Assessing the impact of green technology on CO_2 emission in China

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Abstract

Understanding the factors that influence carbon dioxide emissions plays an essential role for policymakers in maintaining sustainable low-carbon economic growth. This paper empirically investigates the role of green technology development in mitigating carbon emissions in China using annual pre-covid data from 30 provinces during 1997-2019. By taking the number of green patents as a proxy variable, our empirical results show that there is a significant negative relationship between China's provincial green technology innovation level and carbon intensity. Moreover, by applying the panel autoregressive distributed lag (PARDL) model estimation, we observe that the direct impact of green technology development on carbon mitigations remains strongly significant in both long run and short run. The empirical evidence gathered in our research suggests that policymakers can expedite China's decarbonization strategies by prioritizing investment in green technology to reduce carbon emissions and promote sustainable economic growth. These results are of particular significance for economies, which have set ambitious carbon neutrality goals and are currently grappling with high levels of carbon emissions.

JEL codes: K32, O13, P28

Key words: Green technology; Carbon emission; China

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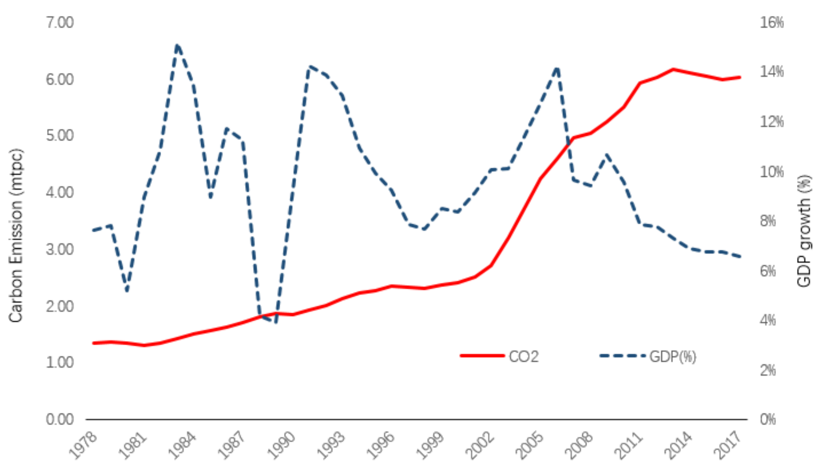
1 Introduction

The current state of the global economy is characterized by significant challenges posed by climate change and environmental degradation which have emerged as major obstacles to achieving sustainable human development. These issues pose a significant threat to the well-being of societies worldwide and have the potential to limit progress towards creating a sustainable future. Prior research in energy and environmental economics has revealed that carbon emissions are primarily responsible for the climate change and environmental degradation we observe today. The increase in carbon emissions not only contributes to global warming but also influences other hazards such as weather extremes (Banholzer et al., 2014) or food insecurities (Anderson et al., 2020), while also imposing a direct risk to human health (Sčasný and Alberini, 2012). Mora et al. (2022) point out that over half of known human pathogenic diseases can be exacerbated by climate change and emphasise the urgent need to address the root cause of climate changes by reducing greenhouse gases emissions (GHG).

Based on the 2023 report from the International Energy Agency (IEA) (2023), the global energy-related CO_2 emissions in 2022 reached 36.8 billion tonnes. Among this, China's total carbon emission accounted for 12.1 billion tonnes, making up 32.9% of the world's total carbon emissions, which surpasses the combined total carbon emissions of North America and Europe. According to data published by the National Bureau of Statistics of China (NBSC) (2019) China's CO_2 emissions per capita were 1.35 metric tons in 1978, when the country began its economic reform plan. This number increased to 2.41 metric tons in 2000 and further rose to 6.12 metric tons in 2018, representing a staggering 353% increase in carbon emissions since the start of China's economic reform (see Figure 1 and Figure 2).

Figure 1: 1978-2018 China carbon emissions and GDP growth

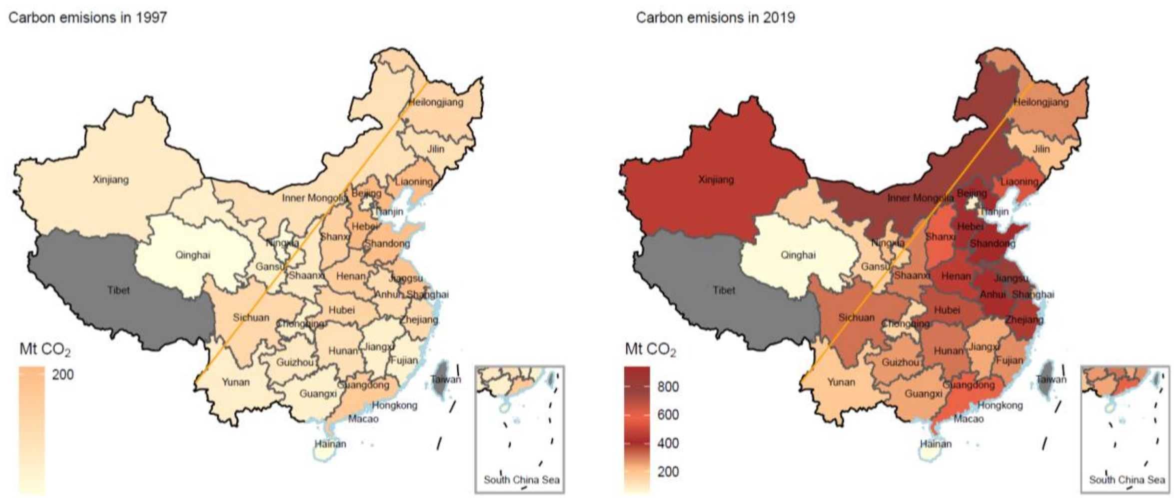


Sources: National Bureau of Statistics of China (2018).

Under the provisions of the Paris Agreement, signatory countries are granted certain privileges and obligations to address the global threat of climate change. To tackle the climate problem China has proposed transitioning its economic development strategy towards a service-oriented structure that relies on clean and low-carbon energy sources to tackle the climate problem (Song et al., 2018). Along with this low carbon economic transition, China pledged to reduce the carbon intensity of GDP by 60-65% below 2005 levels by 2030 (Parry et al., 2016). In addition to that, China has also announced ambitious "Dual carbon" goals during the 75th session of the United Nations General Assembly, with the aim of reaching peak carbon emissions before 2030 and achieving carbon neutrality by 2060. To achieve carbon neutrality by 2060, it is crucial to significantly reduce carbon emissions across all sectors of the Chinese economy and ensuring that the government fulfils its commitment. However, achieving low-carbon economic development in China presents a significant dilemma as the country faces the challenge of balancing environmental concerns with economic growth while meeting the high market demand for fossil fuel energy sources. Thus, green technology innovations have been seen as a key instrument to break through environmental and resource constraints and therefore to promote carbon free sustainable economic development.

As a result, empirical studies have emerged to identify the determining factors of carbon emissions and therefore to provide policymakers with feasible roadmaps to maintain economic transition towards carbon resilience. Many of these studies are conducted under the theoretical framework of the Environmental Kuznets Curve hypothesis (EKC), which aims to identify the influential socioeconomic factors related to carbon emissions (Dogan and Seker, 2016; Dong et al., 2017; Wang and He, 2019; Alam et al., 2021; Li and Wei, 2021). These factors include, but are not limited to, economic growth, energy consumption, urbanization, financial development, foreign direct investment, industrial structure, and many others. For instance, by using autoregressive distribution lag (ARDL) and vector error correction (VECM) model estimations, Liu and Bae (2018) reveal significant dynamic casual relationships among CO_2 emissions, GDP growth, urbanization rate and industrialisation process in both the long and short run. Xu et al. (2020) demonstrate a significant inverted U-shaped relationship between urbanization ratio and industrial pollutant emissions using the STRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model framework. Similarly to Xu et al.(2020), Guo et al. (2019) use the extended STRPAT model to showcase the relevance of financial development in reducing carbon emissions in China from 1997 to 2005. Liu and Song (2020) further assess the linkage between financial development and carbon emissions by employing the Spatial Durbin model and their empirical results confirm the significant connections between these two factors in China.

Figure 2: China provincial carbon emission level in 1997 and 2019



As the largest carbon emitter globally, China's power sector accounts for nearly 40% of the total energy sector emissions (Zhang et al., 2022). Additionally, data from the National Bureau of Statistics of China (2022) indicates that coal-fired power generation accounts for approximately 57% of China's total electricity generation. Hence, an aggressive reduction in coal usage could potentially lead to the collapse of the local power supply system and result in unintended socio-economic consequences. Having a well-defined strategy with minimal transaction costs and optimal social welfare for phasing out coal-fired power plants and replacing them with cleaner energy alternatives during the China's 14^{th} Five-Year Plan (2021-2025) and beyond is crucial to achieving China's ambitious "Dual Carbon" goals (Zhang et al., 2022). With the provision of having significant co-evolution of innovation, investment and deployment of green technologies, Kittner et al. (2017) estimate that China will be capable to achieve net zero carbon power generation by 2040. Taking a wide range of green technologies to decommission conventional coal-fired power supply, Cui et al. (2021) use Global Change Assess model (GCAM) to evaluate the feasibility of plant-by-plant phaseout strategies and conclude that it is highly likely to achieve a complete phaseout of coal power plants in China by 2040. In recent years, several research studies have emphasized the critical significance of renewable energy sources and green technology development in shaping the Chinese energy structure towards carbon resilience. By using spatial econometric analysis, Kuang et al. (2022) conclude that technological innovations have spatial spillover effects on reducing pollution emissions, underscoring the importance of implementing regional pollution control plans with a high level of policy coordination among local governments. Similarly, Chen et al. (2023) apply nonlinear spatial Durbin model estimation to confirm the crucial role of green technology development in reducing carbon emissions in China. Despite the potential for spatial spillover effects of green technology on carbon mitigation, actual impact may vary based on the degree and speed of green technology development and local social-economic circumstances, making it a region-specific issue.

In 2016, China introduced the Energy Production and Consumption Revolution Strategy (2016-2019), which recognized the renewable energy sector as a crucial industry in realizing a sustainable, low-carbon economy (National Development and Reformation Commission (NRDC), 2018). In this context, the objective of this paper is to investigate the role of green technology in mitigating carbon emissions in China. More specifically, this paper aims to address the following two research questions using a set of different quantitative approaches:

1) Is there a significant relationship between patents for green technology development and CO_2 emissions in China?
2) Does the relationship between green technology development and carbon emission reduction remain significant in the long-run or short-run?

Our empirical study, using two-way fixed effect regression on 23 years of annual pre-covid data (1997-2019) from 30 provinces in China, confirms the presence of an inverted U-shaped relationship between economic growth and carbon emissions, indicating the significance of the environmental Kuznets curve (EKC) pattern in China. Additionally, we find a significant negative relationship between green technology development and carbon emission, highlighting the crucial role of technological progress in mitigating carbon emissions in China. Using panel autoregressive distribution lag (PARDL) model estimations, our empirical results show that the direct impact of green technology development on carbon emissions remains highly significant in both the long-run and short-run. Our empirical results contribute to the existing literature in the two following ways. First, our empirical results contribute to the existing literature by providing new evidence into the relationship between green technology innovation and carbon emissions in China. Second, our study contributes to the literature by providing robust evidence on the persistence of the direct impact of green technology on carbon emissions over time, both in the long and short run, in contrast to some studies that suggest a diminishing effect of green technology over time. Finally, our findings inform future research on the effectiveness of green technology policies in mitigating carbon emissions in other developing countries.

The remainder of this paper is structured as follows. Section 2 connects to our research hypotheses development. Section 3 describes the data, and the main empirical methodology that we use for our empirical analysis. Section 4 presents and discusses our main empirical results. Section 5 concludes the paper with policy implications.

2 Research hypotheses development

Based on the above-mentioned literature review, we investigate the following testable hypotheses to address our main research questions.

- **Hypothesis 1 (H1):** Green technology development does not contribute to CO_2 emission mitigation in China.

According to the IEA (2013), out of 450 decarbonization pathway scenarios, green technology development is considered as the most effective option for reducing carbon emissions, accounting for 60% of the carbon emissions reduction target. However, despite the theoretical notion that an increase in green technological progress should result in a significant reduction in CO_2 emissions, the relationship between green technology innovation and carbon mitigation remains inconsistent and inconclusive among existing empirical researches. Ang (2009) examines the relationship between economic growth and pollutant emissions by incorporating total factor productivity (TFP) and finds that environmental quality can be improved through technological innovations if significant resources are directed towards pollution abatement and clean technology. Based on a panel vector autoregressive (PVAR) model estimations, Wang et al. (2012) show that the development of fossil-fuel related technologies has no significant effect on mitigating carbon emissions, while carbon-free technologies have a positive impact on carbon reduction only in eastern regions of China. Lin and Ma (2022) report heterogeneous impacts of green technology on carbon mitigation across different types of cities in China, and their empirical results indicate that green technology did not significantly contribute to mitigating carbon emissions until 2010. Xu et al. (2020) and Chen et al. (2023) use spatial econometric models to examine the significance of green technology development in reducing carbon emissions in China, accounting for the influence of spatial distance and geographic boundaries.

In view of the aforementioned findings, our first hypothesis posits that green technology development does not play a significant role in mitigating carbon emissions in China. To test this hypothesis, in our regression analysis we include the number of green patents as a proxy variable for green technological development in order to determine whether the estimated coefficient is significantly less than zero. The rejection of this hypothesis reveals the effective and distinct role of green technology in reducing carbon emissions in China, implying that a higher level of green technology development would result in more significant reductions in carbon emissions.

- **Hypothesis 2 (H2):** The relationship between economic growth and carbon emissions in China remains insignificant.

The environmental Kuznets curve hypothesis (EKC) proposes an inverted U-shaped relationship between economic growth and carbon emissions, which has been investigated through numerous empirical studies. However, there is no consensus among researchers regarding the sign, magnitude, and significance of the relationship. The EKC hypothesis appears to be a country- or region-specific issue, as evidenced by the variability in empirical results. For instance, empirical support for the EKC hypothesis has been found in China, Southeast Asian countries, the BRICS countries, OECD countries, and the EU countries (Acaravci and Ozturk, 2010; Cheng et al., 2019; Jayanthakumaran et al., 2012; Li et al., 2016; Saboori and Sulaiman, 2013; Shafiei and Salim, 2014). In contrast, the EKC hypothesis is invalidated for Russia, the Middle East countries, and low-income economies (Al-mulali et al., 2015; Dogan and Seker, 2016; Ozcan, 2013; Pao et al., 2011). Besides, we could also see that some of the regions with different EKC results overlap.

Hence, our second hypothesis posits that there is no significant inverted U-shaped relationship between economic growth and carbon emissions in China. To test this hypothesis, we include both GDP and its square term into our regression to determine if the estimated coefficient of GDP is statistically larger than zero and if the estimated coefficient of GDP^2 is statistically less than zero. The rejection of this hypothesis would imply that there is a presence of the EKC pattern of the emission-income nexus in China.

3 Data and empirical methodology

This section outlines the theoretical model specification, data sample and empirical model specifications that we use for our empirical analysis. Our sample data consist of a balanced panel of provincial data from 30 provinces in China. We cover the pre-covid period from 1997 to 2019, excluding Hong Kong, Macao, Taiwan and Tibet. Based on the provincial data, Figure 3a illustrates significant increases in CO_2 emissions across all 30 provinces during the period from 1997 to 2019.

3.1 Model specifications

We adopt a STIRPAT model established by (Dietz and Rosa, 1997) to investigate the role of green technology development in reducing carbon emissions in China. The STIRPAT model can be expressed as follows:

$$I_{it} = \alpha \cdot P_{it}^{b} \cdot A_{it}^{c} \cdot T_{it}^{d} \cdot e_{it}\,. \tag{1}$$

By taking the natural logarithms of both side of Eq. (1), the STIRPAT model can be reformatted as:

$$\ln(I)_{it} = \ln(\alpha) + b\ln(P)_{it} + c\ln(A)_{it} + d\ln(T)_{it} + \ln(e)_{it}\,, \tag{2}$$

where *I* represents environmental impact measured by CO_2 emission per capita. The model considers population (P), affluence (A), and technology (T) as key factors. These are measured by provincial population size, real GDP per capita, and the number of green patents in our study, respectively. The estimated elasticity coefficients (represented by b, c, and d) reflect the proportional relationship between these factors and carbon emissions. To account for additional determinants of green technology development and carbon emissions, we extend our baseline STIRPAT model by considering economic structure, energy consumption structure, urbanization rate and foreign direct investment (FDI) as additional control variables. Our extended STIRPAT model is therefore expressed as follows:

$$\begin{aligned} \ln(CO_2)_{it} = {} & \alpha + \beta_1\ln(\mathrm{Population})_{it} + \beta_2\ln(\mathrm{GDP})_{it} + \beta_3\ln(\mathrm{GDP})_{it}^2 \\ & + \beta_4\ln(\mathrm{Urbanization\ rate})_{it} + \beta_5\ln(\mathrm{Economic\ structure})_{it} \\ & + \beta_6\ln(\mathrm{Energy\ structure})_{it} + \beta_7\ln(\mathrm{Green\ patent})_{it} + \beta_8\ln(\mathrm{FDI})_{it} \\ & + e_{it}\,. \end{aligned} \tag{3}$$

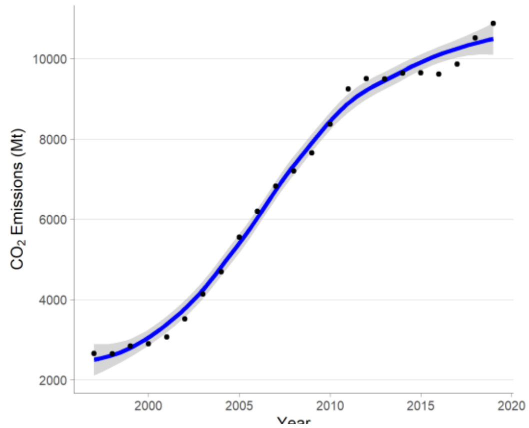
Table 1:definition of variables

Variable	Definition	Data sources
CO_2	CO_2 emission per capita	Carbon emission Accounts & Datasets
Green Patent	Number of green patents	China national intellectual property administration (CNIPA)

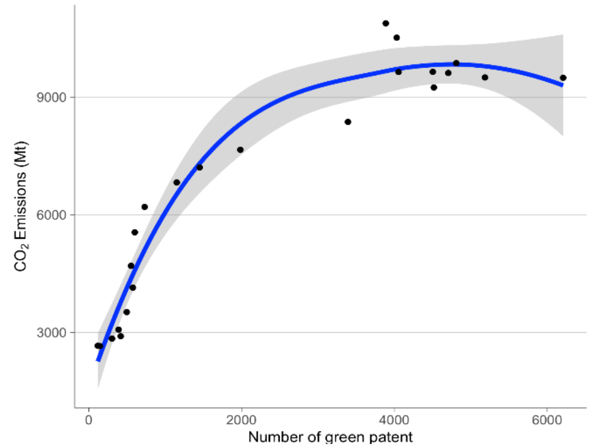
GDP	Real GDP per capita for each province	China Statistical Yearbook
Population	Population size in each province	China Statistical Yearbook
Urbanization rates	The percentage of the urban population in the total population in each province	China Statistical Yearbook
Economic structure	Service industry output value share of total GDP	China Statistical Yearbook
Energy structure	Coal consumption share of total energy consumption	China Statistical Yearbook
FDI	A ratio of foreign direct investment to the total local fixed asset	China Statistical Yearbook

In Eq. (3), the variable "urbanization rate" represents an indicator that quantifies the proportion of the urban population within the total population of each province. The "Economic structure" variable refers to the ratio of the service industry's output value to the total GDP, reflecting the significance of the service sector in the economy. The "Energy structure" variable pertains to the ratio of coal consumption to total energy consumption, signifying the extent of coal dependency. "FDI" denotes the ratio of foreign direct investment to total local fixed assets. It is important to note that, in order to test the validity of the EKC hypothesis in China, we incorporate both GDP and its square term into our regression analysis. While there are generally three types of indicators used to measure green innovation, such as R&D expenditure, the number of green patents, and green total factor productivity, Desheng et al. (2021) emphasize that the patent indicator is the most effective in capturing the progress of innovation in green technologies compared to the other measures. Hence, we use the number of green patents (output) as proxy variable to measure the green technology development. The provincial data on carbon emission and green patents are retrieved from the China Carbon Emission Accounts and Datasets (CEADs) and the China national intellectual property administration (CNIPA), respectively. Table 1 and Table 2 provide the variable definitions, data sources, and summary statistics for each variable incorporated into our empirical analysis. Figure 3b illustrates the relationship between CO_2 emissions and the number of green patents for each province, showing a positive correlation with the presence of diminishing returns. While there is a short-term positive correlation between the number of green patents and carbon emissions, the rate of increase in carbon emissions slows down over time. This suggests that the expansion of green technology development ultimately helps to mitigate the growth of carbon emissions.

Figure 3: China's CO2 Emissions and Green Patent Relationship from 1997-2019



(a): China CO_2 emission level from 1997-2019



(b): CO_2 emissions and green patent relationship

Table 2: Summary statistics

	Mean	Max.	St.dev	Skewness	Kurtosis
$\ln(CO_2)$	1.548	3.493	0.655	0.010	3.078
ln(GDP)	9.943	12.009	0.951	-0.167	2.000
ln(Green Patent)	3.254	7.084	1.556	0.056	2.448
ln(Population)	17.360	18.643	0.763	- 0.806	3.102
ln(Urbanization rate)	-0.788	-0.060	0.368	-0.618	3.496
ln(Economic structure)	-0.897	-0.180	0.192	1.000	4.423
ln(Energy structure)	-0.889	0.000	0.505	-2.039	10.774
ln(FDI)	-4.650	-1.597	1.452	-0.455	3.165

3.2 Empirical methodology

Based on our extended STIRPAT theoretical framework outlined in Eq. 3, we employ a panel two-way fixed effect model to examine the direct impact of green technology on carbon emissions. To be more precise, our empirical estimation model is specified as follows:

$$\begin{aligned} \ln(CO_2)_{it} &= \alpha_0 + \beta_1 \ln(GDP)_{it} + \beta_2 \ln(GDP)^2_{it} \\ &+ \gamma \ln(\text{Green patent})_{it} + x'_{it}\delta + \mu_i + \lambda_t + \varepsilon_{it} \end{aligned} \tag{4}$$

where i represents the province, t denotes the year. μ_i and λ_t represent the unobserved individual fixed effect and time fixed effect, respectively. x'_{it} denotes a set of control variables that we incorporate in our extended STIRPAT, as expressed in Eq. (3). It is important to note that if panel data exhibits cross-section dependence, estimating models with homogeneous slope coefficients using fixed effects may lead to biased coefficients (Sadorsky, 2014). Therefore, to validate our empirical findings, we also apply the panel autoregressive distributed lag (PARDL) estimation approach using the pooled mean group (PMG) estimator, as proposed by Pesaran and Smith (1995) and Pesaran et al.(1999), to assess the significance of long-run and short-run relationships among the underlying variables. The generalised panel ARDL estimation applied in this study is written as:

$$\ln(CO_2)_{it} = \sum_{j=1}^{p} \lambda_{ij} \ln(CO_2)_{i,t-j} + \sum_{j=o}^{q} \delta'_{ij} X_{i,t-j} + \varphi_i + \varepsilon_{it}\,, \tag{5}$$

where X_{it} denotes a $(K \times 1)$ vector of explanatory variables. φ_i represents cross-sectional effect, and ε_{it} refers to the error term. The Eq. (5) can also be reparametrized as a form of error-correction model:

$$\begin{aligned} \Delta \ln(CO_2)_{it} = {} & \phi_i[\ln(CO_2)_{it-1} - \theta_i' X_{it}] \\ & + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta \ln(CO_2)_{i,t-j} + \sum_{j=1}^{q-1} \delta_{ij}^{*} \Delta x_{i,t-j} + \varphi_i + \varepsilon_{it} \end{aligned} \tag{6}$$

$$\phi_i = -1\left(1 - \sum_{j=1}^{p} \lambda_{ij}\right)$$

$$\theta_i = \sum_{j=0}^{q} \frac{\delta_{ij}}{(1 - \sum_k \lambda_{ik})}$$

In Eq. (6), $\phi_i[\ln(CO_2)_{it-1} - \theta_i' X_{it}]$ refers to the error correction term. the parameter θ_i and δ_{it}^{*} represent the long-run and short-run effects of a set of explanatory variables on carbon emissions. φ_i represents the individual fixed effect.

4 Empirical results:

Our primary research goal is to investigate the role of green technology in mitigating carbon emissions in China. To test our Hypothesis 1, we initiate our empirical analysis by using a two-way fixed effect estimation with various model specifications and present our findings in Table 3. Given that the estimated coefficient for $\ln(\text{green patent})_{it}$ is statistically significant and negative at 1% level, our empirical result provides enough statistical evidence to support the validity of Hypothesis 1, suggesting that an increase in green technology development significantly contributes to reducing carbon emissions. This finding, which highlights the significant negative impact of green technology on emissions, is in line with findings reported by Xu et al.(2020), Lin and Ma (2022) and Chen et al. (2023) who have emphasized the importance of green technology in mitigating carbon emissions in China. Additionally, by having a significant positive coefficient for $\ln(GDP)_{it}$ and a significant negative coefficient for $\ln(GDP)_{it}^2$, we have sufficient evidence to reject our Hypothesis 2, revealing the presence of an EKC-patterned relationship between economic growth and carbon emissions in China.

Table 3: Fixed effect model estimation

Dependent Variable:	$\ln(CO_2)_{it}$			
Model:	(1)	(2)	(3)	(4)
Variables				
$\ln(GPD)_{it}$	2.747*** (0.1880)	2.202*** (0.2483)	1.943*** (0.2781)	1.524*** (0.3473)

$\ln(\mathrm{GDP})^2_{\mathrm{it}}$	-0.1089*** (0.0094)	-0.0844*** (0.0128)	-0.0649*** (0.0132)	-0.0548*** (0.0161)
$\ln(\mathrm{Green\ patent})_{\mathrm{it}}$	-0.0622*** (0.0201)	-0.0841*** (0.0213)	-0.0823*** (0.0218)	-0.0931*** (0.0224)
$\ln(\mathrm{Population})_{\mathrm{it}}$			0.1254 (0.1781)	-0.0824 (0.2239)
$\ln(\mathrm{Urbanization\ rate})_{\mathrm{it}}$			0.1824*** (0.0543)	0.2976*** (0.0620)
$\ln(\mathrm{Economic\ structure})_{\mathrm{it}}$			-0.2766*** (0.0728)	-0.2813*** (0.1048)
$\ln(\mathrm{Energy\ structure})_{\mathrm{it}}$			0.1515*** (0.0522)	0.1180** (0.0555)
$\ln(\mathrm{FDI})_{\mathrm{it}}$			0.0341*** (0.0112)	0.0310*** (0.0119)
Fixed effect				
Province	Yes	Yes	Yes	Yes
Year	No	Yes	No	Yes
Fit statistics				
Observations	690	690	690	690
Adjusted R^2	0.91307	0.91786	0.92139	0.92397
Within Adjusted R^2	0.85117	0.31399	0.86542	0.36507
AIC	-279.08	-297.65	-343.78	-346.50
BIC	-129.37	-48.132	-171.39	-74.294

Note: Heteroscedasticity robust standard errors are shown in parentheses. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Regarding urbanization, our empirical results reveal a significant positive relationship between urbanization and carbon emissions. In particularly, by holding everything else constant, a one percentage increase in the urbanization is expected to result in a 0.3% increase in CO_2 emissions. China has experienced rapid urbanization due to the implementation of the reform and opening-up policy, with the urbanization rate projected to grow from 64.7% in 2022 to 75% by 2035 (China Daily, 2019; Fitch 2022). Additionally, foreign direct investment (FDI) has played a crucial role in facilitating this urbanization process, as it has brought in significant capital and resources to support infrastructure development, real estate construction, and other key urbanization-related projects.

Table 4: Panel ARDL Short run estimates

Dependent variable	$\ln(\mathrm{CO_2})_{\mathrm{it}}$	
	Short run	Long run
Variable		
Error correction term	0.342*** (0.0650)	
$\ln(\mathrm{GPD})_{\mathrm{it}}$	0.383***	0.634 ***

	(0.0665)	(0.024)
$\ln(\text{Green patent})_{it}$	-0.034**	-0.055 ***
	(0.0165)	(0.012)
$\ln(\text{Population})_{it}$	-0.066	-0.2667
	(1.192)	(0.147)
$\ln(\text{Urbanization rate})_{it}$	0.143	0.256***
	(0.178)	(0.050)
$\ln(\text{Economic structure})_{it}$	-0.193	-0.254***
	(0.152)	(0.597)
$\ln(\text{Energy structure})_{it}$	0.231***	0.219***
	(0.0674)	(0.310)
$\ln(\text{FDI})_{it}$	0.037***	0.388***
	(0.00822)	(0.117)
Observations		660
Number of provinces		30
Number of years		22
Log Likelihood		1070.596
AIC		-2220.048
BIC		-2139.188

Note: Heteroscedasticity robust standard errors are shown in parentheses. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$

The rapid urbanization process in China in conjunction with the substantial foreign direct investment (FDI) inflows has led to a significant increase in energy demand due to the growing market for urban infrastructure, residential buildings, transportation, and other necessities. However, with the coal being the primary source of energy in China, for approximately 57% of the total power supply, meeting the enhanced energy demand induced by urbanization would likely further push the coal-fired power development, and consequently result in further environmental challenges. Our empirical results suggest that a 1% increase in the share of coal consumption to total energy consumption is linked to an average increase of 0.12% in carbon emissions per capita. Furthermore, a 1% increase in the share of FDI to total local fixed assets is associated with an average increase of 0.03% in carbon emissions per capita. Meanwhile, our analysis also highlights the importance of economic transition towards a service-oriented structure that relies on clean and low-carbon energy. Our results reveal a significant negative coefficient for the variable "Economic structure," measured by the ratio of service industry to total GDP output. This underscores the need to prioritize economic transition towards a service-oriented industry to mitigate the adverse environmental impacts of urbanization and economic growth in China.

Besides the fixed effect estimations, we also apply the panel autoregressive distributed lag (PARDL) estimation approach using the PMG estimator, to assess the significance of long-run and short-run relationships among the underlying variables. The results are presented in Table 4, which shows the estimated short-run and long-run relationships among the underlying variables.

The estimated coefficients of $\ln(\text{green patent})_{\text{it}}$ are statistically significant and negative in both the long-run and short-run contexts. This finding provides us with additional evidence to support the validity of our Hypothesis 1, which asserts that an increase in green technology development significantly contributes to reducing carbon emissions. Moreover, we find that FDI inflows have a significantly positive impact on carbon emissions in both the long-run and short-run, with the long-run effect being approximately ten times greater than the short-run effect. This finding supports the presence of the "pollution heaven" hypothesis in China, suggesting that multinational corporations might relocate their production activities to developing countries, resulting in increased energy demand and, subsequently, higher carbon emissions. The estimated coefficients for $\ln(\text{energy structure})$ expose the positive relationships between coal consumption and carbon emissions across both long-term and short-term scenarios. Coal, as a primary energy source in China, contributes substantially to the country's carbon emissions due to its high carbon content and inefficient combustion processes. Besides, urbanization process and economic transition towards a service-oriented structure are found to have only the long run positive and negative impact on carbon emissions, respectively.

5 Conclusion

Based on the STIRPAT model framework, this paper uses fixed effect model estimations on a balanced panel of 30 provinces from 1997 to 2019 to empirically study the role of green technology development in mitigating CO_2 emissions in China in the period up to the covid pandemic. To ensure robustness, we utilize the panel autoregressive distributed lag (PARDL) estimation approach using the pooled mean group (PMG) estimator to explore the long-term and short-term relationships among underlying variables.

Our empirical analysis, using the number of green patents as a proxy for green technology development, reveals a significant positive relationship between the increase in green technology and carbon mitigation in China. The PARDL model estimation results further demonstrate the significance of both short-term and long-term relationships between green technology and carbon mitigation, highlighting the crucial role that green technology development plays in reducing carbon emissions in China. Additionally, our empirical results confirm the presence of an ECK-pattern relationship between economic growth and carbon emissions in China.

Our empirical findings provide a roadmap with policy implications for Chinese policymakers to achieve sustainable low-carbon economic growth while mitigating the negative impact of economic development on the environment. Given the significant role of green technology in mitigating carbon emissions, there is a need to prioritize investment in green technology and innovation to reduce carbon emissions in China. Policymakers should provide a comprehensive range of incentives, including grants, tax incentives, and academic support, to encourage businesses to develop and adopt cleaner technologies to mitigate their environmental impact. Such policies will not only enhance China's capacity to mitigate carbon emissions but also spur the growth of its green industry, which has the potential to be a significant contributor to its economic development.

China's heavy dependence on coal as a primary energy source has significant negative impacts on the environment, including exacerbating air pollution and hindering the country's efforts to transition towards a low-carbon economy. Addressing China's heavy dependence requires a multi-faceted approach that includes promoting sustainable and low-carbon practices in various industries, implementing stringent plans for phasing out existing coal-fired power plants, and accelerating the transition towards renewable energy sources.

To lessen the impact of FDI on carbon emissions and mitigate the potential for creating "pollution heavens", policymakers could implement strict environmental regulations that align with international standards. This will necessitate the establishment and enforcement of comprehensive environmental policies and regulations, including penalties for non-compliance. Additionally, policymakers must provide incentives for businesses to adopt cleaner technologies, such as tax credits or subsidies, to encourage sustainable practices and to reduce carbon emissions.

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