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Foreign Direct Investment and Green Innovation: Driving Low-Carbon Economic Growth in China Eastern Provinces

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ABSTRACT

This study examines the effect of foreign direct investment (FDI), green technology innovation and economic growth on CO_2 emissions in eastern China. This study employs the extended STIRPAT model and the EKC model to analyze the relevant data of 12 provinces in eastern China from 2001 to 2021. The estimation methods of Pooled OLS, Fixed Effect and Random Effect are compared and analyzed using the static panel data analysis method. Finally, the robust standard error estimation method of the fixed effect is adopted. The robust standard error estimation results indicate that green technology innovation and economic growth have a negative impact on CO_2 emissions. In contrast, population growth rate and the proportion of secondary and tertiary industries have a positive effect. The impact of FDI on CO_2 emissions is found to be insignificant, suggesting that neither the Pollution Haven Hypothesis nor the Pollution Halo Hypothesis is prevalent in the eastern region of China. This suggests that the "inverted U-shaped" EKC does not exist in the eastern region of China. It is therefore evident that the enhancement of green technology innovation is of paramount importance for the reduction of CO_2 emissions in the eastern region.

1. Introduction

The acceleration of industrialization has resulted in the emergence of climate change issues (Sulaiman et al., 2018), with CO_2 emissions identified as a primary contributor to global warming (Ahmed et al., 2019). Over the past two decades, FDI has played an essential role in advancing globalization (Doytch, 2020). It serves as a key driver of globalization, enabling the cross-border transfer of goods and services

(Ali & Adriano, 2019). It also promotes economic growth while having an impact on CO_2 emissions. The reduction of CO_2 emissions has become a significant concern for the international community.

In consequence, countries worldwide have initiated a range of measures to conserve energy, develop clean energy sources, and reduce carbon emissions (She, 2023). As one of the most significant CO_2 emitters, China's CO_2 emissions account for approximately 30% of the total global emissions (World Bank database, 2022). The Chinese government sets 'peak carbon' and 'carbon neutral' targets and formulated laws and regulations on environmental protection to promote green and low-carbon transformation and development. These actions reflect China's initiative in climate governance and move toward sustainable development. Green technology innovation helps reduce CO_2 emissions (Yuan et al., 2022; Gu et al., 2022). It makes better use of resources to lower carbon output. The Chinese government supports this through many policies. One way to measure green technology is by counting green patents (Guo & Yang, 2020).

According to the 14th Five-Year Plan, China will cut CO_2 emissions by 18% before 2025. It also aims to peak carbon by 2030 and be carbon neutral by 2060. Eastern China has strong economic activity, the most FDI and high green technology innovation. It also emits the most CO_2 emissions. So, this area feels big pressure to meet national carbon reduction goals. Therefore, it is valuable to study how FDI and green technology innovation affect CO_2 emissions in eastern China. First, this study shows how FDI and green technology innovation link to CO_2 emissions in the east. Second, this study helps make better policies. Eastern China grows fast but pollutes much. Good policies can balance both. Last, this study gives real ideas to improve foreign investment, help green innovation, and reduce CO_2. emissions These can guide leaders to reach carbon goals and support a move to low-carbon growth of China.

2. Literature Review

2.1 Theoretical Considerations

There are two distinct theories on the relationship between FDI and CO_2 emissions. The Pollution Haven Hypothesis (Walter & Ugelow, 1979; Baumol & Oates, 1988) implies that FDI may increase CO_2 emissions (S. Wang et al., 2017; Nadeem et al., 2020; Abdo et al., 2020) while The Pollution Halo Hypothesis implies that FDI can reduce CO_2 emissions in host countries (Sapkota & Bastola, 2017; Pazienza, 2019; Long et al., 2020).

The "inverted U-shaped" Environmental Kuznets Curve (EKC) proposed by Panayotou et al. (1993) and Grossman and Krueger (1995) illustrate there is an inverse relationship between gross domestic product (GDP) and pollution. Economic growth may initially exacerbate environmental problems; however, at reaching certain economic level, higher economic growth will improve the environmental quality by reducing the level of pollution. Modifications to the Grossman and Krueger model were done by Bradford et al. (2000) by highlighting the characteristics of the inflection point in the EKC model.

Ehrlich and Holdren (1971) proposed the IPAT model to explain the factors affecting CO_2 emissions. Grossman and Krueger (1995), York et al. (2003), and Dietz and Rosa (1994) extended the IPAT model to obtain the STIRPAT model by considers the effects of population, wealth, technology, and other factors on CO_2 emissions. The STIRPAT model has been used by various scholars (Oladunni et al., 2022; Wen et al., 2022; Udeagha & Ngepah, 2022) to analyse the impact of environment quality.

2.2 FDI–emissions (Pollution Haven vs Halo)

The impact of FDI on China's CO_2 emissions has been the subject of considerable academic studies. There are two conflicting views on the impact of FDI on CO_2 emissions (positive and negative impact) and some studies have found an insignificant effect of FDI on CO_2 emissions. Past studies showed that there is variability on the empirical findings regarding FDI-CO_2 emissions nexus in China. Some studies' findings support the Pollution Haven Hypothesis that FDI increase China's CO_2 emissions (M. Zhu & Wei, 2018; K. Zhang, 2019), some empirical findings support the Pollution Halo Hypothesis (Elliott et al., 2013; Dang, 2018; Wen, 2021). Chen & Huang (2019) and Yang & Wang (2022) found that the effect of FDI on CO_2 emissions differs between eastern, central and western regions of China. Huang (2017) and Chen & Huang (2019) found FDI increased CO_2 emissions in eastern and central China, while Yang & Wang (2022) found FDI increased CO_2 emissions in eastern and western China from 2003 to 2009 and there was no significant influence from 2010 to 2019.

Furthermore, there are studies a multitude of scholars have found an insignificant relationship between FDI and CO_2 emissions in developing countries. Blanco et al. (2013) examined the correlation between FDI and CO_2 emissions by utilizing data from 18 Latin American nations over the period from 1980 to 2007 and they observed no significant impact of FDI on CO_2 emissions. Shaari et al. (2014) employing panel data from 15 developing countries spanning the years 1992 to 2012 found that FDI does not have a significant impact on CO_2 emissions, but economic growth leads to an increase in CO_2 emissions in the long run. By examining the impact of trade and FDI on CO_2 emissions among the BRICS nations (Brazil, Russia, India, China, and South Africa), He et al. (2020) discovered a significant causal relationship between CO_2 emissions and trade in the short run but there is no significant causal relationship between FDI and CO_2 emissions. Ren et al. (2024) conducted a study on the relationship between FDI and CO_2 emissions in the G7 countries over the period from 1971 to 2020. They observed that FDI reduced CO_2 emissions for the period 1971–1995, FDI increased CO_2 emissions between the period 2000–2015, but FDI had no significant effect on CO_2 emissions for 2015–2020.

2.3 Green Technology Innovation–emissions

Past studies have showed inconsistent conclusions about the impact of green technology innovation on CO_2 emissions by depending on the specific research object under consideration. Moreover, there is a limited empirical studies examining the role of green technology innovation in China's economic growth and CO_2 emission reduction (X. Hu & Shi, 2022). Qian & Li (2017) employed a modelling approach by integrating green technology innovation with carbon intensity at the industrial level indicated that green technology innovation has emerged as a pivotal factor in reducing CO_2 emissions. Using generalized spatial panel model on 30 provinces in China from 2004 to 2018, Y. Wu & Zhao (2021) found that green technology innovation is significant in reducing CO_2 emissions.

2.4 EKC evidence in China and globally

As early as 1967, the British economist Meechan highlighted in his seminal work, The Price of Economic Growth, that the cost of economic growth at the current stage is the depletion of future environmental resources. The earliest empirical evidence was based on the environmental Kuznets curve (Grossman & Krueger, 1991) to study the relationship between economic growth and the ecological environment. The existence of the "inverted U-shaped" EKC curve has been verified by numerous scholars (Hamit-Haggar, 2012; Ozturk & Acaravci, 2013; Tu, 2016), yet their conclusions have differed. F. Wang et al. (2018) validated the EKC model using data for 27 China provinces indicating 'inverted U' shape between CO_2 emissions and per capita GDP. By categorizing provinces into three regions (upstream, midstream, and downstream) between 2009–2019, M. Hu et al. (2021) examined the relationship between CO_2 emissions, industrial structure, and high-quality economic growth. Their findings indicated that the upstream region with high economic growth has higher CO_2 emissions. Cheng & Da (2022) conducted a comprehensive analysis of the interconnections among income inequality, CO_2 emissions, and economic growth across 30 Chinese provinces from 2003 to 2017, employing the Panel Vector Autoregression (PVAR) model. Their study revealed that CO_2 emissions unidirectionally influenced income inequality, while economic growth also had a one-way impact on income disparity. Moreover, there is a two-way

Granger causality between CO_2 emissions and economic growth. The research indicated that economic growth and CO_2 emissions exhibited a symbiotic relationship in the long term, which, however, was anticipated to diminish progressively over time.

The majority of existing literature on the factors influencing CO_2 emissions in China has been from the perspective of China as a whole or a specific province. Few scholars have paid attention to CO_2 emissions in eastern China. Consequently, this study addresses this gap in the literature.

3. Research Methodology

3.1 The Model Specification

The Environment Kuznets Curve (EKC) model proposed by Grossman & Krueger (1995) in discussing the issues between economy and environment was specified. The model specification of EKC model is expressed as Equation (1):

$$I_{it} = \beta_0 + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \varepsilon_{it} \qquad (1)$$

where I signifies the level of pollution, while Y represents the economic indicator, specifically GDP per capita. B_1, β_2 are the coefficients that correspond to specific aspects of the model, and ε_{it} is the stochastic error component. EKC exists when $\beta_2 < 0$, and Y>0, implying the pivotal characteristics of the "inverted U-shaped" curve.

The Stochastic Impacts by Regression on Population, Affluence, and Technology model (STIRPAT) was developed by Dietz and Rosa in 1994 as an enhancement to the IPAT model proposed by Ehrlich and Holdren in 1971. This model is utilized to investigate the probabilistic impacts of various factors, including population size, economic prosperity, and technological advancements, on environmental conditions. The STIRPAT framework serves as the foundation for the research model in this study. The mathematical representation of the STIRPAT model is given as $I_i = aP_i^b A_i^c T_i^d e_i$, where I_i represents the environmental impact, which aligns with the IPAT model's definition, P_i, A_i, T_i correspond to population, affluence, and technology, respectively, maintaining the same meanings as in the IPAT model. a is a constant parameter within the model, b, c and d are the exponents that denote the influence of population, affluence, and technology, respectively, and are referred to as the driving force indices, and e_i is the stochastic error term, accounting for random variations. I signifies that these variables (I, P, A, T, and e) differ between observations.

This study combines the EKC model with the STIRPAT model. The EKC model demonstrates an "inverted U-shaped" relationship between economic development and environmental pollution, meaning that initial economic growth leads to increased pollution, which then declines after reaching a certain income level. The STIRPAT model explains the driving forces behind carbon emissions from multiple factors, including population, wealth, and technology. Building on this, the study introduces FDI to test the pollution halo and pollution paradise hypotheses, and to explore the impact of FDI on carbon emissions. By integrating these two models, this study offers a more comprehensive analysis of the combined effects of economic growth, FDI, and green technology innovation on CO_2 emissions, revealing their relationships and mechanisms, and providing a richer theoretical foundation for policy formulation. The core explanatory variables include FDI, green technology innovation, economic growth, and the quadratic term of economic growth. The control variables consist of population size, the share of the secondary industry, and the proportion of the tertiary industry. The equation model of this study as below:

$$CO_{2it} = \alpha + \beta_1 FDI_{it} + \beta_2 GTI_{it} + \beta_3 GDP_{it} + \beta_4 GDP_{it}^2 + \beta_5 POP_{it} + \beta_6 PSI_{it} + \beta_7 PTI_{it} + \varepsilon_{it} \qquad (2)$$

where CO_{2it} represents CO_2 emissions for province i at time t, serving as a measure of environmental impact. FDI_{it} denotes the amount of foreign capital actually utilized in province i at time t, acting as an indicator of foreign direct investment. GTI_{it} corresponds to the number of green patent filings in province i at time t, representing green technology innovation, GDP_{it} equals GDP of province i at time t, used as a measure of economic development or affluence, while GDP_{it}^2 is its squared term, included to capture the non-linear relationship with CO_2 emissions. Furthermor, $POPG_{it}$ represents the annual permanent resident population growth rate in province i at time t, serving as a proxy for population growth rate, PSI_{it} is the proportion of added value of secondary industry in GDP for province i at time t, a proxy for the proportion of secondary industry, PTI_{it} indicates the proportion of added value of tertiary industry in GDP for province i at time t, a proxy for the proportion of tertiary industry. β_1, β_2, β_3, β_4, β_5, β_6 and β_7 are the parameters for the variables, while ε represents the error term. The time period under consideration spans from 2001 to 2021, and the index i stands for the province index in eastern China, specifically, $i = 1,2,\ldots,12$. To enhance the economic interpretability of the variables, logarithmic transformations are applied where appropriate.

In this study, static panel data models (Pooled OLS, FEM and REM) were used to investigate the effect of each variable on CO_2 emissions. The pooled OLS model is typically employed when the impact of explanatory variables on the dependent variable is assumed to be consistent across individuals. Under the pooled OLS, the regression coefficients are assumed to be constant over time and across different sections. The explanatory variables are non-random variables, independent of the error term. Furthermore, the model follows the standard classical regression assumptions. This implies that there are no individual- or time-specific unobservable factors influencing the model, and there is no correlation between the error term and the independent variables ($\text{cov}(u_i, X) = 0$).

This study uses both fixed effects (FE) and random effects (RE) models to allow for differences between provinces in both intercepts and slopes. The FE model includes province-specific interceptions that represent time-invariant characteristics. These intercepts help control unobserved features that may be correlated with the independent variables—if ignored, this correlation could bias pooled OLS estimates. By incorporating province-specific intercepts, the FE model captures differences that are stable within each province but vary from one province to another. This approach helps reduce omitted variable bias and improves the consistency of coefficient estimates.

In contrast, the RE model treats province-specific effects as random and assumes they are uncorrelated with the explanatory variables. Under this assumption, the RE model tends to be more efficient than the FE model because it uses variation both within and across provinces. This model is suitable when unobserved heterogeneity is independent of the regressors. It estimates the average effect of the explanatory variables across all provinces. The remaining error term reflects province-specific variations in CO_2 emissions not explained by the model.

This study employs the Breusch-Pagan LM (BPLM) test, as formulated by Breusch and Pagan in 1980, and the Hausman test, introduced by Hausman in 1978, to determine the most appropriate model for the analysis. The BP-LM test suggests a preference for the random effects (RE) model over the pooled OLS (POLS) model if its null hypothesis is rejected. Conversely, the Hausman test points towards the fixed effects (FE) model over the RE model when its null hypothesis is rejected.

3.2 Data and Description of Variables

This study utilizes panel data from 12 provinces in China's eastern region, covering the period from 2001 to 2021. The provinces included are Beijing, Tianjin, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi, Hainan, and Liaoning, as outlined by the standards classification by China's National Bureau of Statistics as shown in Table 1. This dataset provides a robust foundation for examining the relationships between foreign direct investment (FDI), green technology innovation, economic growth, and CO_2 emissions in one of China's most economically dynamic regions. The time span allows for the analysis of long-term trends, capturing both the region's rapid industrialization and its progress toward low-carbon development. The specific variables that have been selected for this study are set out in Table 2.

Table 1. List of provinces in Eastern region of China

Beijing	Tianjin	Hebei
Shandong	Jiangsu	Shanghai
Zhejiang	Fujian	Guangdong
Guangxi	Hainan	Liaoning

Source: Standards classification by China's National Bureau of Statistics

Table 2. Summary of variables

Variables		Symbol	Measurement	Unit	Data sources	Expected sign
Dependent variable	CO_2 emissions	CO_2	CO_2 emissions	million tons	China Emission Accounts and Datasets (CEADs)	
Explanatory Variables	Foreign Direct Investment	FDI	Actual utilization of foreign capital	million US$	China Statistical Yearbook	+
	Green Technology Innovation	GTI	Green patent Authorization	piece	OECD & the Patent Search and Analysis System of the State Intellectual Property Office of China	-
	Economic Growth	GDP	GDP	CNY	China Statistical Yearbook	+
	Economic Growth^2	GDP^2	The square of GDP	CNY	China Statistical Yearbook	+/-
Control Variables	Population Growth Rate	POPG	Annual permanent resident population growt h rate*100	100%	China Statistical Yearbook	+
	The Proportion of Secondary Industry	PSI	The proportion of added value of secondary industry in GDP	%	China Statistical Yearbook & the People's Bank of China	+
	The Proportion of Tertiary Industry	PTI	The proportion of added value of tertiary industry in GDP	%	China Statistical Yearbook & the People's Bank of China	+

The study incorporates a range of variables to investigate the factors influencing CO_2 emissions in the eastern region of China. The dependent variable, CO_2 emissions (CO_2), is measured in million tons and sourced from the China Emission Accounts and Datasets (CEADs). The explanatory variables include Foreign Direct Investment (FDI), quantified by the actual utilization of foreign capital in million US dollars, and Green Technology Innovation (GTI), measured by the number of green patent authorizations, both of which are expected to have contrasting effects on CO_2 emissions. Economic growth (GDP) and its squared term (GDP2), measured in Chinese yuan (CNY), capture the nonlinear relationship between economic development and emissions. Additionally, control variables include the Population Growth Rate (POPG), measured as the annual percentage growth of the permanent resident population, and the proportions of secondary (PSI) and tertiary (PTI) industries in GDP, expressed as percentages. Data for these variables are primarily sourced from the China Statistical Yearbook, supplemented by the People's Bank of China and other relevant institutions, and their expected effects on CO_2 emissions vary depending on the nature of the variable.

4. Findings and Discussion

Table 3 presents descriptive statistics for both the dependent variable, which is untransformed data, and a selection of independent variables that have undergone logarithmic transformation. The data reveal a substantial disparity in CO_2 emissions across China's eastern region, with the highest emissions reaching 947.1629 and the lowest recorded at a mere 1.009399. Notably, there is a considerable variation in FDI, green technology innovation, and GDP as well.

Table 3. Descriptive statistics

Variables	**Unit**	**Obs.**	**Mean**	**Standard deviation**	**Min**	**Max**
CO_2 emissions (CO_2)	million tons	252	325.575	252.746	1.009	947.163
lnFDI	million US$	252	4.135	1.135	1.084	5.879
Green Technology Innovation (GTI)	piece	252	6344.591	10261.550	9.000	60966.000
GDP (lnGDP)	CNY	252	9.685	1.081	6.325	11.731
GDP^2 ($lnGDP^2$)	CNY	252	94.955	20.299	40.007	137.617
Population Growth Rate (POPG)	100%	252	1.149	1.340	-5.066	5.782
PSI(lnPSI)	%	252	0.429	0.107	0.158	0.583
PTI(lnPTI)	%	252	0.481	0.121	0.292	0.839

Table 4 displays the correlation matrix for the dependent and independent variables. Except for the tertiary sector's proportion, all variables contribute to the increase in CO_2 emissions. The correlation coefficients are significant at the 1% level.

Table 4. Correlation matrix

	CO_2	lnFDI	GTI	lnGDP	$lnGDP^2$	POPG	PSI	PTI
CO_2	1.000							
lnFDI	0.509***	1.000						
GTI	0.427***	0.505***	1.000					
lnGDP	0.727***	0.771***	0.647***	1.000				
$lnGDP^2$	0.741***	0.769***	0.685***	0.997***	1.000			
POPG	-0.230***	0.112*	-0.111*	-0.101	-0.108*	1.000		
PSI	0.434***	0.265***	-0.154**	0.265***	0.242***	-0.027	1.000	
PTI	-0.264***	0.240***	0.361***	0.161***	0.163***	0.196***	-0.773***	1.000

Notes: * p<0.1, **p<0.05, *** p<0.01.

Subsequently, this study conducts a range of regression analyses. The comprehensive findings of these regression analyses are detailed in Table 5.

Table 5. Results of FDI, green technology innovation and economic growth on CO_2 emissions of China's eastern region using static approaches, 2000-2021

	POLS	*Fixed effect*	*Random effect*	*FE robust standard error*
lnFDI	4.664	18.744*	9.618	18.744
	(14.622)	(10.408)	(10.657)	(37.621)
GTI	-0.005***	-0.004***	-0.004***	-0.004***
	(0.002)	(0.001)	(0.001)	(0.002)
lnGDP	-678.393***	-1119.877***	-1009.913***	-1119.877***
	(158.684)	(92.867)	(93.647)	(254.016)
$lnGDP^2$	47.700***	63.169***	59.025***	63.169***
	(8.70442)	(4.711)	(4.818)	(12.562)
POPG	-10.819	11.788***	11.041***	11.788***
	(6.903)	(3.849)	(3.989)	(5.794)
PSI	-151.8865	2311.383***	1660.220***	2311.383***
	(236.243)	(352.988)	(331.572)	(907.728)
PTI	-817.717***	2425.873***	1643.607***	2425.873***
	(210.139)	(356.499)	(329.956)	(915.734)
cons	2850.193***	2946.846***	2968.710***	2946.846***
	(630.904)	(322.882)	(339.933)	(499.521)
R^2	*0.741*	*0.165*	*0.296*	*0.165*
$\bar{R}^2$	*0.741*			
F-stat	*99.850*			
	(0.0000)			
RMSE	*130.400*			
Poolability test		*86.270****		
		(0.0000)		
BPLM test	*1019.120****			
	(0.0000)			
Hausman test		*25.920****		
		(0.0001)		
Heteroscedasticity test		*334.200****		
		(0.0000)		
CSD test			*3.972****	
			(p<0.01)	
Wooldridge test		*87.454****		
		(0.0000)		
Number of groups		12	12	12
Number of observations	252	252	252	252

*Notes: Figures in parentheses are standard errors. $\bar{R}^2$ indicates adjusted R-squared, RMSE indicates root mean square error, Poolability test indicates the mixed effects of panel data, BPLM indicates Breusch–Pagan LM test, CSD test indicates cross-sectional dependence, and Wooldridge test indicates serial correlation. All the F-test, BPLM test, Hausman test, Heteroscedasticity test, CSD test and Wooldridge test are reported in p-values. *, **, and *** indicate the respective 10%, 5%, and 1% significance levels.*

The results of the POLS model in Table 5 indicate that the core explanatory variables GTI, lnGDP, and $lnGDP^2$ are significant at the 1% level. This indicates that green innovation is mitigating CO_2 emissions. However, foreign direct investment is statistically insignificant. The negative coefficient of lnGDP and the positive coefficient of $lnGDP^2$ do not support the EKC model in eastern China.

The Pooled OLS (POLS) model assumes uniformity across all cross-sectional units and does not consider the unique characteristics of individual provinces. To overcome this limitation, fixed effects models (FEM) and random effects models (REM) are applied (Baltagi, 2008). The Pooability test and Breush-Pagan LM test indicate that FEM and REM are preferable to POLS. The estimated results of FEM and REM are shown in Table 5. Further, the Hausman test is used to determine whether the RE model or the FE model is preferable. The Hausman test rejects the null hypothesis (p-value<0.01), confirming that the FE model is more preferable. Following this, several diagnostic tests were applied to the FE model: serial correlation test and Heteroskedasticity test. Wooldridge serial correlation test and the Heteroskedasticity test indicate the presence of serial correlation and Heteroskedasticity.

Robust standard error estimation is employed to address the issues of serial correlation and heteroskedasticity for the FE model and the results are presented in Table 5 (Column). The fixed effects robust standard error model provides more reliable regression results. The estimation results of the FE robust standard error model indicate that all variables except lnFDI are significant. The insignificant effect of FDI on CO_2 emissions in eastern China is inconsistent with our hypothesis. This is consistent with findings by He et al. (2020) and Ren et al. (2024). The effect of green technology innovation on CO_2 emissions is inversely proportional to CO_2 emissions. This finding is consistent with the study of Gao et al. (2022). Each additional unit of green technology innovation (green patents) leads to an increase of 0.004 units in CO_2 emissions in eastern China. This suggests that green technology innovation may serve to reduce CO_2 emissions in the eastern region of China. Green technology innovation plays a crucial role in managing decarbonization costs while also providing technical support for the research, development, and large-scale implementation of CO_2 utilization, capture, and storage technologies. Furthermore, it contributes to CO_2 emissions reduction by generating a "technological dividend" effect (Shao et al., 2022). The governments in China's eastern region strive for rapid economic growth while placing greater emphasis on environmental protection. By formulating environmental policies, encouraging the development of green technologies, and promoting green innovation, they gradually steer industrial production and economic structures away from reliance on non-renewable energy sources toward greener alternatives. This transition contributes to the reduction of CO_2 emissions (Zahra & Fatima, 2024).

The effect of GDP on CO_2 emissions is statistically significant and negative, and the square of GDP ($lnGDP^2$) is statistically significant and positive. A 1% increase in GDP results in a decrease of 1119.877% in CO_2 emissions in eastern China, while a 1% increase in the square of GDP leads to a 63.169% increase in CO_2 emissions. This implies that the relationship between economic growth and CO_2 emissions is "U-shaped" in the eastern region of China. Thus, this finding does not support the "inverted U-shaped" of EKC model as found by Pata & Caglar (2021). This is closely linked to the stage of economic development in eastern China. While the region is active in economic growth, with relatively high concentrations of FDI and green technology innovation, excessive industrialization may lead to the simultaneous rise of CO_2 emissions and economic growth. Furthermore, green technology innovation and carbon emission reduction measures have not yet effectively curbed the growth of CO_2 emissions in the short term, especially during periods of high-intensity economic development. The eastern region of China experiences the fastest economic growth while consistently pursuing low-carbon economic development. As the pace of green growth accelerates, the rate of CO_2 emissions continues to decline until reaching a turning point, after which it begins to rise (Zahra & Fatima, 2024).

The impact of control variables, population growth, secondary industry, and tertiary industry on CO_2 emissions is found to be significant at 1% significance level. For every unit increase in the population growth rate, CO_2 emissions in eastern China rise by 11.788 units. A 1% increase in the share of the secondary industry (PSI) causes a rise of 2311.383 units in CO_2 emissions in eastern China. For every unit increase in the share of the tertiary industry (PTI), CO_2 emissions in eastern China increase by 2946.846 units. This implies that higher population growth and greater development of secondary and tertiary industries lead to higher emissions of CO_2.

5. Conclusion

This study examines the links between FDI, green technology innovation, GDP, and CO_2 emissions in 12 eastern Chinese provinces. The results indicate that the EKC in this region does not exhibit the conventional “inverted U-shape.” A static panel data analysis was conducted. First, a Poolability test was performed, which supported the use of a Fixed Effects (FE) model. Then, a Random Effects (RE) model was also considered following the BPLM test. The Hausman test was finally applied to decide between the two, confirming that the FE model was more suitable. To account for possible serial correlation and heteroskedasticity, the FE model was estimated to have robust standard errors. This improved the accuracy and reliability of the findings. The results are statistically significant and show that all variables—except FDI—strongly influence CO_2 emissions in eastern China.

The study emphasizes the important role of green technology innovation in reducing CO_2 emissions. Local governments have been promoting high-quality economic growth that supports low-carbon development. This strategy has helped cut emissions without harming the environment. However, continued population growth may lead to expansion in the secondary and tertiary sectors, which could raise CO_2 emissions and create environmental pressures in the future.

Based on these results, it is advised that the region should focus on attracting high-quality FDI, encourage energy-efficient and low-pollution industries, support green technology innovation, and upgrade production methods to lower CO_2 emissions and improve environmental quality. Several policy recommendations emerge. First, FDI policies should prioritize low-carbon sectors and promote green technology transfer. Such steps would strengthen green innovation, reduce emissions, and support sustainable economic growth. Additionally, adjusting the industrial structure by shifting emphasis from secondary to tertiary sectors can help build a more sustainable and low-carbon economy. Since population growth remains a major driver of CO_2 emissions, effective population management, improved urban planning, green infrastructure, and energy-efficient city design are also crucial for sustainable development in the region.Research indicates that fostering green technology innovation, attracting high-quality foreign investment, and promoting the growth of low-carbon industries are key contributions to achieving the Sustainable Development Goals (SDGs) and advancing the nation’s path toward a low-carbon future.

This study employs static panel data models (Pooled OLS, Fixed Effects, and Random Effects) to analyze CO_2 emissions in Eastern China, as these models are well-suited for capturing the short-term effects of economic factors on emissions. Dynamic panel models, such as GMM, require longer time series and may face challenges with instrument selection and endogeneity. Given the 21 years of data, static models offer more stable and reliable estimates, avoiding the potential instability of dynamic models. Therefore, static panel models are more suitable for the objectives of this study. This study primarily focuses on the static analysis of the impacts of various factors on CO_2 emissions. Specifically, it examines the direct effects of factors such as FDI, green technology innovation, economic growth, population growth rate, and the proportions of secondary and tertiary industries on CO_2 emissions. However, this approach overlooks a critical practical issue of the "inertia" characteristic of CO_2 emissions. This inertia refers to the influence of CO_2 emissions from the previous period on the current period. By excluding this factor, the current study may lead to potential biases in understanding the dynamic characteristics of CO_2 emissions.

To address this limitation, future research will incorporate a dynamic analytical framework for CO_2 emissions, such as GMM. In particular, it will include the lagged CO_2 emission level as one of the key explanatory variables in the model to examine its impact on current CO_2 emissions. Introducing this dynamic perspective will not only provide deeper insights into the inherent characteristics of CO_2 emissions but also allow for the identification of the long-term and short-term effects of various influencing factors.

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Conflict of Interest

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts, and declare the absence of conflicting interests with the funders.

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