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THE CARBON CURVE OF A RISING POWER: HOW GLOBALIZATION AND ENERGY POLICY SHAPE CHINA'S EMISSIONS PATHWAY

[1]Dr. Fawad Hussain Paul, [2]Dr. Ahmed Farhan Saeed, [3]Dr. Sanam Wagma Khattak

[1]Assistant Professor in Economics, College of Education, Department of Sindh
[2]Faculty: Area Study Centre: University of Peshawar. Guizhou Normal University: P.R China
[3]Lecturer Department of Economics University of Peshawar KPK

[1]fawad.paul@gmail.com, [2]Drfarhan@uop.edu.pk
[3]Sanamah@uop.edu.pk

Abstract

This study investigates the relationship between economic growth, coal consumption, globalization, and carbon dioxide (CO_2) emissions in China within the framework of the Environmental Kuznets Curve (EKC) hypothesis. Using annual data from 1970 to 2024, the analysis incorporates the KOF Index of Globalization alongside economic and environmental variables to capture the multidimensional effects of globalization. Employing the combined cointegration approach by Bayer and Hanck and the Autoregressive Distributed Lag (ARDL) bounds testing method, the results confirm a long-run equilibrium relationship among the variables. The findings validate the EKC hypothesis for China, revealing that economic growth initially increases CO_2 emissions, which subsequently decline after reaching a certain income threshold. Coal consumption is identified as a significant contributor to rising emissions, while globalization exerts a mitigating effect, reducing environmental degradation through technological advancement and structural transformation. The VECM Granger causality analysis uncovers feedback relationships between coal consumption and CO_2 emissions and identifies economic growth and globalization as key drivers of environmental outcomes. The study highlights the need for China to transition toward a low-carbon economy by diversifying its energy mix, enhancing energy efficiency, and promoting cleaner energy sources. It also emphasizes the importance of regional policy strategies and sector-specific analyses for sustainable environmental and economic development.

Keywords: Environmental Kuznets Curve (EKC), CO_2 Emissions, Globalisation, Renewable Energy

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INTRODUCTION

Over the past century, carbon dioxide (CO_2) emissions have risen significantly, driven primarily by rapid economic expansion and industrialization. This trend has spurred extensive research into the relationship between economic growth and environmental quality, particularly as framed by the Environmental Kuznets Curve (EKC) hypothesis. Introduced by (1) the EKC posits that environmental degradation initially worsens with economic growth but eventually declines once per capita income surpasses a certain threshold, resulting in an inverted U-shaped relationship.

The interplay between energy consumption, economic growth, and environmental pollution has drawn considerable attention, especially given growing concerns about greenhouse gas (GHG) emissions and their impact on air quality. In a seminal study, (2) identified a causal link from economic growth to energy consumption in the United States, highlighting how economic advancement often increases energy demand, thereby elevating CO_2 emissions.

China exemplifies this dynamic, having become the world's largest consumer and producer of coal. As of 2023, coal accounted for nearly 60% of China's electricity supply, despite substantial investments in renewable energy (S&P Global). Coal combustion is significantly more carbon-intensive than oil or natural gas, making it a major contributor to CO_2 emissions. Nevertheless, coal remains a cornerstone of China's energy strategy, particularly in sustaining its rapidly growing economy.

Globalization has further complicated the connection between economic development and environmental sustainability. At lower income levels, societies often prioritize economic growth over environmental concerns, leading to increased pollution. However, as incomes rise, environmental quality tends to receive greater emphasis. While globalization can exacerbate environmental degradation through heightened industrial activity and resource exploitation, it can also facilitate the spread of cleaner technologies and practices.

China's integration into the global economy has been marked by extensive trade liberalization and foreign direct investment (FDI), especially following its accession to the World Trade Organization (WTO). While this openness has fueled economic growth, it has also raised concerns about environmental degradation. Conversely, globalization may improve environmental standards by boosting income levels and introducing advanced technologies that reduce pollution intensity.

To empirically assess the EKC hypothesis in China, a study examined the long-term relationship between CO_2 emissions, economic growth, coal consumption, and globalization from 1971 to 2024. Using the combined cointegration approach by (3) and the autoregressive distributed lag (ARDL) bounds testing method, the study found evidence supporting the EKC hypothesis. Specifically, it identified an inverted U-shaped relationship between economic growth and CO_2 emissions. Coal consumption was a significant driver of CO_2 emissions, while globalization had a mitigating effect. Additionally, causality tests revealed that both economic growth and globalization Granger-cause CO_2 emissions, with coal consumption also exerting a causal influence.

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In recent years, China has made significant progress in expanding its renewable energy capacity. By 2024, the country had added substantial solar and wind power capacity, contributing to a structural decline in carbon emissions (Financial Times, The Australian). Despite these advancements, coal remains dominant, with new coal-fired power plants still being constructed. This dual approach underscores China's ongoing challenge of balancing economic growth with environmental sustainability.

Looking ahead, China's ability to meet its climate commitments—peaking CO_2 emissions before 2030 and achieving carbon neutrality by 2060—will hinge on its capacity to phase out coal and further integrate renewable energy into its power grid. The EKC framework suggests that as China's per capita income continues to rise, environmental quality may improve, provided that appropriate policies and technologies are implemented to facilitate this transition (Wikipedia)

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature. Section 3 describes the data, model construction, and estimation strategy. Section 4 presents and analyzes the results, while Section 5 provides concluding remarks and policy implications.

REVIEW OF LITERATURE

ECONOMIC GROWTH AND ENVIRONMENTAL DEGRADATION

The relationship between economic growth and environmental degradation has been a significant topic of discussion since the mid-1990s. Numerous studies have explored the existence of an inverted U-shaped curve, known as the Environmental Kuznets Curve (EKC), which describes the link between economic development and environmental pollution. (1) pioneered this debate by proposing that environmental degradation initially worsens with economic growth but improves after a certain income threshold is reached. (4) supported this view, demonstrating that economic growth initially increases environmental degradation but reverses this trend once per capita income crosses a specific level. Similar findings were reported by (5), (6), and (7), who confirmed an inverted U-shaped relationship between economic growth and CO_2 emissions.

Empirical research on the EKC suggests that a nation's environmental quality improves as it attains higher income levels. Studies by (8), (1), (9), and Suri and (10) validated the inverted U-shaped pattern in the economic development process. However, (11) failed to establish such a relationship. Friedl and (12) observed an initial positive link between economic growth and CO_2 emissions, which later transformed into an N-shaped curve due to rising emissions. (13) argued that while the EKC may hold in some cases, it is not universally applicable, indicating no definitive evidence of an inverted U-shaped relationship. (12) further challenged the EKC hypothesis by finding no statistical support for its existence.

(14) examined Romania's case, incorporating energy consumption into the analysis of CO_2 emissions. Their results confirmed the EKC hypothesis, with energy consumption significantly contributing to emissions. Similarly, (15) validated the EKC for India. (16) analyzed Chinese provincial data (1993–2002) and found an inverted U-

shaped relationship between economic growth and energy-related pollutants, emphasizing that poorer provinces require more financial resources to enhance environmental quality. (17) confirmed the EKC for Shenzhen (1989–2003), while (18) noted its validity in Japan but not in China. (19) supported the inverted U-shaped curve using pollution indicators like solid waste, wastewater, and waste gas in China. (20) also validated the EKC for China (1992–2003), identifying 10,000 Yuan as the per capita income threshold. (21) reaffirmed the EKC in Zhejiang province, linking environmental quality to economic performance.

(22) employed a multivariate model to analyze China's carbon emissions, energy consumption, urbanization, and economic growth. They found that energy consumption drives CO_2 emissions, while economic growth influences energy demand. However, neither carbon emissions nor energy consumption directly affected economic growth. (23) examined coal consumption's role in emissions for China and India (1965–2006), concluding that coal use spurs economic growth in both nations. They recommended adopting cleaner technologies to reduce emissions and achieve sustainable development. (24) also confirmed the EKC for China.

(25) used provincial data to study energy consumption, CO_2 emissions, and economic growth in China, finding long-run cointegration and a feedback effect between energy use and growth. Economic growth was also found to Granger-cause CO_2 emissions. (26) further validated the EKC in China. (27) explored China and India, confirming the EKC and noting that energy consumption increases emissions in both countries, while trade openness reduces emissions in India. Guo (2014) supported the inverted U-shaped curve using regional income and CO_2 emissions data.

(28) investigated industrial data (2000–2010), showing that trade openness and FDI boost CO_2 emissions while validating the EKC between industrial income and emissions.

GLOBALIZATION AND ENVIRONMENTAL DEGRADATION

Globalization facilitates the transfer of advanced technology from developed to developing economies, promotes the division of labor, and enhances the comparative advantage of nations. By increasing trade, it improves total factor productivity and stimulates economic activity through foreign direct investment (FDI) and technology transfers. Additionally, globalization creates investment opportunities via FDI and strengthens financial markets. The expansion of trade and economic growth driven by globalization directly influences energy demand and environmental conditions.

Researchers have employed various measures of globalization to assess its impact on environmental degradation. For example, (1) analyzed the environmental effects of the North American Free Trade Agreement (NAFTA) and found that trade openness (globalization) affects environmental degradation through the scale effect, holding composition and technique effects constant. (29) emphasized that trade patterns depend on relative factor endowments, meaning comparative advantage in trade can influence environmental quality based on a country's trade and environmental policies. (30) and (31) argued that trade openness enhances environmental quality via the technique effect, as stricter environmental regulations and energy-efficient technologies are adopted with rising income levels.

In the case of China, (32) observed that trade openness worsens environmental quality due to improved terms of trade, though higher income levels mitigate degradation. (19) analyzed data from 63 developed and developing economies and found that a 1% increase in trade is associated with a 0.58% rise in carbon emissions. (33) and (34) also confirmed that trade significantly impacts the environment. Similarly, (14) reported that trade openness (globalization) increases environmental degradation in Indonesia, while (15) examined the Environmental Kuznets Curve (EKC) hypothesis by incorporating a globalization index into the CO_2 emissions function for Turkey.

ECONOMIC, SOCIAL, AND POLITICAL ASPECTS OF GLOBALIZATION IN CHINA: KEY MEASURES

Globalization fosters interdependence, integration, and internationalization. Since the early 1990s, China's engagement with globalization has presented a double-edged sword. While it has spurred trade expansion, economic growth, and increased investment, it has also led to economic disparities, creating winners and losers. Certain regions, sectors, and social groups have faced adverse effects due to trade openness, particularly concerning environmental degradation and rising CO_2 emissions. In recent years, the Chinese government has implemented significant measures to curb emissions, including promoting alternative energy sources, investing in clean coal technology, and enforcing pollution control policies at local, provincial, and national levels.

The study primarily examines the impact of globalization on CO_2 emissions using the KOF Index of Globalization, developed by Dreher et al. (2008). This index evaluates three key dimensions of globalization—economic, social, and political—making it a suitable measure for analyzing globalization’s effects in China compared to other openness indicators.

ECONOMIC GLOBALIZATION encompasses international trade flows of goods, capital, and services. It is measured using two sub-indices:

ACTUAL FLOWS—including trade volumes, foreign direct investment (FDI), portfolio investment, income payments to foreign nationals, and foreign capital utilization, indicating the extent of foreign participation in domestic production.

TRADE AND CAPITAL RESTRICTIONS—incorporating hidden import barriers, tariff rates, international trade taxes, and capital control indices.

POLITICAL GLOBALIZATION reflects the diffusion of government policies, measured by:

- The number of embassies in a country.
- Participation in United Nations (UN) peace missions.
- Membership in international organizations.

SOCIAL GLOBALIZATION captures the spread of ideas, information, and people, assessed through:

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PERSONAL CONTACTS—measured by international tourism and telecommunications (e.g., internet users, radio ownership).
INFORMATION FLOWS AND CULTURAL PROXIMITY—tracking cross-border exchanges of media, ideas, and cultural influences.

This comprehensive framework ensures an accurate evaluation of globalization's multifaceted impact on China's economy, society, and environment.

TABLE 1 SUMMARIZES THE KEY FINDINGS FROM THE LITERATURE REVIEW.

Authors	Study Focus	Key Findings
Grossman & Krueger (1991)	Relationship between economic growth & environmental degradation	Proposed the EKC hypothesis (inverted U-shaped curve).
Selden & Song (1994)	Economic growth & environmental degradation in early vs. later stages	Confirmed EKC—degradation rises initially, then declines after a threshold.
Heil & Selden (2001)	CO_2 emissions & economic growth	Supported inverted U-shaped EKC for CO_2 emissions.
Friedl & Getzner (2003)	CO_2 emissions trajectory with economic growth	Found N-shaped curve (emissions rise again after initial decline).
Perman & Stern (2003)	Statistical testing of EKC	No strong evidence for EKC in some cases.
Shahbaz et al. (2013a)	Romania: Energy consumption, CO_2 emissions, & growth	Validated EKC; energy use increases emissions.
Tiwari et al. (2013)	India: Economic growth & CO_2 emissions	EKC hypothesis holds for India.
Junyi (2006)	China (1993–2002): Growth vs. energy pollutants	Inverted U-shaped EKC; poorer provinces need more funds for environmental quality.
Yaguchi et al. (2007)	Japan vs. China: EKC validity	EKC exists in Japan but not in China.
Zhang & Cheng (2009)	China: CO_2 emissions, energy use, urbanization, & growth	Energy use → CO_2 emissions; growth → energy use; no reverse causality.
Li & Li (2011)	China & India: Coal consumption & emissions (1965–2006)	Coal use drives growth; cleaner tech is needed for sustainability.
Wang et al. (2011)	China (provincial): Energy, CO_2, & growth	Long-run cointegration; growth → CO_2 emissions.
Jayanthakumaran et al. (2012)	China & India: Energy, trade, & CO_2 emissions	EKC holds; trade reduces emissions in India.
Guo (2014)	China: Regional income vs.	Confirmed inverted U-shaped

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	CO_2 emissions	EKC.
Ren et al. (2014)	China (industrial, 2000–2010): FDI, trade, & CO_2 emissions	Trade & FDI increase emissions; EKC holds for industrial income.

THE DATA, MODEL AND ESTIMATION STRATEGY

DATA

The study investigates the existence of the Environmental Kuznets Curve (EKC) in China by analyzing per capita coal consumption (million tons), per capita CO2 emissions (metric tons), per capita real GDP (Chinese currency), and the KOF globalization index. Data on coal consumption, CO2 emissions, and real GDP were obtained from the World Development Indicators, with population figures used to convert the series into per capita terms. The KOF globalization index, taken from Dreher (2006), includes three sub-indices: economic, social, and political globalization. The analysis covers the period from 1970 to 2024.

MODEL

Following (35), the study integrates coal consumption intensity and globalization into the CO2 emissions function as additional determinants of economic growth and, consequently, CO2 emissions. The general functional form of the model is as follows:

$$E_t = f(C_t, Y_t, Y_t^2, G_t) \text{.........}(1)$$

All variables have been transformed into natural logarithms. The empirical model is specified as follows:

$$lnE_t = \beta_1 + \beta_c C_t + \beta_Y Y_t + \beta_{y^2} Y_t^2 + \beta_G G_t + \mu_t \text{..........}(2)$$

Let lnE_t denote the natural log of CO_2 emissions per capita, $lnC_t lnY_t(lnY_t^2)$ represent the natural log of coal consumption intensity per capita, G_t signify the natural log of the KOF index of globalization, and μ_t be the error term, which follows a normal distribution with zero mean and predictable variance. The impact of coal consumption on CO_2 emissions is expected to be positive $\beta_C > 0$.

The relationship between economic growth (real GDP per capita) and CO2 emissions is inverted U-shaped if $\beta_Y > 0$ and $\beta_{y^2} > 0$, but U-shaped if $\beta_C < 0$ and $\beta_{y^2} < 0$. Additionally, energy-efficient technology adoption through FDI and trade enhances domestic production if $\beta_G < 0$; otherwise, $\beta_G > 0$ holds.

ESTIMATION STEPS

ZIVOT–ANDREWS UNIT ROOT TEST

Several unit root tests are available to examine the stationarity properties of variables, including the Augmented Dickey–Fuller (ADF) test by (36), the Phillips and Perron test by (37), the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test by (38), the Dickey–Fuller Generalized Least Squares (DFGLS) test by (39), and the Ng–Perron test by (40). However, these tests may produce biased and spurious results due to their inability to account for structural break points in the series.

To address this issue, (41) introduced three models to test stationarity in the presence of a structural break:

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1. **MODEL (I):** Allows for a one-time change in the intercept (level) of the series.
2. **MODEL (II):** Permits a one-time change in the slope of the trend component.
3. **MODEL (III):** Incorporates a one-time change in both the intercept and the trend function of the series.

These models help validate the hypothesis of a single structural break in the series, improving the robustness of stationarity testing.

$$\Delta y_t = a + a\Delta y_{t-1} + bt + cDU_t + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \mu_t \ldots\ldots\ldots\ldots(3)$$

$$\Delta y_t = b + b\Delta y_{t-1} + ct + bDT_t + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \mu_t \ldots\ldots\ldots\ldots(4)$$

$$\Delta y_t = c + c\Delta y_{t-1} + ct + dDU_t + dDT_t + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \mu_t \ldots\ldots\ldots\ldots(5)$$

The dummy variable is denoted by DU_t, indicating a mean shift occurring at each point with a time break, while the trend shift variable is represented by DT_t .

$$DU_t = \begin{cases} 1, \ldots, if \ \ t > TB \\ 0, \ldots, if \ \ t < TB \end{cases} and \ DU_t = \begin{cases} t - TB, \ldots, if \ \ t > TB, \\ \quad 0, \ldots, if \ \ t < TB. \end{cases}$$

The null hypothesis of the Zivot–Andrews unit root test is c = 0, indicating that the series is non-stationary with a drift and does not account for a structural break. In contrast, the alternative hypothesis c < 0 implies that the variable is trend-stationary with an unknown single break point.

The Zivot–Andrews test treats every point as a potential break date and estimates regressions for all possible break points sequentially. It then selects the break date that minimizes the one-sided t-statistic for testing hypothesis $c(=\widehat{c-1}) = 1$.

Zivot–Andrews note that when break points occur near the endpoints of the sample, the asymptotic distribution of the test statistics diverges to infinity. To address this, the test excludes the endpoints by restricting the search to a trimming region, specifically (0.15T,0.85T), where T is the sample size.

BAYER AND HANCK COINTEGRATION APPROACH

In econometric analysis, a set of time series is said to be integrated if two or more series are individually integrated, but some linear combination of them exhibits a lower order of integration. (42) formalized the first cointegration test, which serves as a necessary criterion for stationarity among non-stationary variables. This approach offers more powerful tools for datasets of limited length, a common feature of most economic time series. Later, (43) developed the Johansen maximum eigenvalue test, which allows for more than one cointegrating relationship, making it more generally applicable than the Engle-Granger test. Another key approach is the Phillips-Ouliaris cointegration test (44), which relies on residual-based techniques. Other notable methods include the error correction model (ECM) based F-test by (45) and the ECM-based t-test by (46). However, different tests may yield conflicting conclusions.

To improve the power of cointegration testing, (3) proposed a novel approach called the Bayer-Hanck combined test. This method generates a joint test statistic for the null hypothesis of no cointegration by combining results from the Engle-Granger, Johansen, Boswijk, and Banerjee tests. Since this approach synthesizes multiple individual cointegration test outcomes to deliver a more conclusive finding, it is employed in this study to examine the cointegrating relationship among economic growth, coal consumption, globalization, and CO2 emissions in China. Following (3), the combination of computed significance levels (p-values) from individual cointegration tests is derived using Fisher's formulas as follows:

$$EG - JOH =- 2\left[\ln\left(P_{EG}\right) + \left(P_{JOH}\right)\right] \text{..............}(6)$$

$$EG - JOH - BO - BDM =- 2[\ln\left(P_{EG}\right) + \left(P_{JOH}\right) + \ln\left(P_{BO}\right) + \left(P_{BDM}\right), \text{.........}(7)$$

While P_{EG} , P_{BO} ,P_{JOH} and P_{BDM} represent the p-values from individual cointegration tests. If the estimated Fisher statistics exceed the critical values Bayer and Hanck (2013) provided, the null hypothesis of no cointegration is rejected.

THE VECM GRANGER CAUSALITY

After examining the long-run relationship between the variables, we use the Granger causality test to determine the causality between the variables. If there is cointegration between the series then the VECM can be developed as follows:

$$(1 - L) = \begin{bmatrix} lnE_t \\ lnY_t \\ lnY_t^2 \\ lnC_t \\ lnG_t \end{bmatrix}$$

$$= \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix} + \begin{bmatrix} b_{11i} & b_{21i} & b_{31i} & b_{41i} & b_{51i} \\ b_{21i} & b_{22i} & b_{32i} & b_{42i} & b_{52i} \\ b_{31i} & b_{23i} & b_{33i} & b_{43i} & b_{53i} \\ b_{4i} & b_{24i} & b_{34i} & b_{44i} & b_{54i} \\ b_{5i} & b_{25i} & b_{35i} & b_{45i} & b_{55i} \end{bmatrix} * \begin{bmatrix} lnE_{t-1} \\ lnY_{t-1} \\ lnY_{t-1}^2 \\ lnC_{t-1} \\ lnG_{t-1} \end{bmatrix} + \dots$$

$$+ \begin{bmatrix} b_{11i} & b_{21i} & b_{31i} & b_{41i} & b_{51i} \\ b_{21i} & b_{22i} & b_{32i} & b_{42i} & b_{52i} \\ b_{31i} & b_{23i} & b_{33i} & b_{43i} & b_{53i} \\ b_{4i} & b_{24i} & b_{34i} & b_{44i} & b_{54i} \\ b_{5i} & b_{25i} & b_{35i} & b_{45i} & b_{55i} \end{bmatrix} * \begin{bmatrix} lnE_{t-1} \\ lnY_{t-1} \\ lnY_{t-1}^2 \\ lnC_{t-1} \\ lnG_{t-1} \end{bmatrix} + \begin{bmatrix} \alpha \\ \beta \\ \vartheta \\ \gamma \\ \rho \end{bmatrix} ECT_{t-1} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \epsilon_3 \\ \epsilon_4 \\ \epsilon_5 \end{bmatrix} \text{.........}(8)$$

Where the difference operator is denoted as (1-L) and ECM_{t-1} represents the lagged error correction term, generated from the long-run association. Long-run causality is determined by the significance of the coefficient of the lagged error correction term, using the t-test statistic. A significant relationship in the first differences of the variables provides evidence on the direction of short-run causality. The joint χ^2 statistic for the first-differenced lagged independent variables is employed to test the direction of short-run causality between the variables. For example, $B_{12,i} \neq 0\forall_i$, indicates that economic growth Granger causes CO_2 emissions, while $B_{11,i} \neq 0 \forall_i$, shows that CO_2 emissions Granger cause economic growth.

FINDINGS AND DISCUSSIONS

To investigate cointegration among the variables, testing their stationarity is a necessary precondition. For this purpose, we apply the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests, including both intercept and trend. The results, reported in Table 2, indicate that CO2 emissions per capita, real GDP per capita (and its squared term), coal consumption per capita, and globalization (including economic, political, and social globalization) are non-stationary at level. Both ADF and PP tests confirm that all variables are integrated of order one, I(1).

However, ADF and PP unit root tests may yield ambiguous results due to their limited explanatory power. These tests do not account for unknown structural breaks in the series, which can weaken the stationarity hypothesis. To address this issue, we employ the Zivot–Andrews unit root test, which incorporates information about a single unknown structural break. The results, presented in Table 3, reveal that all variables exhibit a unit root at level in the presence of structural breaks. The identified breaks occur in 2006, 1980 (1991), 2006, 2002, 1995, 2004, and 2000 for CO2 emissions, real GDP per capita (and its squared term), coal consumption per capita, globalization, and its sub-components (economic, political, and social globalization). Notably, all variables become stationary after first differencing, confirming their I(1) integration.

Since all unit root tests confirm that the variables are I(1), we employ the combined cointegration approach (3) developed to investigate cointegration. Table 4 presents the results of the EG–JOH and EG–JOH–BO–BDM tests. The Fisher statistic for both tests exceeds the 5% critical value when CO2 emissions and coal consumption are used as dependent variables, rejecting the null hypothesis of no cointegration. Similar results are observed when economic, political, and social globalization serve as measures of globalization, confirming a long-run relationship among the variables. Thus, we conclude that CO2 emissions per capita, real GDP per capita (and its squared term), coal consumption per capita, and globalization (economic, political, and social dimensions) share a long-run relationship in China from 1970 to 2024.

While the (3)cointegration approach provides robust results, it does not account for structural breaks. To address this limitation, we apply the ARDL bounds testing approach to cointegration with structural breaks, following (14). The ARDL bounds test is sensitive to lag length selection; therefore, we use the Akaike Information Criterion (AIC) to determine the optimal lag order, as recommended by (47)for capturing dynamic relationships. The results, shown in Column 2 of Table 5, are evaluated using Narayan (2005) critical bounds. The calculated F-statistic exceeds the upper bound when CO2 emissions (Et) and coal consumption (Ct) are used as dependent variables, and similar findings hold for alternative globalization measures. This confirms the presence of cointegration, reinforcing the long-run relationship among the variables.

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TABLE 2: UNIT ROOT ANALYSIS

VARIABLE	ADF UNIT ROOT TEST (T-STATISTIC)	ADF (PROB. VALUE)	PP UNIT ROOT TEST (T-STATISTIC)	PP (PROB. VALUE)
LNET	-2.2796 (2)	0.4343	-1.9487 (3)	0.6115
LNYT	-3.1344 (1)	0.1360	-3.4000 (3)	0.0653
LNY^{2}T	-2.1809 (2)	0.4808	-2.5580 (3)	0.3008
LNCT	2.5989 (1)	0.2830	2.5434 (6)	0.3069
LNGT	-1.1910 (1)	0.8989	-1.3366 (3)	0.8661
LNEGT	-2.0344 (3)	0.5653	-2.9902 (3)	0.5603
LNPGT	-1.8648 (2)	0.6539	-1.9765 (6)	0.5964
LNSGT	-1.6211 (2)	0.7667	1.8908 (3)	0.6410
ΔLNET	-4.0881 (2)**	0.0136	-4.4714 (3)*	0.0050
ΔLNYT	-4.3743 (1)*	0.0071	-4.4126 (3)*	0.0059
ΔLNY^{2}T	-3.8385 (2)**	0.0251	-4.2013 (3)**	0.0101
ΔLNCT	-4.3487 (1)*	0.0071	-6.0807 (3)*	0.0001
ΔLNGT	-3.9768 (1)**	0.0179	-6.2928 (3)*	0.0000
ΔLNEGT	-4.3235 (1)*	0.0075	-5.2333 (3)*	0.0006
ΔLNPGT	-3.8629 (2)**	0.0235	-5.7411 (3)*	0.0001
ΔLNSGT	-4.4243 (3)*	0.0058	-6.0002 (3)*	0.0001

TABLE 3: ZIVOT–ANDREWS STRUCTURAL BREAK TRENDED UNIT ROOT TEST

VARIABLE	AT LEVEL (T-STATISTIC)	TIME BREAK	AT FIRST DIFFERENCE (T-STATISTIC)	TIME BREAK
LNE$_T$	-4.213 (1)	2006	-5.671 (2)*	2005
LNY$_T$	-3.403 (1)	1980	-4.996 (1)**	1985
LNY^{2}T	-2.928 (2)	1991	-4.542 (1)**	1985
LNC$_T$	-2.809 (1)	2006	-6.472 (2)**	2004
LNG$_T$	-2.248 (2)	2002	-7.762 (1)*	1991
LNEG$_T$	-3.238 (3)	1995	-6.108 (2)*	1982
LNPG$_T$	-2.423 (2)	2004	-6.828 (1)*	1991
LNSGT	-2.446 (1)	2000	-6.288 (2)*	1991

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TABLE 4: RESULTS OF BAYER AND HANCK COINTEGRATION ANALYSIS

Estimated Model	EG–JOH Statistic	EG–JOH–BO–BDM Statistic	Cointegration
$CO_2 = f(Y, Y^2, C, G)$	19.9181**	28.9418**	Yes
$Y = f(CO_2, Y^2, C, G)$	4.9221	4.7596	No
$Y^2 = f(CO_2, Y, C, G)$	4.5444	7.1299	No
$C = f(CO_2, Y, Y^2, G)$	16.6566**	30.3089**	Yes
$G = f(CO_2, Y, Y^2, C)$	5.286	8.5892	No
$CO_2 = f(Y, Y^2, C, EG)$	14.2518**	21.7464**	Yes
$Y = f(CO_2, Y^2, C, EG)$	4.4048	4.0685	No
$Y^2 = f(CO_2, Y, C, EG)$	3.2394	9.917	No
$C = f(CO_2, Y, Y^2, EG)$	13.4418**	23.2834**	Yes
$EG = f(CO_2, Y, Y^2, C)$	5.3771	19.2337	No
$CO_2 = f(Y, Y^2, C, SG)$	19.6516**	29.7105**	Yes
$Y = f(CO_2, Y^2, C, SG)$	4.8972	6.9296	No
$Y^2 = f(CO_2, Y, C, SG)$	4.0007	23.7785	No
$C = f(CO_2, Y, Y^2, SG)$	17.9265**	27.3034**	Yes
$SG = f(CO_2, Y, Y^2, C)$	6.0863	14.5403	No
$CO_2 = f(Y, Y^2, C, PG)$	18.8358**	25.4947**	Yes
$Y = f(CO_2, Y^2, C, PG)$	5.8049	14.2256	No
$Y^2 = f(CO_2, Y, C, PG)$	5.5608	12.5952	No
$C = f(CO_2, Y, Y^2, PG)$	20.3744**	32.6205**	Yes
$PG = f(CO_2, Y, Y^2,$	7.4768	9.7313	No

Estimated Model	EG–JOH Statistic	EG–JOH–BO–BDM Statistic	Cointegration
C)			

LONG-RUN RESULTS

After establishing cointegration among the variables, we examine the long-run and short-run impacts of economic growth, coal consumption, and globalization on CO_2 emissions. The long-run results (Table 6) indicate a positive and statistically significant (at the 1% level) relationship between real GDP per capita and CO_2 emissions, while the squared real GDP per capita shows a negative relationship. This suggests that a 1% increase in real GDP raises CO_2 emissions by 2.56%, whereas the negative coefficient of the squared term supports the delinking of CO_2 emissions and real GDP at higher income levels, confirming the Environmental Kuznets Curve (EKC) hypothesis for China. These findings align with studies by (16), (17), (4), (20), (21), (48), (24), (26), and (27) for China, as well as (14), and (15).

Coal consumption has a positive and significant (at 1% level) impact on CO_2 emissions, with a 1% increase leading to a 0.7317% rise in emissions, ceteris paribus. This result is consistent with (35) for China and (15) for India. Conversely, globalization (economic, social, and political) exhibits a negative and statistically significant relationship with CO_2 emissions (at 1% and 10% significance levels). A 1% increase in overall globalization reduces CO_2 emissions by 0.5519%, with economic, social, and political globalization contributing declines of 0.8371%, 0.2092%, and 0.3017%, respectively. This implies that globalization mitigates CO_2 emissions through income, scale, and technique effects, reflecting the Chinese government's commitment to environmental policies amid rapid economic growth.

SHORT-RUN RESULTS

The short-run results (Table 6) also validate the EKC hypothesis, with statistically significant coefficients. Coal consumption maintains a positive and significant (at 1% level) effect on CO_2 emissions. While globalization shows a negative relationship with emissions, it is statistically insignificant. The error correction terms (ECM_{t-1}) for overall globalization and its sub-components (economic, social, and political) are negative and statistically significant at 5%, 1%, 10%, and 5% levels, respectively, confirming a long-run equilibrium relationship. The estimated adjustment coefficients (−0.2555, −0.3889, −0.2643, and −0.2321) indicate that short-run deviations from equilibrium are corrected annually by 25.55%, 38.89%, 26.43%, and 23.21%, respectively.

Diagnostic tests confirm that the error terms in the short-run models are normally distributed, free from serial correlation, heteroskedasticity, and ARCH effects. The Ramsey RESET test confirms Model stability.

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TABLE 6. LONG AND SHORT RUN ANALYSIS

Dependent Variable = LnE_t								
Long Run Results								
	Model-1		**Model-2**		**Model-3**		**Model-4**	
Variable	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	-9.4608	_5.9136	_12.3384	_6.5138	_8.1357_	_5.4091	_7.3962	_4.6053
lnYt	-2.5	6.5094	3.3199	6.7531	2.0011_	5.9890	2.0925	4.8868
lnY^2t	-0.1232	_5.9736	_0.1594	_6.5473	_0.0951_	_5.0024	_0.1068	_4.5443
lnCt	0.7317	6.9450	0.6141_	6.0812	0.6821_	6.4911	0.8005	6.7062
lnGt	-0.5519	_3.3135	Nil	Nil	Nil	Nil	Nil	Nil
lnEGt	Nil	Nil	_0.8371_	_3.9122	Nil	Nil	Nil	Nil
lnSGt	Nil	Nil	Nil	Nil	-2.092	-3.1821	Nil	Nil
lnPGt	Nil	Nil	Nil	Nil	Nil	Nil	_0.3018	_1.8055
Short Run								
Constant	0.0265	0.6355	0.0198	0.5235	0.0221	0.5376	0.0328	0.9968
lnYt	1.9488	1.8705	2.4737	2.0128	2.0858	1.9476	1.9928	1.8877
lnY^2t	-0.1142	-1.8219	-0.1395	-2.0605	-0.1216	-1.9631	-0.1205	-1.8116
lnCt	0.2783	3.2522	0.3091	3.3558	0.2871	3.1314	0.2709	3.8627
lnGt	-0.0049	-0.0188	Nil	Nil	Nil	Nil	Nil	Nil

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lnEGt	Nil	Nil	-0.0962	-0.5567	Nil	Nil	Nil	Nil
lnSGt	Nil	Nil	Nil	Nil	0.0515	0.6386	Nil	Nil
lnPGt	Nil	Nil	Nil	Nil	Nil	Nil	-0.0687	-0.2341
ECM_{t-1}	-0.2556	-2.2435	-0.3889*	-3.0624	-0.2643***	-1.9909	_0.2321**	-2.2968

Table 6. (Continued)

Diagnostic Tests

Test	F-Stats	P-value	F-Stats	F-Stats	F-Stats	F-Stats	F-Stats	F-Stats
$x^2 NORMAL$	0.9666	0.6171	0.1364	0.9340	1.4794	0.47772	0.6463	0.7238
$x^2 SERIAL$	1.9867	0.1095	1.6121	0.1586	1.3782	0.2502	1.7792	0.1099
$x^2 ARCH$	0.5700	0.4550	0.9752	0.3297	1.9432	0.1716	2.2872	0.1161
$x^2 WHITE$	1.2489	0.3081	1.4806	0.2024	1.2016	0.3347	1.7210	0.1289
$x^2 RAMSEY$	0.0488	0.8266	0.0020	0.9642	0.0045	0.9467	0.0148	0.9038

Note: *, ** and *** indicate significance at 1%, 5% and 10% levels, respectively.

TABLE 7. VECM GRANGER CAUSALITY ANALYSIS

Dependent Variable	Type of Causality: Short Run					Long Run
	$\sum \Delta lnE_{t-1}$	$\sum \Delta lnY_{t-1}$	$\sum \Delta lnY^2_{t-1}$	$\sum \Delta lnC_{t-1}$	$\sum \Delta lnEG_{t-1}$	ECT_{t-1}
ΔlnE_{t-1}	NIL	0.7375 [0.4875]	0.4767 [0.6259]	4.6518** [0.0181]	0.8684 [0.4307]	-0.6722*[-4.2268]
ΔlnY_{t-1}	1.4926 [0.2417]	NIL	15.7684* [0.0000]	2.1256 [0.1377]	0.2281 [0.7976]	NIL
ΔlnY^2_{t-1}	1.4995 [0.2402]	16.8747*[0.0000]	NIL	2.1155 [0.1139]	0.2326 [0.7941]	NIL
ΔlnC_{t-1}	2.4904***[0.1009]	0.1324 [0.8668]	0.1299 [0.8788]	NIL	0.6847 [0.5126]	-0.5607* [-3.2611]
$\Delta lnEG_{t-1}$	0.0604 [0.9416]	1.7892 [0.1852]	1.3259 [0.2813]	0.7558 [0.4587]	NIL	NIL
	$\sum \Delta lnE_{t-1}$	$\sum \Delta lnY_{t-1}$	$\sum \Delta lnY^2_{t-1}$	$\sum \Delta lnC_{t-1}$	$\sum \Delta lnSG_{t-1}$	
ΔlnE_{t-1}	NIL	0.3466 [0.7102]	0.5294 [0.5956]	8.9129* [0.0013]	0.1516 [0.8603]	-0.5086***[-2.026]
ΔlnY_{t-1}	1.1758 [0.3244]	NIL	12.0741* [0.0000]	1.6226 [0.2168]	0.4852 [0.6213]	NIL
ΔlnY^2_{t-1}	1.1409 [0.3351]	18.8482* [0.0000]	NIL	1.4915 [0.2436]	0.6353 [0.5377]	NIL
ΔlnC_{t-1}	1.5062 [0.2413]	0.7311 [0.4915]	1.1268 [0.3401]	NIL	2.1784 [0.1344]	-0.5987* [-3.4021]
$\Delta lnSG_{t-1}$	0.6078 [0.5522]	0.5362 [0.5915]	0.5566 [0.5798]	1.0364 [0.3688]	NIL	NIL
	$\sum \Delta lnE_{t-1}$	$\sum \Delta lnY_{t-1}$	$\sum \Delta lnY^2_{t-1}$	$\sum \Delta lnC_{t-1}$	$\sum \Delta lnPG_{t-1}$	
ΔlnE_{t-1}	NIL	1.4132 [0.2623]	1.8399 [0.1799]	6.0882* [0.0071]	4.5235**[0.0212]	-0.5348*** [-

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						1.7701]
ΔlnY_{t-1}	1.8805 [0.1728]	NIL	8.8467* [0.0051]	2.0402 [0.1504]	10.6056* [0.0005]	NIL
ΔlnY^2_{t-1}	1.8915 [0.1711]	9.92246* [0.0041]	NIL	1.6793 [0.2062]	12.6006* [0.0002]	NIL
ΔlnC_{t-1}	0.7704 [0.4736]	2.1154 [0.1418]	2.5617*** [0.0974]	NIL	2.1288 [0.31401]	-0.7982* [-3.8168]
$\Delta lnPG_{t-1}$	2.6535*** [0.0895]	0.4793 [0.6247]	0.5333 [0.5931]	0.5344 [0.5924]	NIL	NIL

Table 7. (Continued)

	$\sum \Delta lnE_{t-1}$	$\sum \Delta lnY_{t-1}$	$\sum \Delta lnY^2_{t-1}$	$\sum \Delta lnC_{t-1}$	$\sum \Delta lnG_{t-1}$	
ΔlnE_{t-1}	NIL	0.8747 [0.4297]	1.1248 [0.3407]	9.1231* [0.0012]	1.4923 [0.2443]	-0.6272** [-2.1326]
ΔlnY_{t-1}	1.0332 [0.3700]	NIL	5.9026** [0.0125]	2.0484 [0.1444]	1.1794 [0.3235]	NIL
ΔlnY^2_{t-1}	0.9993 [0.3818]	6.4543* [0.0098]	NIL	1.7231 [0.1931]	1.2981 [0.2903]	NIL
ΔlnC_{t-1}	1.5009 [0.3327]	0.6536 [0.5233]	0.9735 [0.3918]	NIL	0.0848 [0.8898]	-0.7628* [3.5041]
ΔlnG_{t-1}	0.2048 [0.8162]	0.0336 [0.9672]	0.0097 [0.9907]	0.6616 [0.5246]	NIL	NIL

Note: *, **, and *** denote the significance at the 1%, 5%, and 10% levels, respectively.

The VECM Granger causality analysis indicates that if cointegration is confirmed, there must be either uni-directional or bi-directional causality among the series. This relationship is examined within the VECM framework, as understanding it is valuable for formulating effective energy policies aimed at sustainable economic growth. Table 7 presents the results on the direction of both long-run and short-run causality. The findings suggest a feedback relationship between coal consumption and CO_2 emissions. Additionally, uni-directional causality is observed running from economic globalization, social globalization, political globalization, and overall globalization to coal consumption.

Economic growth Granger causes CO_2 emissions, a result that further supports the existence of the Environmental Kuznets Curve (EKC) in China (see (14)). Moreover, coal consumption Granger causes economic growth. The causality running from coal consumption and globalization (including economic globalization, social globalization, and political globalization) to both CO_2 emissions and economic growth supports the coal consumption-led CO_2 emissions hypothesis and the globalization-led CO_2 emissions hypothesis.

In the short run, coal consumption Granger causes CO_2 emissions. Economic globalization Granger causes CO_2 emissions, and in turn, CO_2 emissions Granger cause economic globalization, indicating a feedback effect. Furthermore, uni-directional causality is found running from economic growth to economic globalization.

CONCLUSION AND POLICY IMPLICATIONS

This paper investigates the validity of the EKC hypothesis by incorporating coal consumption and globalization into the CO_2 emissions function for the Chinese economy over the period 1970–2024. The combined cointegration approach proposed by (3) is employed to examine the long-run relationship among the variables, while the robustness of this long-run relationship is further tested using the ARDL bounds testing approach, accounting for structural breaks in the series. The VECM causality framework is applied to identify the direction of causal relationships among the variables. The empirical results confirm the existence of a long-run relationship among the variables, validating the EKC hypothesis. Coal consumption significantly increases CO_2 emissions, whereas globalization improves environmental quality. CO_2 emissions are Granger caused by economic growth and globalization (economic, political, and social). Additionally, coal consumption Granger causes CO_2 emissions, and in turn, CO_2 emissions Granger cause coal consumption.

Globalization contributes to rising per capita income and fosters technological advancement in China, which helps reduce the intensity of environmental degradation. Thus, the empirical findings validate the nexus between globalization and environmental quality. At lower income levels, environmental degradation tends to increase as people prioritize higher consumption over environmental concerns. However, as living standards improve through globalization, citizens begin to demand better environmental conditions. Within China’s globalization process, evidence suggests improvements in both social and ecological conditions. Nevertheless, to ensure the sustainability of globalization in the long run, China must enhance its participation in market integration with regional trading partners by reducing or eliminating trade barriers. Environmental and social sustainability are crucial preconditions for the long-term sustainability of globalization, which in turn would strengthen the country's economic development. Therefore, the Chinese government should prioritize initiatives to improve environmental quality.

To achieve sustainable growth amid rising energy demand, the Chinese government must intensify efforts to enhance energy efficiency and reduce pollutant emissions. Energy policy should emphasize the provision of cleaner, low-carbon energy sources. China is already facing severe environmental issues from energy-related activities, with coal accounting for approximately 70% of total primary energy consumption in 2011–2024, the primary source of carbon emissions during this period (China Energy Statistical Yearbook, 2024). Hence, energy policy should diversify the national energy mix, reducing reliance on coal, and actively promote cleaner energy sources such as wind, solar, natural gas, nuclear power, and hydroelectric power.

As China's economic development and globalization continue, environmental challenges will likely intensify alongside projected rapid increases in energy consumption. Therefore, the country's energy development strategy should prioritize energy conservation while simultaneously expanding renewable energy. The government should implement laws, regulations, and fiscal policies aimed at promoting efficient energy use. Special attention must be given to vehicle emissions, particularly those stemming from rising freight and passenger transport energy consumption. Policymakers should also emphasize developing a strategic oil reserve to support long-term economic growth. The sustainability of China's economic growth will depend on adopting a less resource-depleting development model and reducing dependence on energy-intensive and resource-heavy industries. Rapid industrialization, especially in urban areas, has been a major contributor to environmental degradation in China. Accordingly, the country should promote the development and modernization of the agricultural sector, which may help curb the pace of urbanization and alleviate environmental pressures.

For future research on the EKC hypothesis in China, it is recommended to employ regional and provincial data, as aggregate data may obscure the true causality relationships and create spurious feedback effects. Further investigations exploring the EKC hypothesis in the context of globalization across different sectors of the economy, such as agriculture, transport, commerce, industry, and households, would provide deeper insights into the sectoral effects of globalization in China. Such sector-specific studies could serve as valuable foundations for energy policy design, offering micro-level perspectives to inform macroeconomic strategies.

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