding of the concept of sustainable development, green finance and ESG concepts have gradually become important tools for promoting economic transformation. In recent years, scholars have begun to focus on the integration of green finance and ESG. Chen Guojin, Ding Saijie, and Zhao Xiangqin et al. (2021) first incorporated green financial policies and green transformation into the sustainable investment (ESG) asset pricing model, analyzing the theoretical mechanism of the role of green financial policies. Cao Qun and Xu Qian (2019) suggested constructing a financial ESG system that focuses on the implementation of ESG concepts within financial institutions and pays attention to the ESG factors of real economy clients to promote the development of ESG in China.

Green finance provides funding for rural green industries and sustainable development projects through innovative products such as green credit and green bonds, promoting the development of ecological agriculture, clean energy, etc., and facilitating the green transformation of rural economies. It reduces financing costs, guides funds to environmental protection projects, and improves the efficiency of fund use. Meanwhile, it strengthens risk assessment to ensure economic stability. Green finance not only supports rural ecological protection but also promotes industrial upgrading and narrows the urban-rural gap, serving as a powerful tool for achieving the development of new-quality productivity and sustainable development in rural areas.The ESG (Environmental, Social, and Governance) concept promotes rural revitalization by advocating corporate responsibility in environmental protection, social affairs, and governance. It directs funds to environmental protection and social responsibility projects, enhances the quality of the rural ecological environment, pays attention to the interests of farmers and low-income groups, and strengthens the sustainability and social inclusiveness of the rural economy. ESG not only enhances the social influence of enterprises but also injects long-term development momentum into the development of new-quality productivity in rural areas.

The two approaches have different focuses: green finance focuses on financial services, while the ESG concept focuses on corporate social responsibility construction, complementing each other. To sum up, green finance and the ESG concept in Zhejiang Province have a synergistic effect, serving as important means to achieve the development of new-quality productivity in rural areas and important supports for realizing rural revitalization. Based on the above analysis, the following hypotheses are proposed.

H3a: The development of green finance and the ESG concept has a synergistic effect, jointly promoting the development of new-quality productivity in rural areas.
H3b: The degree of regional resource dependence will affect the effect of green finance and the ESG concept on the development level of new-quality productivity in rural areas.

Methodology

Data and Variable

To thoroughly analyze the combined impact of green finance and ESG (Environmental, Social, and Governance) concepts on the development of new-quality rural productivity, this study utilizes panel data from 11 prefecture-level cities in Zhejiang Province spanning from 2000 to 2022. The data on green finance are sourced from the China Financial Yearbook, while other data are primarily obtained from the Guotai Security Database, the National Bureau of Statistics, the Zhejiang Provincial Bureau of Statistics, the China Rural Statistics Yearbook, the China Urban and Rural Construction Statistics Yearbook, and the People's Bank of China. To ensure data integrity, missing values were filled using interpolation methods, and stationarity and heteroscedasticity tests were conducted to enhance the reliability of model estimation. This study constructs a detailed variable system, including one core explanatory variable, two explained variables, and five control variables.

Dependent Variable

Although numerous studies have explored how to measure the development level of new-quality rural productivity (NPF), a unified measurement standard has not yet been established in academia due to different research purposes. Based on data availability and comprehensive representativeness, this study constructs a scientific and comprehensive rural new-quality productivity development system with four first-level indicators and 12 second-level indicators, as detailed in Table 1. Explanatory variables are given in table 2.
Green Finance Index (GFI): This is one of the core explanatory variables in this study, representing the comprehensive index of green finance development in various regions. Drawing on the research methodology of Liu Huakai and He Chun (2024), this study employs a multi-dimensional evaluation system consisting of seven indicators: green credit, green bonds, green investment, green equity, green insurance, green support, and green funds, and calculates it using the entropy method. The specific indicators include the proportion of investment in environmental pollution control, the proportion of credit for environmental protection projects, the coverage rate of environmental liability insurance, the number of green bonds issued, and the market share of green funds, etc.
Corporate Social Responsibility (CSR): This is another core explanatory variable, representing the comprehensive index of corporate social responsibility in various regions. CSR refers to the responsibilities that enterprises should bear for the environment, society, and governance while pursuing economic benefits. The CSR

index is commonly used to measure the performance and impact of enterprises in terms of social responsibility.

Table 1. Rural New-Quality Productivity Development System

First-level Indicators	Second-level Indicators	Meaning of Second-level Indicators
Laborers	Employment Structure of Laborers	Tertiary industry employment / Total employment
	Laborer Income	Per capita net income of farmers
	Laborer Output	Per capita GDP
	Laborer Quality	Average years of education for rural residents
Objects of Labor	Green Invention Achievements	Annual number of green patent authorizations
	Green Resources	Rural greening rate
	Pollution Control Quality	SO_2 emissions / GDP
Means of Labor	Digital Infrastructure	Proportion of administrative villages with internet broadband access
	Traditional Infrastructure	Per capita road area
	Energy Utilization Potential	Comprehensive utilization rate of livestock and poultry manure
Organization of Production	Level of Intelligence	Number of e-commerce enterprises
	Level of Greening	Investment in industrial pollution control

Table 2. Secondary Indicators of Green Finance and Corporate Social Responsibility (CSR)

Primary Indicator	Secondary Indicator	Definition of Secondary Indicator
Green Finance (GFI)	Green Credit	Total scale of green credit
	Green Bonds	Total amount of green bonds issued
	Green Investment	Total amount of green investment issued
	Green Equity	Depth of development of green equity
	Green Insurance	Balance of green insurance investment
	Green support	Environmental Protection Expenditure Ratio
	Green Fund	Market share of green funds
Corporate Social Responsibility (CSR)	Environmental Responsibility	Fund issuance by enterprises in environmental protection
	Corporate Governance	Fund issuance by enterprises in corporate governance
	Social Responsibility	Fund issuance by enterprises in social responsibility
	ESG Strategy Fund Inflow Scale	Net inflow of enterprise ESG strategy funds

Control Variables

In addition to green finance and CSR, other factors such as rural economic development (RED), rural greening awareness (RGA), government intervention (GOV), education level (EDU), and infrastructure construction (INF) also influence the development of new-quality rural productivity to a certain extent. These variables affect the development speed and effectiveness of new-quality rural productivity by influencing regional economic development levels and residents' quality of life. Specific details are presented in Table 3.

Table 3. Variable Selection

Variable Type	Statistical Variable	Symbol	Formula for Measurement
Explained Variables	Development Level of New-Quality Rural Productivity	npf	Natural logarithm of 12 second-level indicators
Explanatory Variables	Green Finance Index	gfi	Natural logarithm of the green finance index
	Corporate Social Responsibility	csr	Corporate social responsibility index
Control Variables	Rural Economic Development Level	red	Per capita net income of farmers
	Rural Greening Awareness	rga	Rural greening rate
	Government Intervention Degree	gov	Fiscal regulatory expenditure
	Education Level	edu	Proportion of rural primary and secondary school teachers with a bachelor's degree or above
	Infrastructure Construction	inf	Proportion of villages with hardened roads

Model Construction

Based on the research purpose of examining the impact of green finance and ESG concepts on the development of new-quality rural productivity, the following multiple linear regression models are constructed:

$$npf = \beta_0 + \beta_1 gfi + \beta_3 red + \beta_4 rga + \beta_5 gov + \beta_6 edu + \beta_7 inf + \varepsilon \quad (1)$$

$$npf = \beta_0 + \beta_2 csr + \beta_3 red + \beta_4 rga + \beta_5 gov + \beta_6 edu + \beta_7 inf + \varepsilon \quad (2)$$

$$npf = \beta_0 + \beta_1 gfi + \beta_2 csr + \beta_3 red + \beta_4 rga + \beta_5 gov + \beta_6 edu + \beta_7 inf + \varepsilon \quad (3)$$

Note: Model (1) examines the impact of green finance on the development level of new-quality rural productivity; Model (2) examines the impact of ESG concepts on the development level of new-quality rural productivity;

Model (3) examines the combined impact of green finance and ESG concepts on the development level of new-quality rural productivity.

In these models, β0 represents the constant term, β1 to β7 represent the regression coefficients corresponding to each variable, npf represents the development level index of new-quality rural productivity, gfi and csr represent the green finance index and corporate social responsibility index, respectively, red, rga, gov, edu, and inf represent the control variables, and ε represents the error term. To reduce heteroscedasticity and avoid the influence of large differences in variable units on regression coefficients, the development level index of new-quality rural productivity, green finance, corporate social responsibility, rural economic development level, rural greening awareness, government intervention degree, education level, and infrastructure construction are all unit-transformed.

Descriptive statistics

Using StataMP18 software for statistical analysis of variables, the descriptive statistics of each variable are listed, including the mean, standard deviation, minimum, and maximum values, to gain a general understanding of the distribution of the variables.

Table 4. Descriptive Statistics for Key Variables

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
npf	253	0.340	0.075	0.201	0.501
gfi	253	0.341	0.076	0.204	0.493
csr	253	0.286	0.132	0.080	0.509
red	253	31.448	2.056	26.822	35.342
rga	253	8.538	2.159	4.331	13.949
gov	253	3.044	2.733	0.354	14.687
edu	253	15.199	3.419	8.340	24.032
inf	253	15.305	3.545	8.580	23.347
gep	253	0.025	0.009	0.007	0.057
gef	253	4.292	1.946	0.974	9.474

As shown in Table 4, the mean value of the development level index of new-quality rural productivity (npf) is 0.340, with a maximum value of 0.501 and a minimum value of 0.201, indicating that the overall development level of new-quality rural productivity in Zhejiang Province is relatively high, but there are certain differences. The mean value of the green finance index (gfi) is 0.341, with a maximum value of 0.493 and a minimum value of 0.204, and a standard deviation of 0.042, indicating that the development level of green finance in the sample is relatively concentrated and has a small fluctuation. The standard deviation of the corporate social responsibility index (csr) is also less than the mean value, indicating that the sample concentration of each variable is good. The distribution of other indicators is also within a reasonable range.

Dependence analysis

Dependence analysis is primarily used to examine the interrelationships among variables. This study employs the Pearson correlation coefficient to measure these relationships. A higher correlation coefficient indicates a stronger relationship between variables, laying the foundation for further analysis. The results show that the development level index of new-quality rural productivity (npf) exhibits a positive correlation with green finance (gfi) and corporate social responsibility (csr), and the correlation is relatively high. Green finance (gfi) and corporate social responsibility (csr) also show a positive correlation with rural economic development (red), rural greening awareness (rga), government intervention (gov), education level (edu), and infrastructure construction (inf). This suggests that during the development of green finance and ESG concepts, factors such as rural economic development (red), rural greening awareness (rga), government intervention (gov), education level (edu), and infrastructure construction (inf) play a significant role in promoting the development of new-quality rural productivity. The VIF (Variance Inflation Factor) test results indicate that VIF < 5, confirming that there is no multicollinearity issue in the model, and the model construction is sound.

Results and Discussion

Benchmark Regression

The results in Table 5 show that green finance has a significant positive impact on the development level of new-quality rural productivity, with a regression coefficient of 0.152 (significant at the 1% level), confirming Hypothesis H1a. The corporate social responsibility index also has a significant positive impact on the development level of new-quality rural productivity, with a regression coefficient of 0.050 (significant at the 1% level), confirming Hypothesis H2a. In the combined model (3), both green finance and corporate social responsibility have a significant positive impact on the development level of new-quality rural productivity, confirming Hypothesis H3a. Regarding the control variables, the regression coefficient of rural economic development (red) is -0.004 and is significant in all models, indicating a negative impact on the development level of new-quality rural productivity. This negative correlation also suggests that high-quality economic development has a significant positive impact on the development level of new-quality rural productivity. The regression coefficients of rural greening awareness (rga), government intervention (gov), education level (edu), and infrastructure construction (inf) are all positive and significant, indicating that these factors play a positive role in promoting the development of new-quality rural productivity.

Table 5. Impact of Green Finance and ESG Concepts on the Development Level of New-Quality Rural Productivity

variable	(1)npf	(2)npf	(3)npf
gfi	0.152***		0.133***
	(5.729)		(4.932)
csr		0.050***	0.036***
		(4.067)	(2.937)
red	-0.004***	-0.004***	-0.004***
	(-6.065)	(-5.212)	(-5.401)
rga	0.003***	0.004***	0.003***
	(5.149)	(6.095)	(5.127)
gov	0.003***	0.003***	0.002***
	(4.635)	(6.250)	(4.316)
edu	0.006***	0.006***	0.006***
	(10.818)	(11.414)	(10.696)
inf	0.007***	0.007***	0.007***
	(12.560)	(12.881)	(12.016)
_cons	0.179***	0.186***	0.170***
	(6.824)	(6.865)	(6.551)
N	253	253	253
R2	0.980	0.979	0.981
F	1940.658	1820.765	1718.400

Note: Figures in parentheses represent z-values. *, **, and *** denote significance levels of 10%, 5%, and 1%,

Robustness Tests

To ensure the robustness of the empirical results, this study conducts a robustness test by replacing the explanatory variables with secondary indicators of green finance and corporate social responsibility, respectively. The results are shown in Table 6.

Table 6. Robustness Test Results

variable	(4)npf	(5)npf	(6)npf
geq	0.349***		0.265***
	(3.813)		(2.988)
gef		0.006***	0.006***
		(5.598)	(5.028)
red	-0.004***	-0.004***	-0.004***
	(-6.382)	(-5.565)	(-5.842)
rga	0.004***	0.004***	0.004***
	(5.964)	(5.893)	(5.668)
gov	0.004***	0.003***	0.003***
	(6.688)	(5.338)	(5.144)
edu	0.007***	0.006***	0.006***
	(11.876)	(10.891)	(11.057)
inf	0.008***	0.007***	0.007***
	(14.125)	(12.703)	(12.940)
_cons	0.203***	0.188***	0.190***
	(7.555)	(7.193)	(7.388)
N	253	253	253
R2	0.979	0.980	0.981
F	1806.022	1929.739	1710.918

Note: Figures in parentheses represent z-values. *, **, and *** denote significance levels of 10%, 5%, and 1%, respectively

Based on the research objectives, this study investigates the impact of green rights and corporate environmental responsibility (measured by the issuance of funds for environmental protection by enterprises) on the development level of rural new productive forces. The following multiple linear regression models are constructed:

$$npf = \beta_0 + \beta_1 gep + \beta_3 red + \beta_4 rga + \beta_5 gov + \beta_6 edu + \beta_7 inf + \varepsilon \quad (4)$$

$$npf = \beta_0 + \beta_2 gef + \beta_3 red + \beta_4 rga + \beta_5 gov + \beta_6 edu + \beta_7 inf + \varepsilon \quad (5)$$

$$npf = \beta_0 + \beta_1 gep + \beta_2 gef + \beta_3 red + \beta_4 rga + \beta_5 gov + \beta_6 edu + \beta_7 inf + \varepsilon \quad (6)$$

Note: Model (4) examines the impact of green rights on the development level of rural new productive forces; Model (5) examines the impact of corporate environmental responsibility (measured by the issuance of funds for environmental protection by enterprises) on the development level of rural new productive forces; and Model (6) examines the combined impact of green rights and corporate environmental responsibility on the development level of rural new productive forces.

The results of Model (4) indicate that green rights have a significant positive impact on the index of the development level of rural new productive forces at the 1% significance level, thereby validating Hypothesis H1a. The results of Model (5) show that corporate environmental responsibility has a significant positive impact on the index of the development level of rural new productive forces at the 1% significance level, thereby validating Hypothesis H2a. The results of Model (6) demonstrate that both green rights and corporate environmental responsibility have a significant positive impact on the index of the development level of rural new productive forces at the 1% significance level, thereby validating Hypothesis H3a. In summary, these findings are consistent with the aforementioned research conclusions.

Heterogeneity Analysis

Heterogeneity tests are employed to examine whether there are differences across various groups, typically conducted through subgroup regressions.

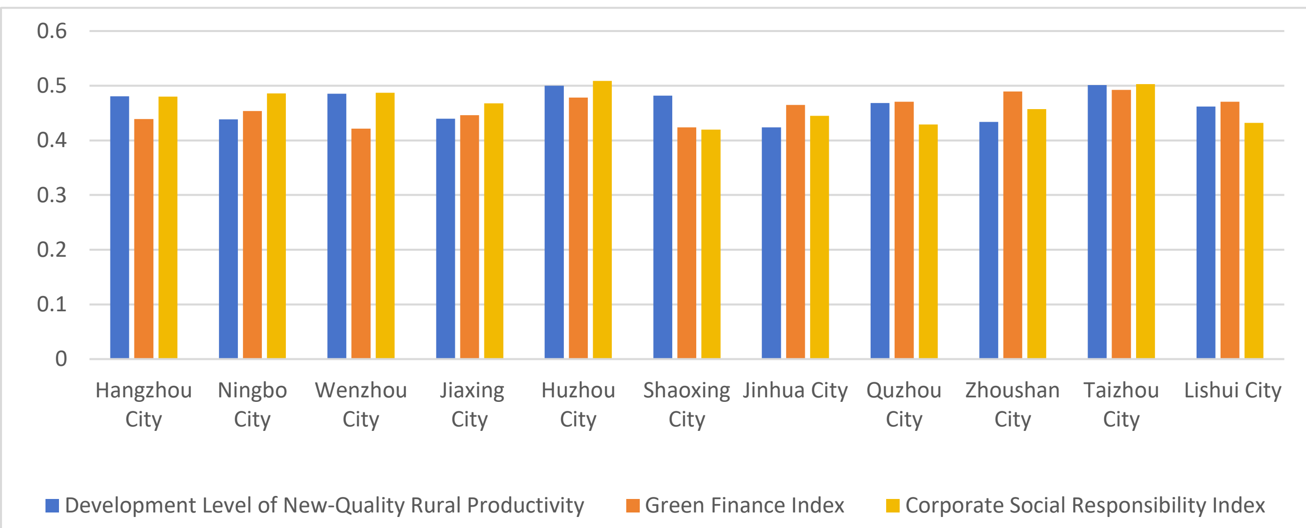

Figure 4. Statistical Chart of Rural New-Quality Productivity, Green Finance Index and Corporate Social Responsibility Index of 11 Cities in Zhejiang Province in 2022

As shown in the Figure 4, there are certain differences in the data among the 11 prefecture-level cities. Furthermore, this study argues that the impact of green finance and corporate social responsibility (CSR) on the development level index of rural new productive forces exhibits heterogeneity across counties in different regions of Zhejiang Province. This section will empirically investigate this hypothesis.

Heterogeneity Analysis Based on Economic Development Levels

Despite the significant positive estimates of green finance and ESG (Environmental, Social, and Governance) principles, regions with different levels of economic development may exhibit certain disparities in their development trajectories. This study categorizes the 11 prefecture-level cities into two groups: economically more developed areas and relatively less developed areas. Table 7 reports the results of the subgroup estimations.

Table 7. Results of Heterogeneity Analysis Based on Economic Development Levels

	(1)		(2)	
variable	economically more developed areas		relatively less developed areas	
gfi	0.154***		0.139***	
	(0.0407)		(0.0369)	
csr		0.0485*		0.0541***
		(0.0281)		(0.0147)
red	-0.00525***	-0.00541***	-0.00311***	-0.00234***
	(0.00114)	(0.00120)	(0.000810)	(0.000828)
rga	0.00333***	0.00442***	0.00344***	0.00360***
	(0.00112)	(0.00113)	(0.000804)	(0.000800)
gov	0.00335***	0.00403***	0.00260**	0.00314***
	(0.000806)	(0.000832)	(0.00104)	(0.000984)
edu	0.00565***	0.00583***	0.00628***	0.00678***
	(0.000976)	(0.00104)	(0.000679)	(0.000657)
inf	0.00566***	0.00603***	0.00740***	0.00774***
	(0.000991)	(0.00104)	(0.000648)	(0.000627)
Constant	0.239***	0.261***	0.146***	0.140***
	(0.0468)	(0.0487)	(0.0316)	(0.0319)
Observations	115	115	138	138
R-squared	0.978	0.975	0.983	0.983
Number of id	5	5	6	6

Note: Figures in parentheses represent z-values. *, **, and *** denote significance levels of 10%, 5%, and 1%, respectively

In the relatively less developed areas, both green finance (GFI) and corporate social responsibility (CSR) have a significant impact on the development level index of rural new productive forces at the 1% significance level, which is consistent with the findings from the full sample. In the economically more developed areas, green finance remains significant at the 1% level, while the coefficient of CSR is 0.0485 and significant at the 10%

level in the northern part of Zhejiang Province. In contrast, in the relatively less developed areas, the coefficient of CSR is 0.0541 and significant at the 1% level. This indicates that the development of ESG concepts positively influences the development of rural new productive forces in both regions, but the impact is stronger in the relatively less developed areas. Hypothesis H2b is thus validated. The observed differences may be attributed to the fact that firms in relatively less developed areas place greater emphasis on social responsibility. A higher proportion of these firms engage in rural development practices by investing in local communities, environmental protection, and job creation, thereby enhancing the development of rural new productive forces. Consequently, the influence of ESG concepts is more pronounced in these areas. The regression results for both regions show significant and positive coefficients for these variables, confirming their positive impact on the development of rural new productive forces. Among the control variables, education level and infrastructure development exhibit relatively large coefficients, suggesting that these factors may play a crucial role in the development of rural new productive forces. An increase in education level can enhance the skills and knowledge of the rural population, promoting economic diversification. Meanwhile, improved infrastructure can reduce transaction costs, attract external investment, and boost economic vitality in rural areas. These two aspects are essential considerations for economic development.

Heterogeneity Analysis Based on Industrial Structure

Given the differences in geographical location, culture, and policy, regions may prioritize different industries in their development. Based on the industrial development emphases of each region, this study categorizes the 11 prefecture-level cities into two groups: areas dominated by the primary and tertiary sectors, and areas dominated by the secondary sector. The subgroup estimation results are presented in the Table 8.

In areas dominated by the primary and tertiary sectors, green finance (GFI) has a significant positive impact on the development level index of rural new productive forces at the 1% significance level, with a coefficient of 0.135. In areas dominated by the secondary sector, GFI also shows a significant positive impact at the 1% level, with a coefficient of 0.190. Corporate social responsibility (CSR) in areas dominated by the primary and tertiary sectors has a significant positive impact on the development level index of rural new productive forces at the 1% level, with a coefficient of 0.0597. In contrast, in areas dominated by the secondary sector, CSR has a significant positive impact at the 5% significance level, with a coefficient of 0.0499. In summary, green finance (GFI) has a significant positive influence on the development of rural new productive forces in both types of regions, but its impact is more pronounced in areas dominated by the secondary sector. Corporate social responsibility (CSR) exerts a stronger positive influence on the development level of rural new productive forces in areas dominated by the primary and tertiary sectors.

Table 8. Results of Heterogeneity Analysis Based on Industrial Structure

variable	(3) dominated by the primary and tertiary sectors		(4) dominated by the secondary sector	
gfi	0.135***		0.190***	
	(0.0347)		(0.0477)	
csr		0.0597***		0.0499**
		(0.0193)		(0.0191)
red	-0.00504***	-0.00496***	-0.00273***	-0.00149
	(0.000876)	(0.000898)	(0.000999)	(0.00107)
rga	0.00313***	0.00390***	0.00366***	0.00402***
	(0.000870)	(0.000856)	(0.00105)	(0.00111)
gov	0.00303***	0.00352***	0.00115	0.00317**
	(0.000680)	(0.000661)	(0.00151)	(0.00140)
edu	0.00535***	0.00560***	0.00698***	0.00752***
	(0.000765)	(0.000771)	(0.000805)	(0.000826)
inf	0.00707***	0.00697***	0.00637***	0.00734***
	(0.000728)	(0.000764)	(0.000820)	(0.000825)
Constant	0.225***	0.240***	0.124***	0.106**
	(0.0357)	(0.0358)	(0.0385)	(0.0410)
Observations	161	161	92	92
R-squared	0.979	0.978	0.983	0.982
Number of id	7	7	4	4

Note: Figures in parentheses represent z-values. *, **, and *** denote significance levels of 10%, 5%, and 1%, respectively

The analysis of resource heterogeneity examines the differential impacts of green finance and corporate social responsibility (CSR) on the development of rural new productive forces in resource-based cities and non-resource-based cities. The results in Table 9 indicate that green finance has a significant positive impact on the development level index of rural new productive forces in both types of cities at the 1% significance level, with coefficients of 0.178 for resource-based cities and 0.119 for non-resource-based cities. This suggests that while green finance positively influences the development of rural new productive forces in both city types, its impact is more pronounced in resource-based cities. Regarding CSR, the coefficient for resource-based cities is 0.0500, significant at the 1% level, while for non-resource-based cities, the coefficient is 0.0286, significant at the 10% level. These findings demonstrate that CSR has a positive influence on the development of rural new productive forces in both types of cities, with a more substantial impact in resource-based cities. This validates Hypothesis H3b.

Heterogeneity Analysis Based on Resource Endowment

Table 9. Results of Heterogeneity Analysis Based on Resource Endowment

	(3)	(4)
variable	resource-based cities	non-resource-based cities
gfi	0.178***	0.119***
	(0.0404)	(0.0342)
csr	0.0500***	0.0286*
	(0.0165)	(0.0164)
red	-0.00237***	-0.00408***
	(0.000886)	(0.000874)
rga	0.00220**	0.00375***
	(0.000875)	(0.000860)
gov	0.00225*	0.00278***
	(0.00119)	(0.000672)
edu	0.00597***	0.00572***
	(0.000766)	(0.000728)
inf	0.00674***	0.00623***
	(0.000715)	(0.000718)
Constant	0.122***	0.196***
	(0.0333)	(0.0353)
Observations	69	184
R-squared	0.991	0.977
Number of id	3	8

Note: Figures in parentheses represent z-values. *, **, and *** denote significance levels of 10%, 5%, and 1%, respectively

This differential impact may be attributed to the distinct economic and environmental contexts of resource-based cities, which often face more significant environmental challenges and have a greater need for sustainable development practices. Consequently, CSR initiatives may be more effective in promoting rural new productive forces in these regions.

Conclusions

Based on the correlation study between green finance and the development of rural new productive forces, this research reviews and critiques existing studies, focusing on “the impact of green finance and ESG concepts on the development of rural new productive forces.” This focus is conducive to promoting coordinated development among the economy, natural environment, social responsibility, and corporate governance. Utilizing panel data from 11 prefecture-level cities in Zhejiang Province over the period of 2000–2022 as the research sample, this study employs software such as STATA and EViews to conduct empirical analyses. The results demonstrate that: Green finance exerts a continuous and sustained positive impact on the development of rural new productive forces. It significantly promotes rural revitalization in cities dominated by the secondary sector as well as those dominated by the primary and tertiary sectors. However, due to the influence of regional industrial structures, its impact is more pronounced in the former. Thus, adopting green finance as a long-term project through a sustainable model can provide stable financial support, facilitate rural industrial restructuring, and drive the development of rural new productive forces, thereby promoting the green transformation of rural economies.

The development of ESG concepts significantly boosts the development of rural new productive forces. However, influenced by regional economic development levels, ESG concepts have varying impacts on rural new productive forces, with a stronger effect observed in economically more developed regions. In these regions, enterprises place greater emphasis on social responsibility, with more firms engaging in rural revitalization practices through investments in local communities, environmental protection, and job creation. This involvement fosters the development of rural new productive forces. Therefore, the integration of ESG concepts with the development of rural new productive forces offers new impetus and direction for sustainable rural development.

Green finance and ESG concepts exhibit a significant synergistic effect in the development of rural new productive forces, jointly driving the green, circular, and sustainable development of rural areas. However, the degree of regional resource dependence affects the impact on rural new productive forces. Both green finance and ESG concepts have a more substantial impact on resource-based cities. Green finance provides precise financial support for green industries and projects that meet sustainable development requirements in rural areas. Meanwhile, through ESG evaluation and management, enterprises are guided to focus more on environmental protection and social responsibility in rural development, thereby deeply tapping into rural new productive forces and achieving sustainable development.

With the accelerated green and low-carbon transformation of China's agriculture, the demand for related green finance is increasing. It is necessary to further leverage green financial instruments such as green bonds and green asset securitization. At the current stage, the "visible hand" should be used to address externalities, price signal distortions, and other issues faced by green investment and financing. Proactive guidance should be provided for the transformation of non-green industries to stimulate the enthusiasm of all investment and financing parties. For industries and fields involved in non-green loans that need to gradually withdraw and transform, advance guidance should be given to optimize the regional industrial structure as a whole, avoiding industry shocks and impacts on regional economic stability caused by insufficient corporate awareness and slow transformation. Meanwhile, accelerate the green transformation of traditional enterprises in rural areas.

Promoting the development of green finance and ESG practices to enhance environmental governance requires cost-sharing between enterprises and the government. As green finance is still in its initial stage, it relies on government subsidies to guide social capital inflows. Additionally, since ESG information disclosure and practices focus on long-term benefits, enterprises need to bear certain short-term costs. It is advisable to select representative enterprises that can afford initial investments and better realize ESG benefits in management and operations to lead ESG actions within the sector, gradually expanding the scope of ESG implementation. For relatively underdeveloped regions, appropriately reduce income taxes on green financial products, provide tax incentives for green projects, increase government funding support for specific projects, and attract social capital through relaxed market access conditions and tax policies. Vigorously develop government-social capital cooperation green development funds to promote the growth of rural green industries and new productive forces. Empirical results show that China's economic development exhibits regional imbalances. Therefore, it is necessary to prioritize the promotion of green finance and ESG concepts in relevant regions, giving preferential support to areas where green finance development is below the threshold and to enterprises with weak ESG awareness. Strongly support the development of green finance in resource-based regions and the enhancement of ESG concepts among enterprises in such regions. Establish specialized policy financial institutions to provide dedicated green financial services, tilting toward areas with low green finance development levels to allocate green financial funds reasonably. The ESG concept emphasizes enterprises' responsibilities in environmental, social, and governance aspects. Thus, the government should play a leading role in encouraging enterprises to participate in rural construction, improve rural infrastructure, expand the scope of market and social entities in social services, strengthen corporate ESG practices, and promote the development of rural new productive forces to achieve comprehensive economic, social, and environmental progress.

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