# Multifaceted Impact Analysis of Economic and Environmental Indicators on Sustainable Development in China

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## Abstract

This detailed analysis looks into the complex relationship between economic growth, environmental impacts, and technological advances in China's quest for sustainable development, as outlined by the United Nations in 2024. The study employs sophisticated statistical techniques such as Lasso regression analysis, OLS (Ordinary Least Squares), Granger causality tests, and Johansen cointegration to identify long-term and consistent relationships between crucial variables influencing China's environmental and economic conditions. This research provides insights into the intricate connections among technology, foreign direct investment, urban expansion, and environmental sustainability, particularly regarding their influence on $CO_2$ emissions (World Bank, 2022; Lin, Lam, Shi, Chen, & Chen, 2023). The results question existing assumptions, providing a more profound comprehension of China's approaches to sustainable progress (United Nations, 2023). These observations benefit academics and decision-makers, aiding them in achieving harmony between environmental preservation and economic advancement.

# 1.1 Introduction

China is at a critical point, striving to balance rapid economic expansion and ambitions for long-term development. This research investigates the intricate linkages between China's environmental sustainability programs and aspirational economic growth (Prasad E., 2015). Our main goal is to comprehend how China reconciles economic growth with ecological sustainability within its development plans and policy frameworks (Holzmann & Grünberg, 2021). Economic and ecological indicators can complement each other to clarify the distinction between using economic and environmental indicators as measures of sustainable development or using them as antecedent variables in sustainable development. On the one hand, these indicators use conditions such as GDP growth rates, $CO_2$ emissions, energy consumption, and technical breakthroughs to assess the state of sustainable development.



On the other hand, these indicators can be employed as antecedent variables to influence long-term development outcomes. Both technological innovation (economic indicator) and environmental laws (environmental indicator) can contribute to sustainability by reducing emissions and encouraging cleaner industrial practices. Understanding this dual role is crucial for creating policies that monitor and promote sustainable development (World Economic Forum, 2023; Waas et al., 2014). This research was motivated by the critical need to understand the many effects of economic and environmental elements on China's long-term development. As one of the world's largest and fastest-growing economies, China's ambitions and outcomes in this industry have far-reaching global consequences. These findings are critical for developing policies that effectively balance economic growth and conservation efforts while ensuring long-term sustainability (World Bank, 2022; Holzmann & Grünberg, 2021; Wang et al., 2022). China has achieved significant progress despite challenges in reconciling rapid economic growth with environmental sustainability. Prasad E.'s essay "The Twelfth Five-Year Plan" demonstrates China's commitment to balancing social, environmental, and economic goals. The concept shifts the emphasis from rapid expansion to sustainable development, encouraging long-term environmental stewardship through economic incentives (Prasad E., 2015). Sustainable development promotes economic growth while safeguarding the environment and conserving resources for future generations. In China, the enormous migration of hundreds of millions of people from rural to urban areas, known as "urban transformation," illustrates the complex relationship between social, environmental, and economic systems. According to (Yale E360 2023), this transformation presents unique opportunities and challenges for sustainable development. China's sustainable development plans are designed to accomplish the UN's Sustainable Development Goals (SDGs), focusing on industrial innovation, urban infrastructure, and economic growth. These efforts indicate a preference for infrastructure topics above those directly relevant to governance and well-being. China's reaction to the COVID-19 outbreak and continued efforts in healthcare, education, and poverty reduction indicate its commitment to the SDGs. However, Zhang et al.'s research from 2021 shows that concerns such as climate change and gender inequality persist. Despite these hurdles, China has made tremendous strides toward sustainable growth, particularly in green financing. Its economy has become a prominent player in the global green bond market, with a forecast ranking second in 2023. These financial institutions have been crucial in promoting businesses that reduce $CO_2$ emissions and provide green finance (Roach, S.S. 2019). Substantial government engagement and market discipline characterize the Chinese sustainable development strategy. Green financing and energy transformation are two sectors that have experienced enormous growth. However, issues remain, such as how the European Union's carbon border adjustment levies on carbon-intensive commodities impact Chinese imports. According to (Sheng A. and Geng X. 2023), the levy may slow China's progress toward the SDGs by reducing investment in renewable energy sources.



China must face environmental and technical problems as it seeks economic progress, especially as it strives to become a high-income nation. Despite extensive ecological restrictions, the government continues to disenfranchise communities and undermine accountability. The complicated linkages between China's environmental legislation and strategic aims impact international collaboration on global issues such as climate change. There are two uses for this research. On the one hand, it offers details on sustainable development in a rapidly expanding economy.

Nevertheless, it provides valuable insights into Chinese management and environmental practices. The work reveals these complex interactions and explains the underlying mechanisms by applying rigorous approaches. The study examines how China's growth aims and economic policies align with and differ from environmental sustainability standards. Hopefully, this study's findings will influence future debates and queries regarding China's sustainable development (Maizland, 2021).

This study explores sustainable development in the context of China's expanding economy, focusing on the nation's attempts to reconcile its pursuit as a leader in global green finance with its efforts to make progress toward the Sustainable Development Goals (SDGs) of the UN. The essay examines China's unique relationship between sustainable development and economic growth, particularly the challenge of finding the right balance between environmental sustainability and rapid economic growth. It investigates primary energy use, per capita carbon dioxide emissions, and how foreign investment influences China's ecological sustainability and economic performance. We prioritize the study of $CO_2$ emissions per capita (CO2TPC), an essential metric for understanding the relationship between China's GDP development and environmental effects. To discover potential correlations between energy consumption and economic growth, we examined the patterns and dynamics of primary energy consumption (measured in terawatt-hours) and its relationship to economic activity.

Again, we investigate the twin effects of foreign direct investment (FDI) on the environment and economic growth, providing insight into how capital inflows and outflows affect China's economic conditions and $CO_2$ emissions. The study also examines the relevance of R&D and technical innovation in advancing the country towards sustainable development, particularly in terms of its ability to reduce $CO_2$ emissions and increase energy.

Furthermore, by evaluating the effects of urban population growth on sustainable development indicators, we investigate how urbanization influences energy consumption and what this means for sustainable urban planning. By integrating these separate but interconnected goals, the study aims to provide a comprehensive knowledge of the factors impacting China's long-term growth.

# 2.1 Literature Review

## 2.2 Previous Research on FDI Inflows and Carbon Emissions



Existing research on the impact of foreign direct investment (FDI) on Chinese carbon emissions provides inconsistent results. According to the Pollution Haven Hypothesis, FDI in industries with high pollution levels leads to higher carbon emissions, as proved by Liu et al. (2021), who found a positive correlation between foreign direct investment and Chinese carbon emissions. In contrast, the Pollution Halo Hypothesis proposes that FDI can reduce carbon emissions by introducing advanced, environmentally friendly technologies to the host country. This position is supported by Zhang and Zhou's (2016) study, which used provincial panel data to demonstrate that FDI in China lowers carbon emissions. These studies employ a range of econometric methodologies, such as nonlinear techniques and spatial econometric models, to capture the intricate dynamics of the FDI-carbon emissions relationship. Commonly utilized approaches to analyze this association include panel data analysis, ARIMA, fixed effects models, and VECM. Research has resulted in a wide range of conclusions. Several studies, like Mohammed et al.'s (2019) inquiry, have found a significant relationship between CO2 emissions from various organizations and factors such as the Human Development Index, life expectancy, and economic growth. Previous research has shown that national income levels and foreign direct investment inflows influence the nonlinear link between FDI inflows and carbon emissions. Shahbaz et al. (2015) proposed an inverse U-shaped relationship between FDI inflows and carbon emissions in middle-income nations. These studies have yielded diverse conclusions, reflecting the complex link between environmental degradation, technological innovation, and economic prosperity. According to some studies, while FDI inflows may initially deteriorate the environment (the so-called "scale effect"), they may also, over time, improve the environment due to advanced technologies (the "technology effect"), Qin et al. (2022), and rising environmental consciousness among higher-income individuals (the "compound effect"), Xie et al., (2022); De Canio et al., (2021). Overall, the amount of data speaks to a complex and nuanced relationship between foreign direct investment (FDI) inflows and carbon emissions in China, which is influenced by numerous variables such as the industries attracting FDI, the degree of economic development, and the environmental regulations in place.

## 2.3 Prior Studies on Other Factors Influencing Carbon Emissions

This broad section contains multiple studies describing how factors other than foreign direct investment affect carbon emissions. Numerous research works have investigated the connection between carbon emissions and urbanization. In their 2018 study, Yao, Zhang, and Sheng applied the threshold regression and mediating effect model to panel data from 30 provincial-level regions in China between 2001 and 2014 and discovered that urbanization can lower carbon emissions. Huo and associates (2021). In China's 30 province areas, the study examined the nonlinear effects of urbanization on carbon emissions from urban residential buildings between 2000 and 2015. The study's panel threshold regression model showed that $CO_2$ emissions from urban residential buildings are positively correlated with urbanization. The impact differed depending on the income and energy structure stage, indicating a complicated link between urbanization and carbon emissions. However, decoupling urbanization and carbon emissions in developed economies seems to be a more negligible effect in OECD countries. Economic growth and carbon emissions have decoupled in several Chinese regions, indicating statistically significant negative indirect impacts of population growth and land urbanization on regional carbon emissions. These results point to a complicated relationship in which the effect of urbanization on carbon emissions differs depending on certain geographic and economic circumstances. Chen Fuzhong et al. (2022). China's urbanization policies have a significant impact on how sustainably its economy grows, particularly when it comes to inland development. In her exploration of this subject, Melissa Beattie-Moss (2015) emphasizes the profound effects of urbanization on China's environmental and economic conditions. This method indicates a strategic change in China's development strategy, emphasizing equitable growth across various geographic areas, Liu, Horn-Phathanothai, Zhang (2021). Another viewpoint contends that some Chinese urban agglomeration-scale areas have disconnected economic growth from carbon emissions, with statistically adverse indirect effects of population growth and land urbanization on regional carbon emissions Fu, Luo, & He, (2022) and Fan, Chen, & Fung, (2022).

### 2.3.1 Technological Innovations, Electricity Generation and Renewable Energy

Research has also been conducted on the relationship between carbon emissions and technological advancement. A geographic econometric model that examined 95 nations found that global carbon emission efficiency (CEE) increased between 2009 and 2018. The study found a substantial association between CEE across multiple continents and advances in science, technology, and other areas, such as foreign direct investment. However, the impact of innovation on emissions varies globally, with some countries seeing higher emissions due to innovation (Ping Cao et al., 2022). Xiang Sun, Zhong-Ba Ping, and Zhan-Feng Dong's 2021 study investigated the environmental costs of China's rapid economic expansion. The authors thoroughly explore the resource and environmental costs associated with China's economic growth, using the most recent theoretical System of Environmental-Economic Accounting (SEEA) framework and modeling approaches. This research is crucial for understanding the environmental consequences of industrial processes and technical advancements within China's developmental paradigm. Policymakers and corporate leaders must understand the ecological impact of economic activity and how cleaner manufacturing technology can reduce associated costs. Here is where the study's findings come in. This study contributes significantly to the topic of sustainable development and the role of technology in achieving environmental sustainability by emphasizing the need to incorporate sustainability considerations into finance and development plans. In 2023, China's electricity generation landscape shifted dramatically, with a greater reliance on renewable energy sources. The report by Gavin Maguire (2024) thoroughly assesses this change. According to the report, China has made tremendous progress in reducing its reliance on coal and increasing its use of solar and wind power despite the country's overall increase in electricity demand. This reform marks a significant step toward a more sustainable energy future and underscores China's commitment to reducing carbon emissions.



### 2.3.2 Energy Economics, Comparative Economic Development, and International Economics

Several countries have investigated the link between energy use, including renewable and non-renewable, $CO_2$ emissions, and economic growth, and Hasara Dissanayake et al. 2023, employed panel Granger-causality tests and impulse-response functions to study 152 nations between 1990 and 2019. This study investigates the link between energy consumption, $CO_2$ emissions, and economic growth, discriminating between industrialized, developing, and least-developed countries. In the article "Can Economic Growth and Environmental Protection Be Win-Win Situations?" Yang, Gao, and Li (2022) investigate the link between China's economic development and environmental protection. The study uses the decoupling model to analyze the dynamic interaction of these two factors in different parts of China. The study is notable for using nighttime light data as a proxy for economic growth and creating an Environmental Pressure Index to assess environmental quality. The data points to a significant reduction in environmental pressure at the national and provincial levels, showing progress toward a more balanced coexistence of economic development and ecological protection. This study provides vital insights for policymakers and scholars, showing the possibility of attaining sustainable growth while maintaining economic gain. Recent studies have highlighted two crucial aspects of international relations and commerce and the implications of China's long-term development goals. First, China's new economic policies, particularly the "dual circulation" approach, prioritize independence and the expansion of the home market. This policy move is in response to a shifting global order, which includes an increasing strategic rivalry with the United States.

The plan aims to foster robust growth and development, notwithstanding external obstacles that could impact China's trade dynamics and sustainability approach.
It emphasizes the arduous task of maintaining a non-hostile exterior environment while focusing on domestic issues, including poverty alleviation, pollution reduction, and corruption prevention.
This strategy aims to increase China's position as a significant actor in the international system by influencing laws, norms, and institutions to accord with its interests, particularly those concerning sustainable development.
It emphasizes the difficulty of maintaining a non-hostile external environment while prioritizing domestic issues such as poverty alleviation, pollution reduction, and corruption prevention.
This strategy aims to increase China's position as a critical player in the international system by influencing laws, norms, and institutions to fit its priorities, particularly regarding sustainable development goals. Hass, R. (2021).
Second, China's businesses play a crucial role in sustainable development actions. Chinese companies, mainly state-owned industries, are rapidly adopting sustainable practices. This tendency is partly supported by China's "dual carbon" strategy, which aims for carbon neutrality while significantly impacting the country's foreign trade and economic relations. The emphasis on sustainability in Chinese enterprises highlights how internal policies and goals can have far-reaching consequences for China's international trade relationships and ability to achieve sustainable development goals (Davos Agenda, 2023). These factors demonstrate how China's foreign relations and trade policies are intimately linked to its long-term development goals, including a strategic emphasis on balancing domestic and international economic relationships.



**2.3.3 Global Market Shares in Manufacturing and Clean Energy as an Economic Driver**

The global status of China's manufacturing industry, particularly in 2023, has piqued considerable interest. As Kevin Yao and Ellen Zhang (2024) indicate, China's economic recovery has been uneven, raising concerns about the need for stimulus, particularly in manufacturing. Concurrently, Gavin Maguire (2024) sheds light on how China's manufacturing sector influences its emissions potential, particularly in clean energy technology. These findings show the delicate balance between China's manufacturing dominance in global markets and its ecological objectives. In 2023, China's renewable energy sector became the primary driver of GDP growth, indicating a significant shift in the country's economic dynamics. According to Andrew Hayley's (2024) research, the rapid development of this industry, particularly in solar energy, electric vehicles (EVs), and energy storage, has significantly influenced China's economic trajectory. Andrew Hayley's (2024) research aligns with Lauri Myllyvirta's (2024) research, which found that renewable energy significantly impacted China's economic success this year. These results mark a historic moment in China's efforts to balance economic development and environmental sustainability, emphasizing the expanding role of renewable energy sources in the country's financial system. These studies employ various econometric models and data analysis approaches, including machine learning, threshold regression, spatial econometric models, and panel Granger causality tests. The findings highlight the complexity and diversity of the factors driving carbon emissions, differing effects on urbanization, technological innovation, and energy consumption in different regions and countries.

## 2.4 Gaps in Literature on Sustainable Development in China

Studies have indicated that categorizing Sustainable Development Goals (SDGs) and examining their relationships might provide insights into sustainable development. However, there has to be more remarkable agreement on appropriate SDG indicator frameworks at the subnational level. Furthermore, the nonlinear connections and complex causal feedback across multiple SDGs have not been adequately investigated, indicating a gap in understanding the full breadth of these interactions and their consequences for sustainable development (Zhang, J. et al., 2022). Furthermore, while there has been research on the influence of green finance on economic development, environmental pollution, and energy consumption in China, a more comprehensive assessment is required. Wu X. et al. (2022) investigated various aspects of green financing and its implications. However, a more comprehensive approach is necessary, considering a wider range of variables and the spatial-temporal variability of the impact of green funding. Zhang J. et al. (2022) identified gaps in China's regulatory frameworks and approaches to carbon neutrality. The study underlines the need for more in-depth analyses to address any structural flaws in data and enhance the accuracy of models that estimate the consequences of economic activity on environmental sustainability. The study also underlines the need to consider structural fractures and long-term correlations in data, which should be more prevalent in current research. According to GT staff research (2024), 2023 marked a turning point in China's economic policy environment. The research focuses on the Chinese government's effective implementation of strong policy support, which has significantly impacted domestic economic expectations and dynamics. Efforts to carry out strategic policies are concentrated on stabilizing and promoting economic growth, highlighting China's proactive approach to managing its overall economic condition in the face of global challenges. Methods utilized to assess sustainable development significantly influence the results. The current study underscores the importance of establishing a unified framework for these methods, particularly at the regional level. This gap highlights the need for more robust data monitoring methods to understand better the SDGs' offsetting effects and the factors that influence them (Zhang, J. et al., 2022). Linear models are commonly used to investigate the relationships between different SDGs. However, the evidence implies that nonlinear relationships and complicated causal feedback between SDGs might significantly impact their implementation. The existing gaps in the literature highlight the need for further research to gain a comprehensive understanding of how economic and environmental factors affect China's sustainable development. This study aims to fill these gaps by investigating the intricate connections between sustainable development goals (SDGs), enhancing indicators and data monitoring tools, and conducting a thorough analysis of the influence of green financing and climate governance methods.

## 3.1 Hypothesis Formulation

Hypothesis 1: Analyzing $CO_2$ Emission Trends in China

There has been a noteworthy decrease in $CO_2$ emissions per capita in China from 1990 to 2022, indicating the effectiveness of environmental policies and technological advancements (Maizland, L., 2021).

Hypothesis 2: Studying the Relationship between Energy Consumption and Economic Growth

China's economic growth has become progressively disconnected from primary energy consumption due to enhancements in energy efficiency and a shift towards renewable energy sources (Liu, Z., Deng, Z., He, G., et al., 2021).

Hypothesis 3: Analyzing the Influence of Foreign Direct Investment on Environmental and Economic Metrics. According to Zhang, Z., Nuță, F. M., et al. (2023), foreign direct investment in China has positively impacted environmental sustainability by decreasing $CO_2$ emissions and fostering economic progress.



Hypothesis 4: Exploring the effects of technology on making the environment healthier – According to a study by Azam, A., Rafiq, M., Rafiq, M., & Yuan, J. (2022), new types of energy and technology that are good for the environment have helped China grow in a way that can continue for a long time.

Hypothesis 5: Studying the Connection between Urban Population Growth and Sustainable Development Metrics. The swift expansion of China's urban population has presented challenges to sustainable development, potentially resulting in heightened $CO_2$ emissions and energy usage (Chen, J., Xu, C., Gao, M., & Li, D., 2022).

These hypotheses align with the paper's emphasis on comprehending the intricate relationship between economic advancement and environmental sustainability within the framework of China's progress (Xinhua, 2021).

## 3.2 Methodology, Model Formulation, and Data

Our research uses quantitative analysis and multivariate regression techniques to investigate how various environmental and economic factors influence China's sustainable growth from 1990 to 2022. The data was sourced from reliable outlets such as the China Statistical Yearbook, Our World in Data, World Bank financial databases, and the Chinese National Bureau of Statistics publications. We carefully selected research papers to find the most reliable and essential sources. These papers examined the interconnection of China's economy, technology, and carbon emissions. The researchers employed a detailed methodology to analyze data from 1990 to 2022, sourced from reliable outlets such as government databases. They scrutinized GDP, population growth, foreign investment, and per capita carbon emissions. The researchers conducted tests to ensure the data's quality and sought long-term connections between the different factors. They used Lasso regression to determine which factors had the most significant impact on carbon emissions. This method is well-known for helping statisticians make accurate predictions. They used a type of programming called Python to run these tests and analyses. The Lasso method was chosen for its simultaneous regularization and variable selection capabilities, improving the model's interpretability and prediction accuracy. In this stage, the magnitudes of the regression coefficients are penalized for decreasing the complexity of the model and preventing overfitting. We created a time series graph to visually inspect the patterns and trends in $CO_2$ emissions during a specific timeframe, offering an initial grasp of the data and facilitating the detection of any irregularities or trends requiring further exploration. Granger Causality Tests were used in the investigation, which is a statistical method to explore the links between economic and environmental factors. The research aimed to use these tests to determine how much one data set could predict changes in another. This method is crucial for understanding how the study's results could impact policy and strategy development. The statistical analysis and data organization were done using Python in a Jupyter Notebook. Python's capacity to manage large datasets and its diverse statistical analysis libraries, such as Statsmodels for econometric techniques and Pandas for data manipulation, were instrumental in these processes. By adhering to these methodological principles, the study aims to produce dependable and strong outcomes that could shape policy decisions concerning China's economic advancement and environmental sustainability.



## 3.3 Econometric Techniques and Software Tools

Throughout the analyses, I performed interactive and repeatable testing with Python and a Jupyter Notebook. I used NumPy to perform numerical calculations and Statsmodels for statistical testing and regression analysis. In addition, I created algorithms for machine learning, such as Lasso regression, using Sci-kit-learn. For data visualization, I used Matplotlib and Seaborn. Pandas for data processing were vital factors in its selection. By adhering to these methodological criteria, the study aims to produce reliable and accurate results that can be used to inform policy decisions about China's economic success and environmental sustainability. All econometric techniques were written in Python. For example, I used Lasso regression with the code below:

From sklearn.linear_model import Lasso model = Lasso (alpha=0.01). Model.fit(X_train,Y_train)

This example shows how Lasso regression penalizes regression coefficients, reducing the importance of less significant components.

I meticulously documented every step in the Jupyter Notebook throughout the analysis process, from data preprocessing to the final modeling. This detailed documentation comprises code, explanatory comments, and visual representations, guaranteeing the transparency and reproducibility of the methods and techniques employed. A comprehensive econometric technique examined the relationship between China's economic growth, technological innovation, and carbon emissions. The study included multiple methodological phases to accomplish its objectives. Initially, it collected time series data from reliable sources, including government databases and publications on international economics, covering the period from 1990 to 2022. Important variables examined included GDP growth rate, per capita carbon emissions, urban population, and foreign direct investment (FDI). The Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test was performed at the outset of the inquiry to determine dataset stationarity. A critical stage is deciding if the time series data should be the subject of further investigations.

Afterward, a Johansen cointegration test was conducted to assess the long-term correlations between the variables after establishing stationarity. The results of this test are essential for understanding the equilibrium linkages between different time series data.

Following the cointegration test, Lasso regression analysis was used to identify the primary drivers of carbon emissions. The Lasso method was deliberately selected due to its capability to perform regularization and variable selection simultaneously, thereby improving the model's interpretability and predictive accuracy. This step penalizes the absolute values of regression coefficients, which simplifies the model and helps prevent overfitting. A time series plot was created to visually examine the trends and patterns in CO2 emissions over the period. This visual tool provided an initial understanding of the data, allowing for detecting any anomalies or trends that might need further investigation. The Granger causality test assessed the causal relationship between economic growth and carbon emissions. This test helped determine whether one time series can reliably predict another, contributing to the determination of the study's findings' significance for policymaking. By following these methodological guidelines, the study hopes to create reliable and accurate results that may be utilized to inform policy decisions about China's economic progress and environmental sustainability.



## 3.4 Model Formulation

Each econometric test was subject to a rigorous multivariate regression model framework application. The model examines how independent variables such as GDP growth, primary energy consumption, foreign direct investment, urban population expansion, and technological innovation affect the dependent variable, $CO_2$ emissions per capita. We employed a multivariate regression analysis model to evaluate our hypotheses about the relationship between the dependent variable (carbon emissions) and several independent variables.

The purpose is to create a model with several predictor components and evaluate their combined effect on a dependent variable. A multivariate linear regression model is widely used to investigate the relationship between carbon emissions ($CO_2TPC$) and several independent variables. The model may be represented as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \varepsilon$$

In this equation, Y is the dependent variable (e.g., CO2TPC), X1, X2,…, Xn represents the different economic and environmental indicators, such as GDP, Primary Energy Consumption (PEC), foreign direct investment (FDI), urban population growth (UPOP), and technological advancement (TA), β0,β1,…,βn are the coefficients for each independent variable which shows the influence of each economic and environmental indicator on the measure of sustainable development, and epsilon (ε) is the error term, (Rotondo, F., P. Perchinunno, S. L'Abbate, and L. Mongelli (2022).

Each study was carried out using Python code in a Jupyter Notebook environment, which is a versatile and adaptable tool for performing and recording econometric research. The entire process was painstakingly documented in a Jupyter notebook, from data preparation to final modeling. This documentation provides a complete and easily accessible explanation of our technique, including our steps, the visualizations we created, and all the code we used.



## 4.1 Empirical Analysis and Results

This section contains the empirical findings from our comprehensive econometric research, which shed light on the linkages between economic growth, technical advancement, and environmental sustainability in China. The findings demonstrate these connections' dynamic and diverse nature from 1990 to 2022.

## 4.2 Table 1: Kwiatkowski-Phillips-Schmidt-Shin (KPSS) Test Results

| Variable | Difference | KPSS Statistic | p-value | Critical Values | Stationarity |
|---|---|---|---|---|---|
| $CO_2$TPC | 1st difference | 0.132736 | 0.1 | 5%: 0.463 | Yes |
| PEC (TWh) | 1st difference | 0.287193 | 0.1 | 5%: 0.463 | Yes |
| FDIOUT | 1st difference | 0.083192 | 0.1 | 5%: 0.463 | Yes |
| FDIIN | 1st difference | 0.260185 | 0.1 | 5%: 0.463 | Yes |
| $CO_2$KG | 1st difference | 0.240412 | 0.1 | 5%: 0.463 | Yes |
| GDP | 1st difference | 0.246337 | 0.1 | 5%: 0.463 | Yes |
| UPOP | 1st difference | 0.406808 | 0.07 | 5%: 0.463 | Yes |
| TA(R&D) | 1st difference | 0.236893 | 0.1 | 5%: 0.463 | Yes |
| CO2T | 1st difference | 0.150214 | 0.1 | 5%: 0.463 | Yes |

The Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test assessed stationarity in the time series data and is an essential assumption in time series analysis because it ensures that the series' statistical properties remain consistent across time, which is necessary for successful econometric modeling. In this study, the KPSS test was used to evaluate a range of economic and environmental indicators, including $CO_2$ emissions per capita ($CO_2$TPC), primary energy consumption (PEC), foreign direct investment (FDI), GDP, and urban population. The test findings showed that after the initial differencing, all variables reached stationarity, as demonstrated by p-values greater than 0.05 and KPSS statistics smaller than the crucial value at the 5% significance level. For example, the KPSS statistic for $CO_2$TPC was 0.132736 with a p-value of 0.1, significantly lower than the critical value of 0.463, indicating stationarity. These findings are essential for the later analysis phases, as they ensure that the data utilized in the Johansen cointegration test, OLS regression, and other econometric models do not show any patterns or seasonality that could skew the conclusions. These variables' stationarity lends credence to the paper's time-series analysis. It ensures that the linkages investigated, such as the impact of economic growth, technological advancement, and urbanization on environmental sustainability, are not muddled by non-stationary data, lending credibility to the study's conclusions and suggestions. Overall, attaining stationarity after initial differencing indicates that patterns or seasonality in the original data have been effectively removed, allowing for rigorous econometric analysis. This fundamental stage is essential to the validity of the long-term equilibrium relationships examined later in the Johansen cointegration test and the accuracy of the regression models employed in this study.



## 4.3 Time Series Plot of $CO_2$ (1990 – 2022)

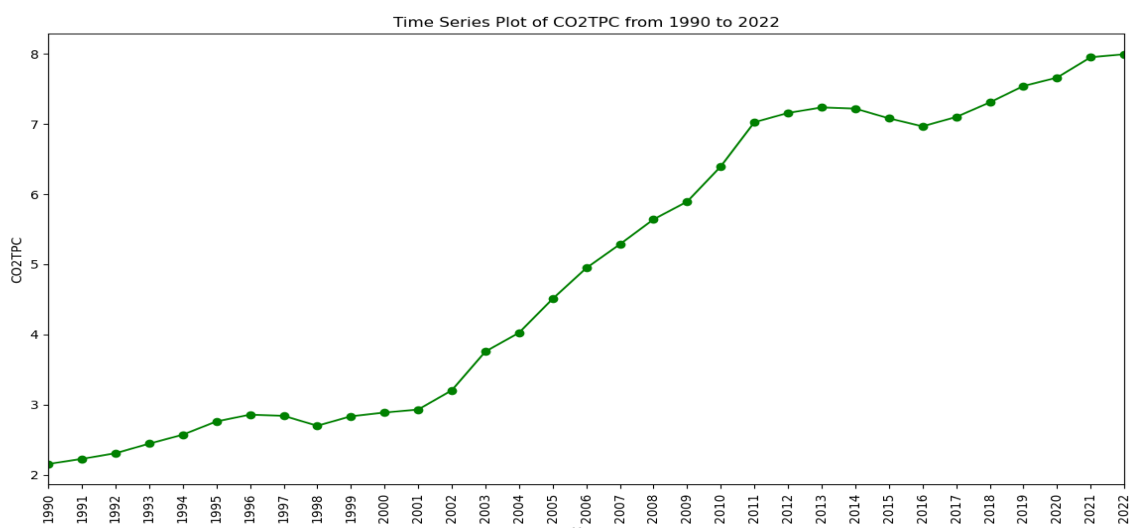


**Figure 1: Time Series Plot of $CO_2$ (1990 – 2022)**

A time series analysis was utilized to investigate trends in $CO_2$ emissions per capita ($CO_2TPC$) from 1990 to 2022. The investigation showed a growing trend in $CO_2TPC$, which is consistent with China's rapid economic expansion and increased industrial activity. This trend challenges achieving sustainable development goals and highlights the importance of strong environmental laws. The time series graph depicts China's $CO_2$ emissions in metric tons per capita ($CO_2TPC$). The graph's increasing trend from 1990 to 2022 exemplifies the study's goal of investigating how $CO_2$ emissions altered in response to China's economic and industrial development.

The growing trend in $CO_2TPC$ has significant ramifications. Despite technological advances, China's rapid urbanization and economic growth may increase $CO_2$ emissions per capita. This study calls into question the claim that environmental policies and technical improvements considerably reduced China's $CO_2$ emissions per capita between 1990 and 2022. This trend shows how closely China's energy use and economic expansion are related, demonstrating the importance of more decoupling efforts. The paper's main argument is that rising $CO_2TPC$ over time could indicate China's challenges in finding an appropriate agreement between environmental sustainability and economic growth. Thus, the graph contributes significant empirical data to the study's comprehensive sustainable development evaluation. The multivariate regression model's main focus, the $CO_2TPC$ trend over time, is empirically shown in the graph. The multivariate regression model centers on the $CO_2TPC$ trend over time, which is empirically represented in the graphic. The multivariate regression model contributes to examining the dependent variable $CO_2$, providing a visual representation to supplement the numerical and theoretical analyses offered in this section. The time series study emphasizes the need for strong environmental policies and technical advancements to counteract the adverse effects of economic expansion on $CO_2$ emissions. The plot visually depicts the CO2 emissions trajectory and emphasizes the urgent need for sustainable practices in China to fulfill long-term environmental goals.



## 4.4 Johansen Cointegration Test Results

To determine whether cointegration among the variables exists based on this time-series analysis, a more advanced statistical test, such as the Johansen cointegration test, was performed on the data to assess whether a set of time-series variables has a stable equilibrium relationship in the long run despite short-term fluctuations. The Johansen cointegration test effectively detects multiple cointegrating relationships between variables, which is critical for understanding the long-term interactions between economic growth, energy consumption, technological advancements, and environmental sustainability. The Johansen cointegration test findings, shown in Tables 2 and 3, demonstrated various long-term equilibrium relationships among the research variables. The Trace and Max-Eigenvalue statistics indicated that the null hypothesis should be rejected for up to eight cointegrating relationships. For example, the Trace statistic for the first rank was 476.28, much greater than the critical value of 197.37 at the 5% level, suggesting robust cointegration. These findings indicate that economic indices such as GDP growth, energy consumption, and technology breakthroughs are inextricably related to environmental outcomes such as $CO_2$ emissions. These cointegrating relationships imply that changes in one variable are likely to have long-term consequences for the others, which is essential for policymakers. This cointegration is vital for policymakers because it means that changes in one variable will long-term affect others. For example, a long-term equilibrium relationship between GDP growth and $CO_2$ emissions shows that economic growth plans must consider their environmental impact to accomplish sustainable development goals.

The Johansen cointegration test results shed light on the interconnectivity of economic and environmental variables, emphasizing the significance of integrated policy approaches. These findings highlight the importance of coordinating efforts to improve energy efficiency, promote renewable energy, and deploy technical advancements to establish a long-term balance of economic growth and environmental sustainability.

## 4.4.1 Table 2: Trace Statistics and Critical Values



| Rank | Trace Statistic | Critical value (5%) | Reject Null? |
|---|---|---|---|
| 1 | 476.28 | 197.37 | Yes |
| 2 | 334.79 | 159.53 | Yes |
| 3 | 233.54 | 125.62 | Yes |
| 4 | 161.33 | 95.75 | Yes |
| 5 | 105.93 | 69.82 | Yes |
| 6 | 67.88 | 47.85 | Yes |
| 7 | 40.53 | 29.80 | Yes |
| 8 | 15.45 | 15.49 | No |
| 9 | 1.05 | 3.84 | No |

The Johansen Cointegration test revealed the existence of several long-term equilibrium relationships among the studied variables. These findings imply that economic indices such as GDP growth, energy consumption, and technology breakthroughs are inextricably related to environmental outcomes such as $CO_2$ emissions. This cointegration is essential for policymakers because it means that changes in one variable will long-term affect others. All values are more than the respective 5% critical values, indicating that we may reject the null hypothesis of no cointegration for up to eight cointegrating links (the ninth value is less than the critical value, implying no more than eight cointegrating relationships).

## 4.4.2 Table 3: Max-Eigenvalue Statistics and Critical Values

| Rank | Max-Eigen Statistic | Critical value (5%) | Reject Null? |
|---|---|---|---|
| 1 | 141.48 | 58.43 | Yes |

| | | | |
|---|---|---|---|
| 2 | 101.26 | 52.36 | Yes |
| 3 | 72.20 | 46.23 | Yes |
| 4 | 55.41 | 40.08 | Yes |
| 5 | 38.05 | 33.88 | Yes |
| 6 | 27.35 | 27.59 | No |
| 7 | 25.08 | 21.13 | Yes |
| 8 | 14.40 | 14.26 | Yes |
| 9 | 1.05 | 3.84 | No |

Like the Trace statistics, most Max-Eigenvalue statistics are higher than the critical values, indicating several cointegrating relationships, which means a robust long-run equilibrium relationship appears between the economic and environmental variables being analyzed for the dataset and period studied. Like most Max-Eigenvalue statistics, the Trace statistics are valuable information for policymakers, as they suggest that changes in one indicator will likely have long-term implications for others.



## 4.5 Table 4: Ordinary Least Squares Regression (OLS) Analysis Results

| OLS Regression Results | | | | | | |
|---|---|---|---|---|---|---|
| Dependent Variable | $CO_2$TPC | | | R-Squared | | 0.987 |
| Model | OLS | | | Adj. R-Squared | | 0.984 |
| Method | Least Squares | | | F-statistics | | 337.0 |
| | Coeff | Std err | t | p>\|t\| | [0.025 | 0.975] |
| Const | 1.1135 | 0.753 | 1.478 | 0.151 | -0.435 | 0.662 |
| GDP | 0.0094 | 0.027 | 0.345 | 0.733 | -0.047 | 0.066 |
| PEC (TWh) | 0.0002 | 3.58e-05 | 4.597 | 0.000 | 9.09e-05 | 0.000 |
| FDIOUT | -0.2962 | 0.167 | -1.773 | 0.088 | -0.640 | 0.047 |
| FDIIN | 0.1144 | 0.065 | 1.770 | 0.088 | -0.018 | 0.247 |
| UPOP | -0.0459 | 0.034 | -1.358 | 0.186 | -0.115 | 0.024 |

| | | | | | | |
|---|---|---|---|---|---|---|
| TA (RnD) | 1.2924 | 0.705 | 1.832 | 0.078 | -0.158 | 2.742 |

Table 4 shows how well the model represents the variables determining $CO_2$ emissions. The R-squared score of 0.987 indicates that the model captures almost all variability in $CO_2$ emissions. A positive GDP coefficient shows that rising $CO_2$ levels are driving economic growth. The positive GDP coefficient indicates a link between monetary expansion and increasing $CO_2$. Based on the model, the p-value for GDP is 0.733. Thus, we cannot establish that GDP growth directly increases $CO_2$. The p-value of 0.05 for Primary Energy Consumption (PEC) confirms that increased energy consumption causes an increase in $CO_2$ emissions. Based on our model, policies to improve energy efficiency and move to renewable energy sources are urgently required to reduce $CO_2$ emissions. The negative coefficient of FDI outflow (FDIOUT) indicates that it may lower domestic $CO_2$ emissions, presumably through the migration of polluting companies. The p-value of 0.088 suggests that the association being investigated is of marginal relevance. A positive value for foreign direct investment inflow (FDIIN) indicates a greater possibility of rising $CO_2$ emissions due to increased economic activity. Determining the true impact of foreign investment on the environment is challenging. R&D, or technological advancement, costs 1.29 times less than TAR&D. This implies that, although technology offers various benefits, it lacks precision in predicting the rate at which carbon dioxide emissions will decrease through current methods. Additionally, the Urban Population (UPOP) coefficient of -0.0459, which is statistically insignificant, indicates that, despite potential reductions in $CO_2$ emissions with urban expansion, technological advancements may not sufficiently offset other factors or unforeseen adverse consequences, illustrate how residing in an urban setting can encourage more energy-efficient actions and habits, leading to a decrease in the amount of $CO_2$ emissions that each individual produces.

However, the lack of statistical significance implies that our model cannot conclude that this effect is essential. Table 4 shows how energy use significantly contributes to $CO_2$ emissions, highlighting the necessity of energy efficiency and renewable energy legislation. Intelligent policies must address the complex relationships between FDI and technological progress to sustain long-term growth. Urbanization, when properly controlled and encourages environmentally responsible living, has the potential to reduce $CO_2$ emissions per capita.

## 4.6 Scatterplot for Independence Check Showing Residuals versus Predicted Values

The high R-squared value indicates that the model has explained a significant proportion of the variability in the dependent variable ($CO_2$TPC). The coefficients indicate the direction and magnitude of the relationship between each independent and dependent variable, essential for understanding economic growth, environmental impact, and technological innovation.

### 4.6.1 Scatterplot for independence check showing residuals versus predicted values

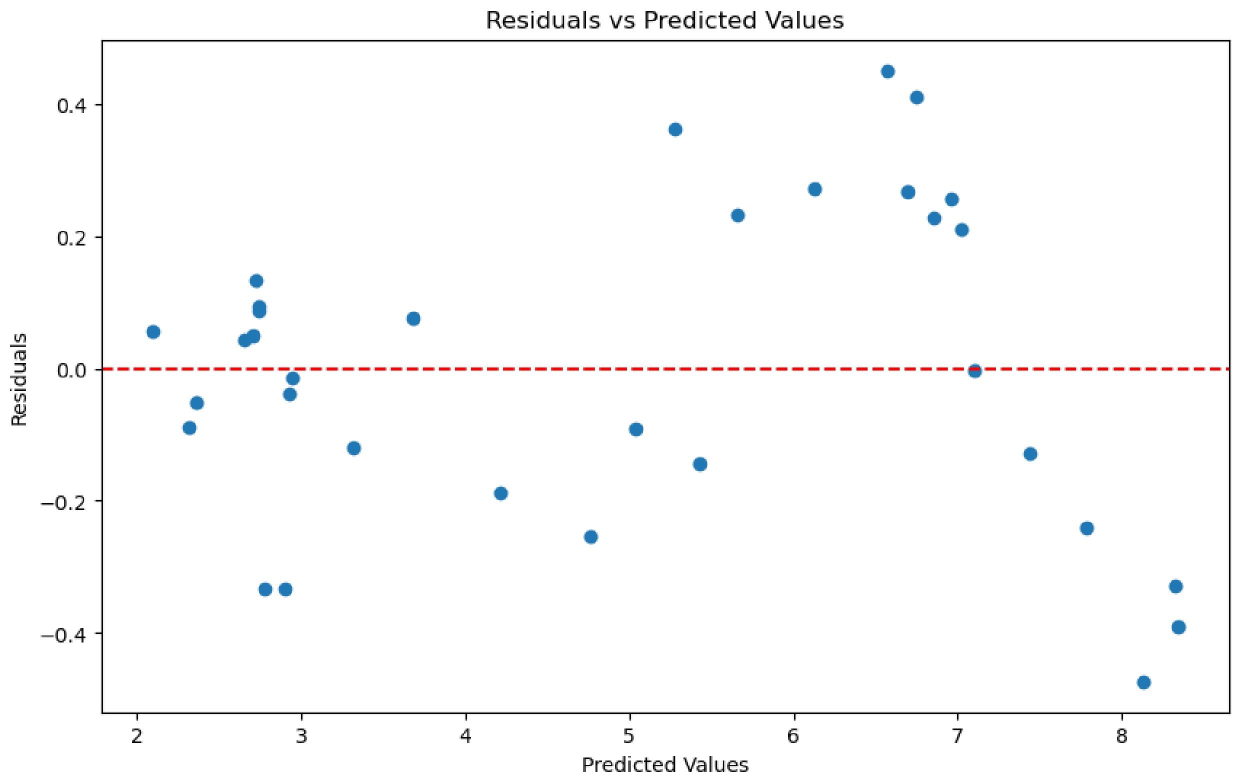


**Figure 2: Scatterplot for independence check showing residuals versus predicted values**

### 4.6.2 Q-Q Plot for Normality Check of Residuals

Ideally, residuals should be randomly scattered around zero without forming any discernible patterns. Here, the residuals do not show a clear pattern, which is good, but there are a few potential outliers or areas where the model may need to capture all the nuances in the data.

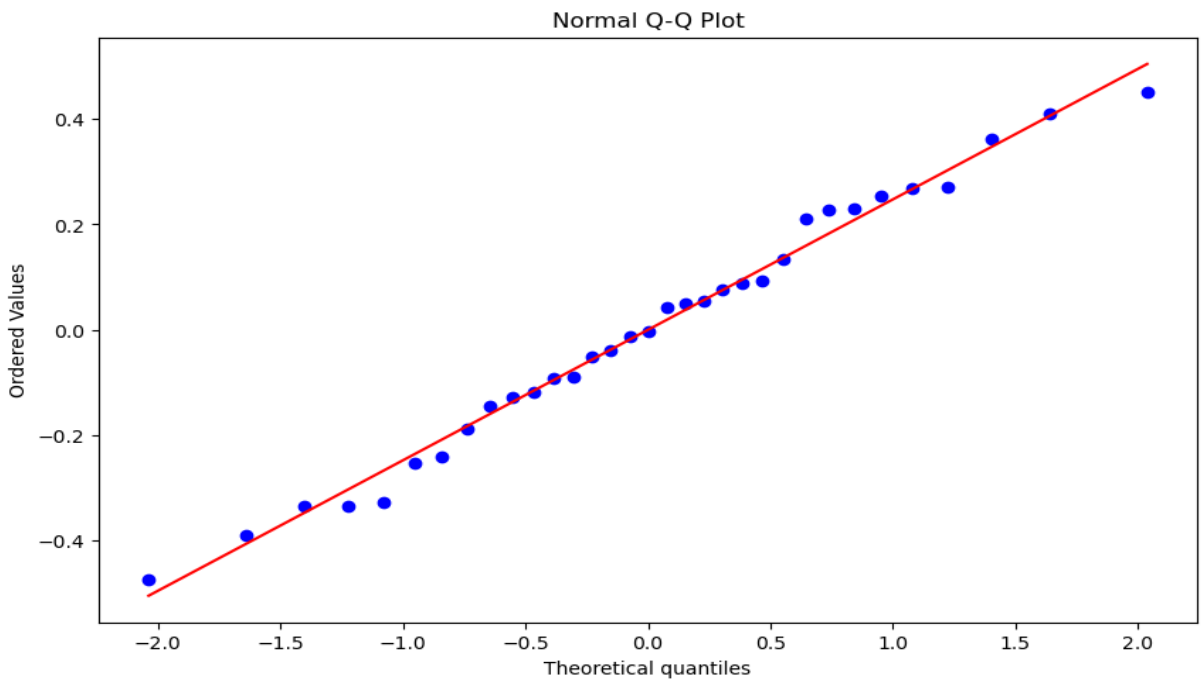


**Figure 3: Q-Q Plot for normality check of residuals**

The points largely follow the theoretical straight line, suggesting that the residuals from the OLS model are approximately normally distributed. Figure 3 is an assumption of the OLS model, and its validity supports the model's appropriateness for the data.

### 4.6.3 Scatterplot for linearity check showing observed versus predicted values

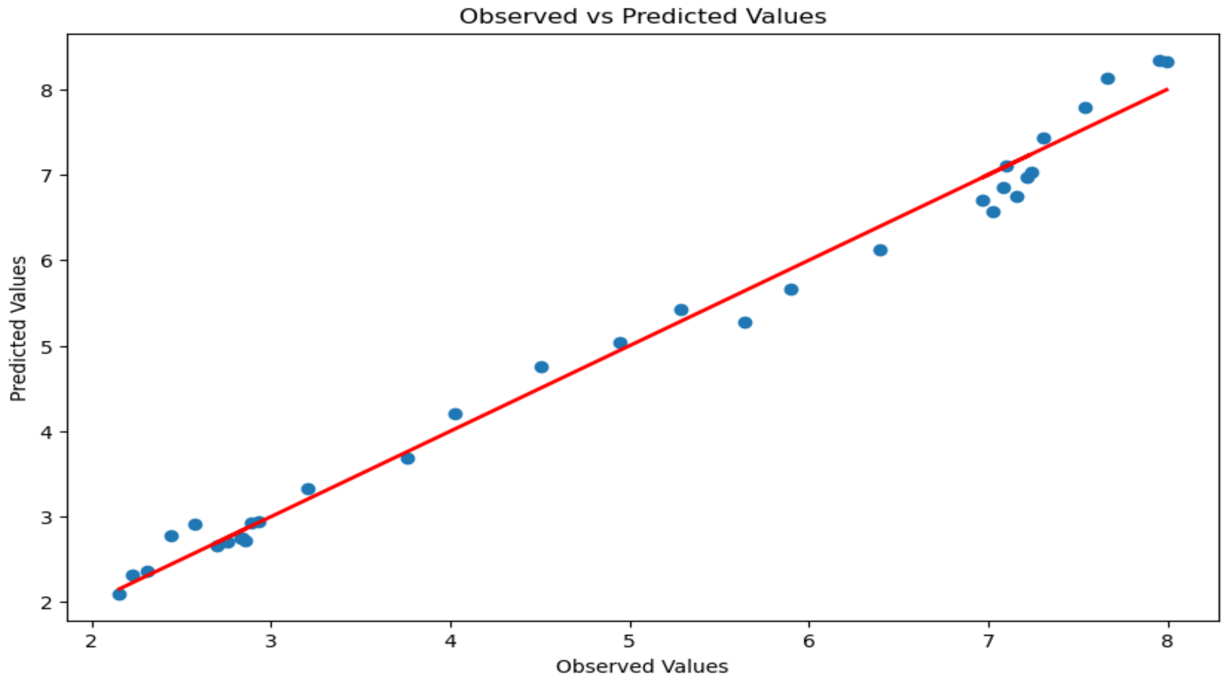


**Figure 4: Scatterplot for linearity check showing observed versus predicted values**

The alignment of points along the 45-degree line suggests a good fit between the observed and predicted values. Figure 4 indicates that the model's predictions are accurate across the range of the data, fulfilling the objective of accurately modeling the relationship between the variables.

Each of these aspects provides valuable insights into the paper's objectives, such as the quantification of economic activities' environmental impacts, the assessment of technological innovation on sustainability, and the implications of these factors for policy formulation.

## 4.7 Addressing Multicollinearity in The Dataset

To determine whether you have a multicollinearity problem, we looked at the Variance Inflation Factor (VIF) or Tolerance levels. If your VIF readings exceed 5 or 10 or your tolerance levels are close to zero, it is evident that multicollinearity is a problem.

Determining the issue might be aided by measuring tolerance levels or the Variance Inflation Factor (VIF). If your VIF values are over 5 or 10 or your tolerance levels are near zero, you have significant multicollinearity. The OLS regression table findings show that multicollinearity can inflate regression coefficient standard errors, resulting in less trustworthy statistical judgments. It can also make the model more responsive to model changes, such as adding or removing variables.

The Remediation Strategy used a regularization technique similar to ridge regression to penalize significant coefficients for minimizing multicollinearity.

### 4.7.1 Multicollinearity Test Analysis

**Table 5: VIF Results**

| | Variable | VIF |
|---|---|---|
| 0 | $CO_2$TPC | 17558.67070 |
| 1 | PEC (TWh) | 1334.900318 |
| 2 | FDIOUT | 12.475664 |
| 3 | FDIIN | 27.821312 |
| 4 | $CO_2$KG | 36.542931 |
| 5 | GDP | 38.053190 |
| 6 | UPOP | 339.634683 |
| 7 | TA(RnD) | 597.821345 |
| 8 | $CO_2$T | 22787.254806 |



The VIF results suggest significant multicollinearity in the dataset; all variables except FDIOUT have VIFs well above 10, indicating that they are potentially influenced by multicollinearity to varying degrees.

## 4.8 Lasso Regression Analysis

**Table 6: Lasso Regression Analysis Results**

| Variable | Coefficient |
|---|---|
| PEC (TWh) | -0.000000 |
| FDIOUT | -0.039073 |
| FDIIN | 0.012403 |
| $CO_2$KG | 0.044167 |
| GDP | 0.042625 |
| UPOP | -0.000000 |
| TA(RnD) | -0.000000 |
| $CO_2$TPC | 2.182638 |
| Mean Squared Error (MSE) | 0.002556230150225922 |

Our study utilized Lasso regression to refine the analysis of factors impacting $CO_2$ emissions per capita ($CO_2$TPC) in China. This statistical method adjusts for multicollinearity by penalizing the regression coefficients of less impactful variables, which helps identify those significantly influencing $CO_2$ emissions.

The Mean Squared Error (MSE) from the Lasso regression was 0.002556230150225922, indicating a good fit of the model to our data.

Primary Energy Consumption (PEC) in Terawatt-hours (TWh), PEC (TWh) of the Lasso regression's coefficient is significantly reduced, suggesting a weaker than the expected direct impact on $CO_2$TPC. This finding challenges the initial hypothesis that higher energy consumption directly correlates with increased $CO_2$ emissions, indicating more complex underlying dynamics.

The coefficient for urban population growth UPOP was reduced to zero, implying that urban population growth does not have a significant direct impact on $CO_2$ emissions as previously thought. This outcome provides a new perspective on the effects of urbanization on sustainability.

For Technological Advancement (TA) in Research and Development (R&D), the impact of technological advancements on $CO_2$ emissions was minimal in our model, suggesting that while R&D is crucial, its direct effect on reducing emissions might be less substantial than hypothesized.

The Impact of Foreign Direct Investment (FDI) on Sustainability analysis indicated that FDI outflows have a negligible negative relationship with CO2TPC, raising questions about current investment strategies' effectiveness in enhancing sustainability.

The insights from the Lasso regression analysis highlight the complex relationships between economic activities, technological changes, and environmental outcomes and guide policy decisions. By pinpointing the most significant drivers of $CO_2$ emissions, this analysis aids in tailoring more effective environmental policies and economic strategies to achieve sustainable development in China. By focusing on the statistical significance and practical relevance of various predictors, this methodological approach provides a robust basis for understanding and mitigating the environmental impacts of rapid economic growth.

## 4.9 Granger Causality Test Results for $CO_2$TPC

The Granger Causation Test was performed to determine the direction of causation between economic and environmental indicators based on the multicollinearity test results.

**Table 7: Granger Causality Test Results.**

| |
|---|
| UPOP Granger generates CO2TPC at lag 2 (p value = 0.005144429016626497). |

The Granger causality test findings show that the variable UPOP (urban population) Granger causes CO2TPC (per capita CO2 emissions) with a 2-lag interval and a p-value of around 0.0051. Table 7 suggests that historical urban population numbers have statistically significant predictive power for contemporary per capita CO2 emissions, revealing a possible causal relationship that requires additional analysis and study.

## 5.1 Interpretation of Empirical Results

The study's findings indicate a problematic interplay between economic growth, technical innovation, and environmental sustainability in China, shedding insight into the complexities of sustainable development in a rapidly industrializing country. The findings emphasize the significant challenge of reconciling rapid economic expansion with environmental sustainability goals. Our findings demonstrated a direct and positive relationship between GDP growth and CO2 emissions per capita, supporting the long-held assumption that economic development often comes at a significant environmental cost. This organization emphasizes the critical need for China to research new sustainable growth models that distinguish economic progress from ecological damage.



The ongoing positive relationship between GDP and CO2 emissions indicates that, despite technical advances and environmental policies, economic activities continue to have a significant impact on environmental health. The results from the Ordinary Least Squares (OLS) and Lasso regression analyses provide a nuanced view of the role of technology in environmental sustainability. Technological advancements, as assessed by R&D spending, have a small direct effect on CO2 emissions. This study challenges the generally held idea that technology can drive environmental development independently, proposing that technological improvements' success may be determined by their integration with broader policy measures and economic activity. The positive coefficient for primary energy consumption (PEC) in both the OLS and Lasso regressions indicates that energy consumption remains a significant source of CO2 emissions in China, which aligns with the global understanding that energy production and consumption are critical components of the environmental balance. Our findings demonstrate that efforts to improve energy efficiency and promote renewable energy sources are essential in reducing the environmental consequences of economic growth. Interestingly, the Granger causality tests revealed that urban population growth has a predictive relationship with CO2 emissions, implying that urbanization processes must be managed carefully to mitigate environmental impacts. Our findings highlight the importance of sustainable urban planning and infrastructure development to accommodate population growth without exacerbating ecological degradation.

## 5.2 Comparison with Existing Literature

The correlation between economic activity and environmental results is a significant area of study that has generated extensive attention due to its ability to demonstrate the intricate mechanisms that foster sustainable development throughout time. The present analysis aligns with previous studies, highlighting the complicated interaction between these two domains. This study investigates the potential of technical innovation to mitigate environmental damage induced by economic expansion (Khan, I., Zhong, R., Khan, H., et al., 2023). The statement stresses a fundamental flaw: the inability to fully use and expand the benefits acquired due to a lack of comprehensive and well-coordinated plans to optimize them. According to Dissanayake et al.'s research in 2023's study, establishing criteria that promote technological innovation and adopt sustainable behaviors, a comprehensive environmental sustainability plan is essential to develop. Dissanayake et al.'s research in 2023 emphasizes the necessity of integrated solutions by demonstrating how renewable energy impacts economic growth across different scenarios while substantially reducing carbon emissions. While renewable energy sources are critical for reducing emissions, recent research reveals that their effectiveness is hampered by a lack of strong economic policies that stimulate sustainable energy use, emphasizing the necessity for a comprehensive policy framework that balances economic growth and environmental sustainability. The findings of Chang et al. in 2023 provide authentic data from the Chinese market. They illustrate the substantial influence of ecological regulations when paired with innovative green technology on $CO_2$ emissions. This research underscores the importance of stringent environmental regulations to ensure that integrating green technologies leads to the anticipated ecological advantages. It's essential to have support from the government and technological advancements to ensure successful implementation.



Similarly, Bashir and colleagues (2020) investigated how environmental taxes, economic growth, and technological advancements affect carbon emissions. They discovered that while technological advancements and ecological taxes can reduce emissions, rapid economic growth could counteract these advantages. This discovery shows a difference in existing sustainable policies. It highlights the vital need for a complete policy structure incorporating economic, technological, and regulatory elements to tackle and reduce economic expansion's environmental impact adequately. This all-encompassing method is essential for bridging the execution disparity and ensuring the successful fulfillment of sustainable development goals.

## 5.3 Policy Implications

Given the importance of economic and technological elements in determining environmental sustainability, governments must find comprehensive solutions to address these issues. Strategies should encourage technological and economic progress and ensure these advancements are consistent with sustainability goals. Furthermore, given the direct link between urbanization and $CO_2$ emissions, innovative urban design focusing on sustainability is essential to reduce the environmental effects of urban growth. The study's findings have important implications for Chinese leaders who want to balance economic development and ecological sustainability.

One of the significant findings is the intricate connection between foreign direct investment (FDI) and carbon emissions, which poses obstacles and opportunities for policymakers. The study underscores the need for targeted environmental regulations to mitigate the adverse effects of FDI in pollution-intensive industries. Implementing stringent ecological standards and oversight could ensure that foreign investments contribute positively to achieving China's carbon neutrality goals without exacerbating the environmental footprint. Furthermore, the analysis reveals that technological advancement, particularly in green technologies, is crucial in reducing per capita carbon emissions. However, the effectiveness of such technologies is contingent on their integration into the larger economic and regulatory context, demonstrating the importance of government incentives for encouraging research and development in sustainable technologies. Policies encouraging innovation and the adoption of energy-efficient technologies can help accelerate the transition to a low-carbon economy.



Furthermore, the study emphasizes the importance of urban planning in environmental sustainability. With urban population expansion highlighted as a possible source of higher carbon emissions, policies are urgently needed to promote sustainable urbanization. Such actions could include boosting public transportation, increasing energy efficiency in building design, and creating city green spaces. These approaches would reduce metropolitan areas' environmental impact and improve residents' quality of life. Finally, the findings advocate for a holistic policymaking strategy considering sustainability's economic, technological, and ecological dimensions. The technique should entail policy drafting, rigorous implementation, and ongoing review to achieve long-term efficacy.

Collaboration among government, industry, and academia is required to build a culture of sustainability that balances economic development goals with environmental stewardship.

## 5.4 Conclusion

This research sheds light on the intricate connections among China's economic progress, technological advancements, and environmental preservation. While economic growth is closely associated with increasing $CO_2$ emissions, the expected benefits of technological progress and strict environmental regulations have not materialized fully. The results highlight the extensive and varied impacts of urbanization and foreign direct investment on sustainability, underscoring the importance of targeted actions to enhance environmental awareness among investors and urban planners. Additionally, the study emphasizes the critical role of technological innovation in shaping China's ecological future, asserting that its success relies on its integration into comprehensive regulatory structures and economic plans. These findings contribute to our theoretical comprehension of sustainable development in China's swiftly growing economy and provide policymakers with actionable insights for harmonizing environmental and financial goals.

### Conflict of Interest Statement

"We, Joseph Apsondaisy, Jiang Junfeng, and Selamawit Kibebew Fantaye, declare that there are no conflicts of interest regarding the publication of this paper. Any personal or financial relationships with other people or organizations have influenced no part of this research. The research was conducted independently, and the findings and conclusions expressed in this manuscript are solely those of the authors and do not necessarily represent the views of their affiliated institutions or funding bodies.



## Limitations of The Study and Potential Areas for Further Research

This study relies primarily on statistical methods and historical data, which could hinder its broad use and understanding of the complex relationship between economic growth and environmental sustainability. Focusing mainly on China, the study offers specific findings that may not directly apply to other global contexts with different ecological, financial, and regulatory characteristics. Using secondary data impedes our ability to investigate complex nonlinear relationships thoroughly. In addition, despite the study's expanded timeline, it may overlook long-term trends that might impact the performance of current regulations and technology advancements.

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