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Effects of Energy Consumption, Agricultural Trade, and Productivity on Carbon Emissions in Nigeria: A Quantile Regression Approach

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Abstract: The focus of this investigation was to examine the effects of energy consumption, agricultural commerce, and productivity on CO_2 emissions in Nigeria using quantile regression. Time series data from 1960 to 2021 were used. The findings revealed that the impact of agricultural raw materials imports (AGRIMs) and exports on carbon footprints is positive. There is a prevalence of a set of notable percentile differences in the conditional distribution of the variables on CO_2 emissions. Initially, the coefficient of energy consumption (EnCons) was high, but constantly nosedived from the 25th quantile until it reached the 90th quantile when it picked up again, and the same was true in the case of AGRIM. Thus, a 1% increase in agricultural imports will bring about 0.0047—a significant unit increase in CO_2 emissions in Nigeria from the 0.382946 coefficient in the 10th quantile to the 0.264392 coefficient in the 50th quantile, and thereafter, the effects become insignificant. Profound significant variance across disparate percentiles in the conditional spread of AGRIM, food production index (FPI), CPI, and FDI was found. It further showed that the effects of the regressors on carbon emissions differ over the quantiles. Overall, AGRIM and EnCons have positive and significant effects on carbon emission. However, the agricultural raw material export has significant negative effects on CO_2 emissions as the movement (transportation) of goods within a country prior to export involves a huge level of carbon release. This study provides recommendations and policy implications.

Keywords: agricultural commodity trade; CO_2 emission; energy consumption; quantile regression

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1. Introduction

The quest for survival, sustainability, and growth has consistently put humankind on its toes in recent times [1,2]. According to [3] (Zhou et al., 2022), this is because economic growth and global warming have been seen to be going side by side for the past several decades [4,5]. Man's explorative and innovative technologies when deployed as instruments for economic growth seem to have pitched man against itself (nature), as a result of its causative role in [3] greenhouse gas (GHG) emissions, which is the main cause of global climate change events such as floods, droughts, storms, extreme temperatures, melting glaciers, and rising sea level [3,6–8]. Further, deleterious effects associated with the deployment and utilization of man's own inventions are aggravated by food security challenges owing to the destruction of fertile lands, pollution of water bodies, destruction of ecosystems, and contamination of the environment, with the consequences of industrialization and globalization jeopardizing man's chance for survival [9]. Thus, conserving the environment has become an issue of concern which has dominated political, economic, social, and health discussions. This is due to the calamitous degrading effects of climate variability and global warming on the environment [10]. One of the main characteristics of industrialization and progress, which are important forces behind economic growth, is environmental deterioration, both in terms of quantity and quality [11–13]. Refs. [14,15] defined environmental degradation as the destruction of ecosystems and the degradation of the environment due to the depletion of resources including soil, water, and air; habitat destruction; pollution; and the loss of natural habitats. Meanwhile, the authors of [16] defined it as the degradation of the earth negatively impacting the environment by disrupting biodiversity; eradicating wildlife and depleting resources such as land, water, and air.

In Nigeria, the use of energy and intensities of usage has been identified by [17] as one of the key factors driving environmental degradation in recent times. This is prominent because the pursuit for energy and the use of energy have witnessed a monumental rise within the space of the last two decades due to its deciding role in real sector productivity with the agricultural sub sector as a key one [18]. References [19,20] provided further evidence that the rapid burgeoning of global trade after the World War II has obviously encouraged the economic growth of various countries (Nigeria inclusive), though on the other hand, it has brought about the upsurge in carbon dioxide emissions, hence confirming the observations in [21,22] that economic growth brings about a rise in the degree of CO_2 emissions. This is especially the case with countries of the world seeking to expand their trade frontiers irrespective of the damning consequences that arise from the high-power industrial carbon-emitting machines which have further deepened the case for climate variability. Thus, this substantiates the stance of [23] that the natural environment is altered by climate change, which also slows down economic progress and poses threats to the wellbeing of society because of the overriding impact of climate change on the extent to which international trade can be carried out as per the terms of the Paris agreement of 2015.

Trade liberalization appears to benefit both the host and home nations. It also appears to have certain negative ramifications that need to be considered [19,24]. As trade liberalization advances, the government is compelled to lower industrial costs by ignoring or sacrificing the environment [22,25]. Worldwide warming has now become a significant worldwide worry, reigniting concerns over the trade's environmental consequences. Nature is essential to the world's survival and sustainability. Nevertheless, in contrast, nature does not require people [19]. This recognition resulted in the United Nations Convention on Climate Change Advocacy, as well as the 2015 Paris Agreement. Worthy of note too is the fact that the Nigerian Government, through recent national policies, has been championing a more robust international agricultural trade. The championing of this trade has necessitated the increased transportation of goods and services from rural areas to urban centers for export aggregation, an activity known to increase the release of carbon into the atmosphere. The available evidence has shown that recent decades have seen a major increase in global agricultural commerce, which grew by 6% per year between 2000 and 2016 [26]. Agricultural items saw the largest rise in global merchandise exports, rising by 3.1% yearly and 36% from 2008 to 2018 [27]. The development of export crops, which causes deforestation and soil erosion, raises the issue of transportation-related energy usage and emissions, which furthers the indirect environmental consequences of agricultural commerce on climate change [28].

Nigeria is Africa's most populous country and the most resource-endowed in West Africa [29,30]. Agriculture, a key pillar of Nigeria's economy, contributes approximately 24% of the nation's GDP and employs over 70% of its workforce. However, the sector is a significant source of greenhouse gas (GHG) emissions, driven by deforestation, livestock emissions, and the use of nitrogen-based fertilizers [31,32]. In addition, the energy sector's reliance on fossil fuels, accounting for over 80% of the country's electricity generation, exacerbates carbon dioxide emissions, which constitute 68% of total GHG emissions in Nigeria coupled with 41% energy consumption per capita and 33% energy intensity [33–36]. This dual dependency on agriculture and fossil fuels underscores Nigeria's unique vulnerability to climate change. Rapid urbanization and population growth, combined with weak governance in environmental management, would further intensify carbon emissions.

Despite huge natural endowment, Nigeria is faced with the challenge of environmental degradation resulting from the pressure on its vast resource coupled with poor utilization and exploration of these resources. Energy production and consumption is one of the numerous sources of environmental pollution and degradation [37,38]. This is particularly so because Nigeria's energy sector is primarily reliant on oil and natural gas, with fossil fuels constituting a significant portion of energy production and exports [39]. The oil and gas industry is responsible for substantial carbon dioxide and methane emissions, particularly through gas flaring—a practice where excess natural gas is burnt off during oil extraction [40,41]. This contributes directly to the country's greenhouse gas emissions and is a major source of air pollution [41]. Remarkably, despite its vast energy resources, Nigeria struggles with an unstable electricity supply. This has brought about a heavy reliance of the majority of its citizens and industries on diesel and petrol generators for power, which increases carbon emissions and worsens urban air quality [40,42]. However, the widespread use of generators is both a symptom of an underdeveloped power grid and a driver of localized pollution [43].

Nigeria is an agrarian nation, and its agriculture is highly climate-sensitive [44–46]. Rising temperatures and erratic rainfall due to climate change—exacerbated by carbon emissions—directly impact crop yields, food security, and the livelihoods of millions dependent on agriculture [47–49]. Increased droughts in the northern region and flooding in the south disrupt food production and threaten economic stability [44,50]. Addressing the impact of carbon emissions entails significant financial investment [51]. The cost of adapting agriculture to climate variability, improving energy infrastructure, and mitigating the adverse health effects of emissions places added pressure on national resources [52]. Carbon emissions in Nigeria result primarily from a fossil-fuel-heavy energy system and agriculture-driven deforestation and land-use changes [37,53]. These emissions contribute to climate change impacts, which in turn affect agriculture—a major economic pillar [44]. To address these challenges, Nigeria needs comprehensive reforms in energy and agriculture, alongside investments in renewable energy and climate adaptation strategies.

Nigeria's agriculture is predominantly rain-fed, leaving it highly susceptible to erratic weather patterns caused by climate change. Prolonged droughts, unpredictable rainfall, and flooding disrupt food production and threaten food security for millions of Nigerians [31,54]. Moreover, agricultural intensification practices—such as increased use of chemical fertilizers and land clearing for crop cultivation—have been linked to higher CO_2 emissions. Studies confirm that agricultural activities in Nigeria contribute significantly to methane and nitrous oxide emissions, compounding the environmental challenges [34,54]. Agricultural emissions are one of the main causes of global warming. They account for almost a third of anthropogenic greenhouse gases (GHGs). These GHGs include nitrous oxide released by fertilizers, methane released by rice and livestock, carbon dioxide released by clearing forests to produce agricultural land, and indirect emissions from the production of agricultural inputs based on fossil fuels and from food processing, packaging, and transportation [22,55,56]. Hence, research on the effects of the relationships between energy consumption, trade openness, and agricultural productivity on carbon emissions is imperative to succinctly understand the extent to which each of the variables affect carbon emissions.

Although Nigeria has introduced frameworks like the 2015 National Renewable Energy and Energy Efficiency Policy (NREEEP), National Renewable Energy Action Plan (NREAP), Sustainable Energy for All Action Agenda (SE4All-AA), and Climate Change Act of 2021, the implementation of these remains limited. As evident in the literature review section, there is a lack of comprehensive studies focusing on the intersection of energy consumption, agricultural trade, and productivity in influencing CO_2 emissions within Nigeria's unique socio-economic context. This study addresses this gap by employing a quantile regression approach to examine the differentiated impacts of these factors on emissions.

2. Literature Review

The following section presents a review of empirical studies relevant to the current study. These studies explore the interplay between economic growth, energy consumption, trade openness, and CO_2 emissions, among other variables, across diverse geographical and economic contexts. By analyzing their methodologies, findings, and policy implications, this review aimed to identify knowledge gaps and establish a foundation for understanding the factors influencing environmental sustainability and economic development. The details of the empirical literature are summarized in Table 1. In summary, the studies highlighted examine relationships between economic growth, energy consumption, trade openness, and CO_2 emissions, often using linear methodologies like ARDL. While some focus on Nigeria, they overlook the specific role of agricultural trade and productivity in shaping emissions. Additionally, the heterogeneous effects across different levels of emissions remain unexplored. Given Nigeria's reliance on energy-intensive agricultural practices, these gaps leave critical policy questions unanswered. This study addresses these gaps by employing a quantile regression approach to analyze how energy consumption, agricultural trade, and productivity influence emissions across quantiles, offering targeted insights for sustainable policy development in Nigeria.

Table 1. Empirical reviews.

Authors	Countries	Period	Variables	Methodologies	Key Findings	Policy Implications
[57]	34. Sub-Saharan Africa (SSA) countries	1990–2016	CO_2 emissions, GDP, trade, urbanization and renewable Energy consumption	Panel quantile regression analysis	GDP boosts GHG emissions across quantiles, notably already marked by low CO_2 emissions. Trade with other countries improves environmental sustainability in the regions with the lowest and highest levels of greenhouse gas emissions, but has the reverse effect on CO_2 emissions at the median—the bidirectional causative relationship amid global commerce, urbanization, economic growth, and CO_2 emissions.	As SSA's member nations expand, green technologies must be included in the manufacturing sector to reduce CO_2 emissions.
[58]	Middle-Income Trap (MIT) states among Latin American nations.	2000–2020	Foreign direct investment, gross domestic product, commerce (advanced technology export, data, etc.), tourism/in-tourist, and health	Multiple regression path analysis coupled with Autoregressive Distributed Lag (ARDL) regression	The three main variables that significantly reduce CO_2 pollution in nations with greater incomes are trade, GDP, and foreign direct investment (FDI); but, in MIT countries, these positive effects are quite small. While commerce, GDP development, and FDI may significantly increase environmental quality through CO_2 emission, education and travel/tourism services have little effect on the environment.	With MIT nations suffering from a slowdown or halt in the growth of their economies, this report offers a strong foundation for creating an eco-friendly and growth-oriented strategy.
[59]	Nigeria	Annual time series data for periods 1980–2019	CO_2 emissions, Energy Consumption, FDI, GDPPC and Trade Openness	ARDL method	Trade openness and CO emissions have a negligible positive correlation. Nigeria's CO_2 emissions are trending upward, although trade openness fluctuates during the periodic evaluation.	To promote a cleaner economy, the Nigerian government should be more aggressive and persistent in enforcing trade and environmental regulations. It should also be more committed to attracting only manufacturers of clean goods and should not back down from the need of improving environmental welfare.
[60]	Panel of 12 MENA Countries	1990–2011	GDP, CO_2 emissions, energy use, financial development, urbanization, inflation, open trade, and capital stock	Cobb–Douglas production function, simultaneous-equation panel data models	Proof that the connection betwixt development in the economy and CO_2 emissions is bidirectional. Bidirectional causation exists from trade openness to economic development. Between trade openness and financial development, the feedback hypothesis is confirmed. A neutrality hypothesis between financial development and greenhouse gas emissions is found. Empirical research confirms the environmental Kuznets curve.	These factual findings are of special significance to policymakers because they provide evidence for the creation of sensible economic policies that uphold economic development while promoting environmental quality.

Table 1. *Cont.*

Authors	Countries	Period	Variables	Methodologies	Key Findings	Policy Implications
[61]	Sixty (60) emerging and developing economies	2002–2012;	Conventional trade-environment framework with FDI, financial development, urbanization, and political globalization as extra variables.	Dynamic panel data model; the fixed-effects model and GMM	When endogeneity was taken into consideration, trade openness was shown to have no appreciable influence on EPI but to raise CO_2 emissions; trade openness, wealth, energy consumption, and population were found to have a negative impact on environmental quality.	The secret to environmental sustainability in rising economies is effective institutional, energy, economic, and infrastructure policy.
[62]	Twenty (20) OECD countries.	1991–2020	Gini coefficient (GN), GDP, trade openness, real crude oil price (ROP), usage of renewable energy, and CO_2 emissions per person.	Panel data; AMG assessor	Empirical findings indicate a strong positive long-term relationship between these nexuses, except for carbon emissions, which have a negative correlation with REC. The findings also demonstrate a one-way causal relationship between CO_2 emissions and real oil prices, economic inequality, REC, and trade openness.	Governments and policymakers in the OECD gradually open their economies to more commerce with other countries while ensuring the welfare of the country by attaining energy efficiency through the transition to renewable energy sources.
[63]	Nigeria	1981–2014	Co_2 emissions per capita, GDP per capita, Real GDP per capita as a proxy for income or wealth, Agricultural Value Added as a proxy for agricultural innovation, biocapacity and energy per capita	Dynamic autoregressive distributed lag (ARDL) simulations	Agricultural innovation has strong predictive power on CO_2 emissions, income level to predict long-term energy utilization, The empirical evidence based on the ARDL procedure confirmed the long- and short-run validity of the EKC hypothesis for Nigeria	These findings demonstrate that improvement in livelihoods, environmental awareness creation, and prioritization of ecosystem management and restoration will have a long-term effect on environmental sustainability.
[64]	Nigeria	1980–2022	CO_2 emission, GDP, Energy Consumption, crude oil prices and trade openness (controlled variables)	ARDL	There is a long-run relationship between the variables. The long-run and short-run Autoregressive Distributed Lag (ARDL) estimates unequivocally demonstrate that both economic growth and the non-renewable energy consumption exert statistically significant, and positive impacts on CO_2 emissions.	Adequate regulations, restrictions, and innovative ways to foster economic growth through energy consumption from non-renewable energy sources should be implemented alongside policies from the Energy Regulatory Commission.
[65]	Nigeria	1980–2020	Consisting of energy consumption (ENC), financial development (FND) (measured as domestic credit to Private Sector), Economic growth (proxy by RGDP growth rate), economic growth squared (GDP^2), globalization (measured by Total Exports (TEXPs) and Total Imports ((TIMPs)) and Urbanization (URB).	Autoregressive Distributed Lag technique in the presence of structural breaks	Findings support the existence of an environmental Kuznets curve hypothesis for Nigeria in the long and short run. Energy consumption and total import exacerbate environmental deterioration in the long and short run, whereas total export improves environmental quality in the long and short run.	The government, policymakers, and all energy stakeholders should take additional measures to ensure the implementation and diversification of energy sources to accommodate more renewable energy sources that emit less carbon in order to promote efficiency in Nigeria's production processes and lower carbon emissions.
[38]	Nigeria	1980–2021	Real gross domestic product proxy by oil production; carbon emissions from gas flaring proxy by oil consumption; investment; crude oil production growth rate	Autoregressive Distributed Lag (ARDL) bounds testing framework and the Granger causality test. T	The findings revealed that economic growth and energy consumption significantly increases energy-related emissions. An increase in income level influences investors and industrialists to invest in the industrial sector, increasing production, diversification, and expansion. However, increased production and the expansion of industries increase energy demand. Energy demand met by consuming fossil fuel increases energy-related emissions in Nigeria and negatively affects environmental quality.	The study is relevant to the post-2015 Sustainable Development Goals agendas for two fundamental reasons: the world needs Sustainable Development Goal 7—ensuring access to affordable, reliable, sustainable, and modern energy by 2030. (b) Large extractive industries primarily drive growth in Nigeria, and the country's population is expected to double in about 30 years.

Table 1. *Cont.*

Authors	Countries	Period	Variables	Methodologies	Key Findings	Policy Implications
[66]	Oman	Data from 1972–2014.	CO_2 emissions, per capita GDP, and percentage of trade to GDP	Unit root tests and ARDL model	Per capita GDP and trade openness appear to have a positive correlation with CO_2 emissions. It implies that a nation's ecosystem is destroyed by commercial openness and a higher GDP per capita.	The findings provide Oman's government room to think about the environment while deciding on trade policy.
[67]	Thirty-five Asian countries	Temporal series of panel data spanning 1991–2016	Trade openness, labor, GDP, real income, energy consumption, ecological footprints, and gross fixed capital formation	Regression, FMOLS and DOLS	For high income, upper medium income, and lower middle-income nations, the results demonstrate a positive (negative) influence of size (method) on ecological footprint, supporting the environmental Kuznets curve theory. Additionally, energy use adds to ecological footprint, while trade openness and composition impact lessen environmental deterioration.	The findings propose sustainable trade agreements among the area and assigns more extensive policy consequences.
[68]	Sixty-four-four Belt and Road Countries	2001–2019	GDP, FDI, trade Openness, CO_2 emission, Renewable energy consumption	Panel quantile regression.	The impact of trade openness on CO_2 emissions is positively substantial and varies depending on the level of CO_2 emissions. While trade openness has a negative indirect effect on CO_2 emissions through the technology and energy substitution effects, it has a favorable indirect effect through the economic benefit.	It is advised to increase the use of renewable energy, reduce energy intensity, and formulate relevant legislation to lower carbon emissions while taking local factors into account.
[69]	Nigeria	1971–2015	GDP, FDI, trade Openness, CO_2 emission, Renewable energy consumption	ARDL bound test, FMOLS and DOLS, and wavelet coherence	The long-term cointegrating relationship between the variables is revealed by the results of the bounds test. Long- and short-term economic expansion often has a favorable impact on CO_2 emissions. Over time, energy use has a beneficial influence on CO_2 emissions, whereas foreign direct investment often has a negative impact on CO_2 emissions.	The causality test relied on wavelet coherence, which offered more convincing support for the study's long-term estimates.

3. Materials and Methods

Theoretical Framework and Data

Ref. [70] proposed that economic and demographic variables might have an impact on environmental quality in their renowned ecological model (IPAT). The authors pointed out that population (P), affluence (A), and technology (T) might all have an influence on environmental impact (I). Owing to the difficulties in assessing the non-proportional influence of each variable on (I), the (IPAT) paradigm was not fully adopted. Ref. [71] proposed the Stochastic Impacts by Regression on Technology, Wealth, and Population (STIRPAT) paradigm because of the shortcomings of the (IPAT), which served as the foundation for our investigation. As stated by STIRPAT model, economic and demographic variables both affect how the environment is changing. The STIRPAT equation is specified as

$$I_t = \psi_0 P_t^{\xi 1} A_t^{\xi 2} T_t^{\xi 3} \mu_{it} \tag{1}$$

The logarithmic structure of the model, following [72] is given as

$$lnI_{it} = \psi_i + \xi_1 lnP_{it} + \xi_2 lnA_{it} + \xi_3 lnT_{it} + \mu_{it} \tag{2}$$

where ξ_1, ξ_2, and ξ_3 are the parameters of P, A, and T, respectively

ψ_i, μ_{it}, t, and i represent the constant, disturbance term, time dimension, and countries, respectively. In this study, and in line with existing literature, CO_2 emissions is our environmental impact indicator (I). Energy Consumption, Trade Openness, Agricultural Productivity capture P, A, and T, respectively. In accordance with [72,73]. The authors of Ref. [74] who argued that it could be decomposed into various variables, we extended the STIRPAT model to Foreign Direct Investment. We adopted trade in place of technology since trade transfer technological innovation (diffusion) from developed economies to emerging economies or less developed (LDC) economies. Technological innovation aids in reducing energy pollutants and accelerates economic activities. Also, trade openness may have a negative impact because of dumping activities from the developed economies who sees LDC as a pollution haven. Therefore, by incorporating the variables into Equation (3) we derive the model for the study as

$$lnCO_{2t} = \xi_0 + \xi_1 EnCon_{it} + \xi_2 lnTO_{it} + \xi_3 AgrP_{it} + \xi_3 FDI_{it} + \xi_4 CPI_{it} + \mu_{it} \quad (3)$$

where $lnCO_2$, $EnCon$, $lnTO$, $AgrP$ FDI, and CPI are the natural logarithm of carbon emissions, Energy Consumption, the natural logarithm of Trade openness, Agricultural Productivity, Foreign Direct Investment and Consumer Price Index, respectively The data for the study were sourced from the World Bank, World Development Indicators, [75], and span from 1960 to 2021. The sample period was based on the availability of the data. These were transformed into natural logs before using them for analyses. The description and measurements/functional definition of the variables are as presented in Table 2. Energy consumption was measured as Energy use (kg of oil equivalent) per $1000 GDP (constant 2017 PPP). Trade openness, was measured in terms of agricultural export (AGRX), agricultural import (AGRIM), food export and food import, Real exchange rate (local currency unit relative to the dollar), inflation (Consumer price index reflecting the percentage in the cost of a basket of food), Aggregate Trade Openness was measured in terms of ratio of sum of export and import to GDP (Import plus export) and Foreign Direct Investment(FDI) was measured as the inflow of foreign direct investment. Agricultural Productivity was measured as food production index. CO_2 emission was measured as CO_2 emissions in solid fuel consumption in Kilo tonnes.

Table 2. Variable list and description.

Variables	Description	Source
CO_2	CO_2 emissions from liquid fuel consumption (kt)	WDI
EnCons	Energy use (kg of oil equivalent per capita) [EG.USE.PCAP.KG.OE]	WDI
RxR	Real Exchange Rate (LCU)	WDI
CPI	Inflation (Consumer Price Index)	WDI
FDI	Foreign direct investment, net inflows (BoP, current US$)	WDI
AgrX	Agricultural Raw Material Export(% of merchandise exports)	WDI
AgrIm	Agricultural Raw Material Import (% of merchandise imports)	WDI
FPI	Food production index (2014–2016 = 100)	WDI

4. Methodology

Quantile Regression

To observe the effects of Energy Consumption, Trade Openness and Agricultural Productivity on Carbon emissions in Nigeria, this study utilizes quantile regression (QR) to estimate the parameters all through the conditional distribution of CO_2 emissions. Quantile regression serves as a notable approach to analyzing relationships between variables by investigating the conditional quantiles of the dependent variable, instead of the singular focus on the mean, as it pertains to ordinary least square (OLS) regression [76]. Its strength and worth are in capturing variables heterogeneity across diverse conditional distributions, handling heteroscedasticity, providing robust estimates even in the presence of outliers or skewed distributions, flexibility in model specification, and its usefulness in policy and risk analysis [77]. Hence, it is a robust and flexible tool for establishing complex relationships and tailored insights that are often hidden in mean-based analyses [78]. In [79], quantile regression models were used to determine the relation between a set of covariates and specific percentiles with relation to the outcome variable. Using this technique, we carefully examined the repercussions of energy consumption, trade openness, and agricultural productivity on the conditional distribution of carbon emission with particular focus on

Nigeria. This is important for policy formulation because QR aids in the articulation of the effects of the independent variables on CO_2 emissions. Solving the optimization problem in Equation (2), we obtain the θth quantile estimate of CO_2 emissions:

$$\underset{\beta \in R^k}{Min}\left[\sum\nolimits_{i\in_i;y_i\geq x_i'\beta}\theta\left|y_i-x_i'\right|+\sum\nolimits_{i\in_i;y_i<x_i'\beta}(1-\theta)\left|y_i-x_i'\beta\right|\right] \quad (4)$$

where $\theta \in (0,1)$.

Ref. [80] states that the QR decreases the total weighted absolute deviation along various quantiles. Within this research, we concentrate on the 10th quantile, the 25th quantile, the 50th quantile (the median), the 75th quantile, and the 90th quantile in order to understand how the regressors in the prototype affect the magnitude of CO_2 emissions based on initial levels of CO_2 emissions in the country under observation.

5. Empirical Result

To understand the relevant properties of the data, a number of analytical tools were employed such as mean, median and standard deviation. The summary statistics of the variables used for the analysis are in Table 3; the mean for CO_2 is 9.899 with a standard deviation of 1.011. For ENCONS, the mean and standard deviation are 6.518 and 0.095, respectively, while the corresponding mean and standard deviation values for AGRIM, AGRX, FPI, and RXR are −0.107 (0.468), −0.347 (1.963), 3.763 (0.621), and 5.084 (0.639), respectively. For FDI_IN and CPI, the mean and dispersion are 20.525 (1.251) and 1.290 (2.987), respectively. Except for FEX with a Kurtosis of 3.503, which suggests a normal distribution, the majority of the other variables have kurtosis values of less than three, indicating a flatter distribution (platykurtic), meaning fewer extreme values. The CO_2 and CPI from Table 2 have p-values of 0.023 and 0.042, respectively, indicating they are statistically significant at the 5% level. From the foregoing information, it is observed that most of the variables exhibit a great degree of skewness, with CO_2 showing a significant level of skewedness to the left. However, regarding the evidence relating to standard deviations, there are various degrees of variability across diverse parameters, with EX and IMP displaying greater variableness. The output from the Jarque–Bera test suggests that most variables are not normally distributed, especially CO_2 and CPI, as well as other variables with significant Jarque–Bera statistics.

Table 3. Descriptive statistics.

	CO_2	CPI	ENCONS	FDI_IN	FEX	FIMP	FPI	RXR	EX	IMP
Mean	9.899	1.290	6.518	20.525	1.013	2.683	3.763	5.084	25.425	25.268
Median	10.283	0.942	6.535	20.111	1.034	2.751	3.744	4.952	25.531	24.833
Maxi.	11.158	5.870	6.666	22.903	4.167	3.420	4.716	6.286	30.759	30.993
Min.	7.538	−2.720	6.369	19.058	−4.157	2.092	2.907	3.908	19.440	19.980
Std. D.	1.011	2.987	0.095	1.251	1.933	0.315	0.621	0.639	3.971	3.782
Skewness	−0.821	0.035	−0.448	0.475	−0.502	−0.155	0.119	−0.068	−0.097	0.045
Kurtosis	2.514	1.435	1.847	1.845	3.503	2.227	1.400	1.562	1.521	1.478
J.-Bera	7.578	6.340	5.508	5.689	3.261	1.790	6.763	5.386	5.745	6.005
Prob.	0.023	0.042	0.064	0.058	0.196	0.409	0.034	0.068	0.057	0.050

Impact of Agricultural Raw Materials Import and Export on Carbon Emission

Based on the output of the quantile regression presented in Table 4, we could observe the interplay between different independent variables and how they affect CO_2 emissions over different quantile conditional spread values. (We implemented three diagnostic tests, namely, Ramsey's RESET test for model stability, Jarque–Bera (J–B) normality test and autocorrelation. The results of these diagnostic tests are reported in Appendix A Table A1. Based on the findings, our empirical estimates contain no specification errors and are normally distributed. We thus consider our obtained quantile regression estimates to be plausible.) ENCONS (Energy Consumption) is observed to have significant positive effect on CO_2 emissions across all quantiles—at the 0.1 quantile, it has the coefficient of 15.55481, significant at the 1% level, indicating that for the lower tail of the distribution, an increase in energy consumption strongly correlates with higher carbon emissions with a declining effect as you move towards the 0.5 quantile, but stays positive and significant. Then, surprisingly, the coefficient spikes again at the 0.9 quantile (14.021) suggesting that ENCONS has a strong positive effect on CO_2 at both the lower and upper ends of the distribution.

Table 4. Results for agricultural raw material imports and exports.

Variable	0.1	0.25	0.5	0.75	0.9
ENCONS	15.55481 *** (0.0000)	14.07135 *** (0.0000)	9.302728 *** (0.0000)	8.580428 *** (0.0000)	14.02114 *** (0.0000)
AGRIM	0.382946 *** (0.0006)	0.316268 ** (0.0047)	0.264392 ** (0.0147)	0.170810 (0.1310)	−0.058678 (0.6885)
AGRX	−0.056411 (0.0766) **	−0.050724 (0.1228) **	−0.086342 (0.0684) **	−0.083955 (0.1858)	−0.008413 (0.7925)
FPI	2.506349 ** (0.0012) ***	1.663564 * (0.0396) **	0.342385 (0.5898)	0.108726 (0.8652)	0.307104 (0.7229)
FDI_IN	−0.197436 * (0.0507)	−0.178552 (0.0962)	−0.047236 (0.6011)	0.004625 (0.9586)	−0.060807 (0.4096)
CPI	−0.581441 ** (0.0016)	−0.378898 * (0.0430)	−0.058373 (0.7023)	−0.033568 (0.8276)	−0.199644 (0.3564)
RXR	0.365145 ** (0.0156)	0.272136 ** (0.0831)	0.060075 (0.6362)	−0.018477 (0.8923)	0.016347 (0.8823)
C	−98.29669 *** (0.0000) ***	−85.52437 *** (0.0000) ***	−51.27189 (0.0002) ***	−46.25014 (0.0011) ***	−80.89429 (0.0002) ***
Adjusted R^2	0.819533	0.792481	0.734285	0.698864	0.684225
R^2	0.795697	0.765072	0.699190	0.659091	0.642519
Observation	61	61	61	61	61

Note: (1) This table shows the results of the quantile regression model with carbon emissions as dependent variables, while Energy Consumption, AGRIM, AGRX and other variables and control variables as independent variables. (2) Figures in parentheses are *t*-values *** Statistical significance at the 1% level. ** Statistical significance at the 5% level. * Statistical significance at the 10% level.

The significant differences in the impact of energy consumption on CO_2 emissions across quantiles reflect Nigeria's unique energy landscape and economic structure: at lower quantiles, where carbon emissions are relatively low, the significant positive effect of energy consumption may be attributed to the reliance on traditional biomass and inefficient energy use in rural and low-income settings. Limited access to cleaner energy technologies and the reliance on fossil fuel-based generators for electricity exacerbate carbon emissions even at lower economic activity levels. At mid-level quantiles, the effect diminishes, possibly due to the moderate adoption of energy-efficient practices in urban and semi-industrial areas. These regions might benefit from policy-driven improvements in energy efficiency, though the scale is not extensive enough to neutralize emissions significantly. The resurgence of a strong positive effect at higher quantiles aligns with Nigeria's heavy reliance on fossil fuels for its industrial and energy sectors. High quantiles represent industrial and urbanized regions with significant economic activities and energy demands, where the carbon-intensive nature of energy production becomes a dominant factor. This is compounded by the underdevelopment of renewable energy sources, which limits the potential for decoupling energy consumption from emissions at these levels.

The effects of AGRIM on CO_2 were observed to be varied across quantiles, commencing positive and declining as the quantile advances. Specifically, at the 0.1 quantile, AGRIM had a significantly positive impact of 0.38, but this effect falls as we approach the higher quantiles. However, by the 0.75 quantile, the effect becomes insignificant (0.17), and by the 0.9 quantile, it turns slightly negative (−0.058678) but remains insignificant. The differing significance of agricultural imports on CO_2 emissions across quantiles highlights the structural and policy-related factors influencing Nigeria's agricultural trade and its environmental impact. At lower quantiles, the significant positive impact of agricultural imports on CO_2 emissions can be attributed to the carbon-intensive nature of Nigeria's reliance on imported agricultural raw materials. These imports often involve long transportation distances and high-energy input for storage and distribution, adding to emissions even at lower levels of economic activity. Additionally, weak domestic production in critical sectors drives the dependency on imports, which indirectly contributes to increased emissions from associated logistics. As quantiles increase, representing higher emission levels, the impact of agricultural imports diminishes and eventually becomes insignificant. This shift may reflect a relative increase in domestic production capacity or diversification in economic activities, which dilutes the proportional contribution of imports to overall emissions. Policy initiatives promoting local agricultural value chains and substitutions for imported goods could also play a role in reducing the carbon intensity of imports at higher levels.

Furthermore, the results for AGRX, as depicted in Table 4, shows that at the 0.1 quantile, the negative impact is significant at the 5% level (−0.056), but it weakens and loses significance as you move to higher quantiles, and by the time we approach the 0.9 quantile, the impact becomes negligible and statistically insignificant (−0.008). Thus, the assertion that agricultural exports are overtly negative across the distribution, indicating that higher levels of exports are associated with lower CO_2 emissions with a varying level of significance and strength. At lower quantiles, agricultural exports have a significant negative impact on emissions, indicating that exporting agricultural goods at this level contributes to lower domestic carbon emissions. This could be due to a focus on low-carbon agricultural commodities or the externalization of emissions to importing countries. The weakening and eventual insignificance of the negative impact at higher quantiles suggest that as agricultural production scales up to meet export demands, domestic emissions from production and processing increase. These emissions could offset the environmental benefits of exports, particularly if mechanization and fossil-fuel-based inputs are heavily utilized in export-oriented agriculture.

As regards the FPI, at the 0.1 quantile, it was found to have a strong positive effect of 2.506 at the 1% significant level. Again, the effect decreases and became insignificant after the 0.25 quantile, opining that FPI's impact on emissions is more relevant for lower emission levels. Therefore, FPI is seen to have a significantly positive impact on CO_2 at lower quantiles but becomes irrelevant at higher quantiles. The differing significance of food production's impact on CO_2 emissions across quantiles reflects the role of Nigeria's agricultural practices, production capacity, and energy usage in influencing environmental outcomes. At lower quantiles, where carbon emissions are relatively low, food production shows a significant positive impact on emissions. This relationship can be attributed to the fact that food production in these settings often relies on traditional farming methods, which are less efficient and more carbon-intensive due to the use of fossil fuel-powered machinery, reliance on inorganic fertilizers, and open-field burning of crop residues. Post-harvest processing and storage for food production are frequently carried out with inefficient, energy-intensive systems, contributing to increased emissions even at lower production levels. As quantiles increase, the impact of food production diminishes and becomes insignificant. This trend suggests that as food production scales up, larger-scale food production may benefit from economies of scale and more efficient practices, such as better irrigation techniques, mechanization, and centralized storage systems, which help mitigate emissions relative to production output. Government policies aimed at enhancing agricultural productivity, such as subsidies for renewable energy and training in sustainable farming, may begin to offset the carbon footprint of food production in these settings. At higher quantiles, where emissions are dominated by industrial and urban activities, the direct impact of food production becomes negligible. This shift likely reflects that food production becomes part of a larger, more complex economic system where industrial emissions, energy generation, and transportation outweigh the direct emissions from agricultural activities. As food production modernizes, the adoption of climate-smart and regenerative practices may further reduce its relative contribution to emissions at higher levels of economic activity.

FDI was found to have a generally negative but weak impact on CO_2 emissions: negative impact (−0.197) with 10% significant at the 0.1 quantile; however, the effect loses its significance and becomes negligible in the higher quantiles. At the 0.1 quantile, the CPI has a significant negative impact (−0.581), but this impact becomes insignificant by the 0.5 quantile. Thus, CPI has a negative impact on carbon emissions at lower quantiles, with the effect diminishing at higher quantiles. RXR has a significant positive impact at the 0.1 quantile (0.365, significant at 5%), but this effect diminishes and becomes insignificant at higher quantiles. Hence, the effect of RXR is positive at lower quantiles and becomes insignificant at higher quantiles. The R^2 values are highest at the lower quantiles (0.1), indicating the model explains more variance in carbon emissions at lower emission levels. As we move to higher quantiles, the R^2 decreases slightly, suggesting the model is less effective at explaining variance in higher levels of carbon emissions. Specifically, Energy Consumption (ENCONS) is the most consistent predictor of carbon emissions across all quantiles, with a strong positive impact. Agricultural Raw Materials Import (AGRIM) has a diminishing positive impact on carbon emissions as you move from lower to higher quantiles. Agricultural Exports (AGRXs) have a generally negative impact, particularly significant at lower quantiles. Food Production Index (FPI) and Real Exchange Rate (RXR) are significant at lower quantiles, indicating they play a role in lower emission levels but not at higher levels. The Consumer Price Index (CPI) and Foreign Direct Investment (FDI_IN) have negative impacts at lower quantiles, though these effects diminish or disappear at higher quantiles.

6. Impact of Food Import and Export on Carbon Emission

Table 5 presents the results from a quantile regression analysis across different quantiles (0.1, 0.25, 0.5, 0.75, 0.9) for various variables but particularly food import and export. The breakdown of the results based on key variables shows that ENCONS (Energy Consumption) has significant positive coefficients across all quantiles (0.1–0.9), indicating that as energy consumption increases, the dependent variable, CO_2 emissions also increases. The coefficients range from approximately 9.78 (at the 0.5 quantile) to 15.17 (at the 0.25 quantile), with all p-values less than 0.001, highlighting a strong and consistent effect of energy consumption on CO_2 emissions variable across all quantiles. Whereas FIMP (Food Import) and FEX (Food Export) coefficients are small and mostly insignificant across all quantiles, with p-values much greater than 0.05, suggesting that food imports and exports do not have a statistically significant impact on the CO_2 emissions at any of the quantiles.

The effect of the Food Production Index is marginal and not statistically significant across most quantiles. The coefficient is positive at lower quantiles (0.1, 0.25) but turns slightly negative at the highest quantile (0.9), although none of these effects are significant. On FDI, negative coefficients are observed across all quantiles, with significance at the 0.1 and 0.25 quantiles ($p = 0.0662$ and 0.0472, respectively indicating a potentially negative relationship between FDI inflows and the CO_2 emissions, particularly in the lower quantiles. For CPI and RXR both variables have non-significant coefficients across all quantiles, suggesting no statistically significant impact on the CO_2 emissions. However, the constant term is negative and significant across all quantiles, implying that even when all other variables are zero, the dependent variable would take a negative value. Adjusted R^2 values range from approximately 0.69 to 0.77 across the quantiles, indicating a moderately strong fit of the model, especially in lower quantiles. R^2 values are slightly lower than the Adjusted R^2, which is expected, but still show a decent model fit.

Table 5. Results with food imports and exports.

Variable	0.1	0.25	0.5	0.75	0.9
ENCONS	14.26569 *** (0.0004)	15.17485 *** (0.0000)	9.779724 *** (0.0001)	11.73668 *** (0.0002)	13.61986 *** (0.0000)
FIMP	−0.004841 (0.9876)	−0.129848 (0.7425)	0.192900 (0.5184)	0.117840 (0.6438)	−0.051638 (0.7908)
FEX	−0.042643 (0.4526)	−0.009151 (0.8799)	−0.010142 (0.8734)	0.007552 (0.9048)	0.007713 (0.8759)
FPI	1.866129 (0.0984)	0.894985 (0.4557)	0.520435 (0.6074)	0.310436 (0.7821)	−0.017606 (0.9853)
FDI_IN	−0.217014 * (0.0662)	−0.265201 ** (0.0472)	−0.058367 (0.6071)	−0.088688 (0.3789)	−0.049981 (0.5368)
CPI	−0.381057 (0.1970)	−0.196210 (0.4868)	−0.078938 (0.7476)	−0.115411 (0.6919)	−0.115745 (0.6465)
RXR	0.398665 (0.2871)	0.223923 (0.3453)	0.153953 (0.4223)	0.093766 (0.5340)	0.011099 (0.9326)
C	−87.53671 ** (0.0028) ***	−87.67235 *** (0.0006) ***	−55.71286 ** (0.0037) ***	−66.32740 ** (0.0045) ***	−77.22025 *** (0.0003) ***
Adjusted R^2	0.765463	0.748511	0.693101	0.688865	0.685632
R^2	0.734487	0.715296	0.652567	0.647772	0.644112
Observation	61	61	61	61	61

Note: (1) This table shows the results of the quantile regression model with carbon emissions as dependent variables, and Energy Consumption, AGRIM, AGRX, and other variables and control variables as independent variables. (2) Figures in parentheses are *t*-values. *** Statistical significance at the 1% level. ** Statistical significance at the 5% level. * Statistical significance at the 10% level.

The results suggest that energy consumption is a key driver across all levels of the dependent variable's distribution. Foreign direct investment has a negative impact at lower quantiles, which could indicate that in scenarios with lower outcomes of CO_2 emissions, FDI might be less beneficial or even detrimental. Other variables like food imports, food exports, the food production index, consumer price index, and real exchange rate do not show significant impacts across the quantiles. The constant negative and significant intercept suggests that factors not included in the model have a substantial and consistently negative effect across all quantiles.

Impact of Trade Openness on Carbon Emission

Table 6 presents the results of a quantile regression analysis examining the impact of various variables with particular emphasis on trade openness on carbon emissions across different quantiles (0.1, 0.25, 0.5, 0.75, 0.9). The coefficients for energy consumption are positive and statistically significant across all quantiles (p-values < 0.001). This suggests that as energy consumption increases, carbon emissions also increase consistently across all levels of carbon emissions and the impact of energy consumption is strongest in the lower quantiles (0.1 quantile: 14.66) and somewhat lower but still significant at higher quantiles (0.5 quantile: 9.01; 0.9 quantile: 13.10). The TO (Trade Openness) output in Table 6 shows the coefficients for trade openness are negative across all quantiles, indicating that greater trade openness is associated with a reduction in carbon emissions. The findings contradicted the findings of [81,82], who demonstrated that the level of commerce influences environmental benefits but substantiated that of [10], who posits that the greater net export effects in developed countries indicate that developing countries can develop into pollution hotspots and house filthy industries. The effect is statistically significant at all quantiles except the highest quantile (0.9), with the most substantial impact observed at the median (0.5 quantile: −0.47), where the p-value is highly significant ($p < 0.001$).

Table 6. Impact of trade openness on carbon emissions.

Variable	0.1	0.25	0.5	0.75	0.9
ENCONS	14.66140 *** (0.0005)	12.03100 *** (0.0005)	9.013289 *** (0.0000)	10.71362 *** (0.0000)	13.09729 *** (0.0001)
TO	−0.290152 ** (0.2492)	−0.203308 ** (0.2831)	−0.467680 *** (0.0001)	−0.153876** (0.2561)	−0.183609 (0.1278)
FPI	0.416420 *** (0.8715)	0.352816 *** (0.7529)	−0.511239 ** (0.3405)	0.164485 *** (0.8317)	0.784148 ** (0.3881)
FDI_IN	−0.277925 (0.0086)	−0.256933 (0.0287)	−0.144948 (0.0293)	−0.006371 *** (0.9303)	−0.070787 (0.2540)
CPI	−0.093914 (0.8763)	−0.022173 (0.9328)	0.159956 (0.2090)	−0.076565 (0.6879)	−0.261100 (0.2929)
RXR	−0.064343 (0.8880)	−0.007890 (0.9712)	−0.125143 (0.2116)	0.049780 (0.6583)	−0.039184 (0.6997)
C	−81.82868 * (0.0233)	−64.93233 ** (0.0085)	−44.07339 *** (0.0002)	−60.53955 *** (0.0005)	−76.34502 *** (0.0007)
Adjusted R^2	0.767093	0.759561	0.728366	0.709666	0.709517
R^2	0.741215	0.732846	0.698184	0.677406	0.677241
Observation	61	61	61	61	61

Note: (1) Table displays the findings of the quantile regression model with carbon emissions as dependent variables, while Energy Consumption, AGRIM, AGRX, and other variables and control variables have distinct parameters. (2) Figures in parentheses are *t*-values *** Statistical significance at the 1% level. ** Statistical significance at the 5% level. * Statistical significance at the 10% level.

The FPI (Food Production Index) impact on carbon emissions varies across quantiles, with mixed results. The coefficients are mostly positive but not statistically significant, except at the 0.5 quantile where the coefficient is negative and significant (−0.51), suggesting that higher food production might reduce carbon emissions in the middle of the distribution. The coefficients for FDI inflows are negative across most quantiles, indicating that an increase in FDI inflows is associated with a reduction in carbon emissions. The effect is statistically significant at lower quantiles (0.1, 0.25, 0.5) with a particularly strong effect at the 0.1 quantile (−0.28) but becomes insignificant at the higher quantiles (0.75, 0.9). In contrast, CPI and RXR show mostly non-significant coefficients across all quantiles, suggesting that they do not have a significant impact on carbon emissions. The constant term is negative and significant across all quantiles, indicating that even in the absence of the other variables, the baseline level of carbon emissions would be negative, suggesting the presence of other unobserved factors that could be offsetting emissions. Adjusted R^2 and R^2 values range from approximately 0.68 to 0.77 across quantiles, indicating a moderately strong fit of the model, particularly in lower quantiles.

It is therefore interpreted that Energy Consumption is a key driver of carbon emissions, consistently increasing emissions across all levels of the distribution, and Trade Openness tends to reduce carbon emissions, with the strongest effect at the median level, suggesting that policies promoting trade openness might help reduce emissions, particularly in economies with a moderate carbon output. The FDI Inflows also seem to reduce emissions, especially at lower levels, indicating that foreign investments could be associated with cleaner technologies or more efficient production methods in less polluting sectors. Meanwhile, the Food Production Index has a mixed impact, with some evidence of reducing emissions at the median level, possibly reflecting shifts in production patterns. The non-significance of CPI and RXR suggests that inflation and exchange rate fluctuations do not have a notable impact on carbon emissions in this context. It is our recommendation that policies that promote self-sufficiency in domestic agricultural production, thereby reducing the reliance on high-carbon-footprint imported products, be encouraged and enacted.

7. Conclusions

The analysis presented in this study offers valuable insights into the factors influencing carbon emissions, particularly in relation to agricultural imports and exports, energy consumption, and trade openness. The quantile regression analysis reveals that energy consumption is a consistent and significant driver of carbon emissions across all quantiles. Nigeria's energy policies, while increasingly aiming at diversification and renewable energy adoption, have yet to make a substantial impact. Subsidies for fossil fuels and limited infrastructure for renewable energy expansion perpetuate the carbon intensity of energy consumption, especially at the extremes of the economic spectrum. The results emphasize the need for differentiated policy interventions: At lower quantiles, efforts should focus on expanding access to cleaner energy technologies in rural areas. At mid-level quantiles, promoting energy-efficient technologies and infrastructure in urban centers can mitigate emissions. At higher quantiles, accelerating the transition to renewables and reducing dependence on fossil fuels in industrial sectors is critical. Agricultural raw material imports show a diminishing positive impact on emissions, while agricultural exports tend to reduce emissions, especially at lower quantiles. Nigeria's high dependency on agricultural imports is driven by gaps in domestic production capacity. Policies aimed at achieving self-sufficiency, such as restrictions on certain agricultural imports and investments in local farming, have begun to address this dependency. However, the carbon footprint of imports remains significant, especially where supply chains rely on energy-intensive storage and transportation. Efforts should focus on reducing the reliance on imports by enhancing domestic agricultural production through sustainable practices. Incentivizing the adoption of renewable energy and efficient logistics for transportation and storage can mitigate the carbon intensity of necessary imports. To sustain the negative impact on emissions, policies should promote low-carbon farming practices, encourage organic certification, and invest in green technologies for processing and transportation. Export incentives could be tied to adherence to sustainability standards. Agricultural exports are encouraged as part of Nigeria's economic diversification strategy. While exports contribute to foreign exchange earnings, the environmental benefits at lower quantiles may not scale sustainably without adopting low-carbon farming practices. The reliance on traditional agricultural methods for export-oriented crops may initially reduce emissions but risks reversing these gains as production scales without corresponding investments in sustainability.

Regarding the impact of agricultural production, the variations across quantiles align with the structural challenges and policy efforts in Nigeria's food production sector. Traditional smallholder farming, prevalent in lower quantiles, remains resource-intensive and inefficient, contributing to emissions. Modern practices, more common in mid and upper quantiles, can achieve higher yields with relatively lower emissions. High levels of post-harvest losses in Nigeria exacerbate emissions at lower quantiles, as energy is expended on production without a corresponding output of consumable food. Policy initiatives, such as promoting agro-ecological practices and improving climate resilience in food systems, have helped reduce the intensity of emissions as food production scales up. At lower quantiles, efforts should focus on transitioning smallholder farmers to more efficient, low-carbon practices. Subsidizing access to renewable energy-powered equipment and promoting organic farming can reduce emissions at these levels. At mid-level quantiles, strengthening post-harvest infrastructure, such as cold storage powered by renewable energy, and encouraging precision agriculture practices can sustain the trend of reduced emission intensity. At higher quantiles, expanding the adoption of climate-smart agriculture and integrating food production into broader sustainability frameworks (e.g., circular economies) will ensure emissions from food systems remain minimal as economic activities grow. Foreign direct investment and consumer price index demonstrate negative impacts on emissions at lower quantiles, although these effects diminish at higher levels. The study highlights the complexities of the relationship between trade, investment, and environmental outcomes, suggesting that policies aimed at reducing carbon emissions need to consider the varying effects of these factors across different levels of emissions. The findings underscore the importance of adopting a nuanced approach to environmental policy, one that recognizes the differential impacts of economic activities across the spectrum of carbon emission levels. Future research could further explore these dynamics in different contexts, providing a more comprehensive understanding of how economic factors contribute to environmental outcomes. This conclusion synthesizes the key findings and implications of the empirical results presented in the document.

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Appendix A. Diagnostics Tests

Table A1. Diagnostics Tests.

Test	Statistics	*p*-Value	Decision
Jarque–Bera test	2.866	0.239	Normally distributed
Ramsey RESET test	0.136	0.228	Parameters are stable; no misspecification
Autocorrelation (Q-Statistics (12))	2.227	0.316	No autocorrelation

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