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Original Research

Does Cross-Border E-Commerce Reduce Carbon Emissions? Evidence from Quasi-Natural Experiment

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Abstract

As the main form of digital trade, cross-border e-commerce has become an important factor influencing China's green and low-carbon transition. This article used the multi-period Difference-in-Differences (DID) method to comprehensively examine the effect of cross-border e-commerce on urban carbon emissions based on data from 283 cities in China from 2009 to 2019. The results showed that cross-border e-commerce can significantly reduce urban carbon emissions. However, there is significant heterogeneity in the effect of cross-border e-commerce on urban carbon emissions due to differences in digital infrastructure, environmental regulatory intensity, geographic location, and city level. Further mechanism testing found that cross-border e-commerce primarily reduces carbon emissions through green technological innovation and industrial structural upgrading. This article provides directional insights for the future development of cross-border e-commerce comprehensive pilot zones and offers empirical evidence for China to promote the coordinated development of environmental protection and trade.

Keywords: cross-border e-commerce, cross-border e-commerce comprehensive pilot zones, carbon emissions, green innovation capability, industrial structural upgrading

Introduction

Since its opening up, China has achieved a remarkable development miracle, with its economic scale rising to become the world's second-largest in just over thirty years. However, during this process, the development characteristics of "high investment, high energy consumption, and high emissions" have led to increasing contradictions between environmental degradation and economic development, which restrain the high-quality development of the Chinese economy. Energy conservation and emissions reduction are not only an inevitable choice for China's sustainable economic development but also an inherent requirement for the modernization of China. As China's economy enters a phase of high-quality development, "green" has been incorporated into the new development concept, making green development and low-carbon transition the prevailing

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trend of the times. In September 2020, Chinese President Xi Jinping announced China's international commitment to pollution reduction and carbon mitigation at the United Nations General Assembly.

China aims to achieve peak carbon emissions before 2030 and strive for carbon neutrality by 2060. At the subsequent Climate Ambition Summit, he further stated that by 2030, China's carbon intensity (carbon dioxide emissions per unit of GDP) will decrease by more than 65% compared to the level of 2005.

According to data from the BP Statistical Review of World Energy, China's carbon dioxide emissions reached 10.17 billion tons in 2019, accounting for 28% of the global total. To effectively control the increase in carbon emissions, China actively responds to global carbon reduction actions and has made significant efforts towards this goal. By 2021, China has achieved a 50.8% reduction in carbon intensity compared to 2005, making important contributions to the green transition of its economy. However, China is still in a phase of overall carbon emission increase and has yet to reach its peak emissions. Promoting economic green and low-carbon transition guided by energy conservation and emission reduction goals is an urgent and crucial challenge that needs to be addressed.

Meanwhile, despite the difficult development of traditional foreign trade, cross-border e-commerce has experienced rapid growth. According to China Customs data, from 2015 to 2023, the scale of cross-border e-commerce has grown from CNY 0.36 trillion to CNY 2.38 trillion, with an average annual growth rate of 32.9%. However, the growth rate of traditional foreign trade during the same period was only 7.35%. To accelerate the development of cross-border e-commerce, the Chinese government is promoting the establishment of cross-border e-commerce comprehensive pilot zones (CBECPZ). From 2015 to the end of 2022, China has established a total of 165 pilot cities for cross-border e-commerce comprehensive pilot zones, covering 31 provinces and regions, forming a set of management systems and rules that adapt to and lead the development of global cross-border e-commerce. This provides a replicable and promotable experience for promoting the healthy development of global cross-border e-commerce. It is obvious that cross-border e-commerce has become an important engine for the development of foreign trade, especially in the context of "dual circulation", which is of great significance for accelerating circular and low-carbon development and achieving green and high-quality development. In the specific implementation process, can cross-border e-commerce promote environmental improvement and green low-carbon transition? What are the main pathways involved?

Through the literature review, we found that most early studies were primarily about the effect of e-commerce on the environment. For example, Xiao and Wang [1] empirically tested the significant positive effect of e-commerce on green GDP based on panel data from 31 provinces in China from 2013 to 2020. Based on the mediating effect of heterogeneous technological innovation, Yuan [2] confirmed that e-commerce could significantly improve carbon emission efficiency; Liu, Deng, and Cao [3] conducted a quasi-natural experiment based on the establishment of national e-commerce demonstration cities and found that e-commerce significantly promotes the green and high-quality development of cities. With the further promotion of cross-border e-commerce reform, scholars have begun to study the effect of cross-border e-commerce from the perspective of quasi-natural experiments in CBECPZ. These studies follow the classic theory of the relationship between trade and the environment, exploring the mechanism of cross-border e-commerce on the environment from aspects such as technological effects, structural effects, and energy utilization efficiency. For example, in terms of low-carbon and green development, Ma and Zhang [4] found that the establishment of CBECPZ has a significant promoting effect on the reduction of sulfur dioxide in cities and the effect on economically developed cities with a high proportion of the secondary industry is more significant. Based on data from 1260 Chinese listed companies from 2009 to 2022, Zhang and Zhang [5] empirically verified that the establishment of CBECPZ can significantly promote enterprise environmental performance, and enterprises with strong debt financing capabilities and improved equity incentive systems have a more significant effect on environmental performance. Based on panel data from 270 cities in China from 2010 to 2021, Ma et al. [6] verified that the establishment of CBECPZ can effectively reduce pollution levels, and this positive effect is more pronounced in non-resource-based cities, areas with higher levels of financial development, and central and western regions.

In summary, some scholars have explored the effect of cross-border e-commerce on pollution emissions and green development, but existing literature has not yet explored the direct effect of cross-border e-commerce on city carbon emissions. As China's "dual carbon" goals are increasingly approaching, exploring the relationship between cross-border e-commerce and carbon emissions has important practical significance.

Based on this, this article selects 283 cities from 2009 to 2019, empirically tests the effect of cross-border e-commerce on carbon emissions from the perspective of taking CBECPZ as a quasi-natural experiment, and analyzes the underlying mechanisms. The marginal contributions of this article are as follows: First, different from previous studies that mainly explored the role of cross-border e-commerce from the perspective of economic effects. This article focuses on whether cross-border e-commerce can enable the green and low-carbon transformation of the economy, thus providing a valuable supplement to the existing literature on cross-border e-commerce by exploring its effect on carbon emissions from the perspective of CBECPZ. Second, it examined the transmission mechanisms through which the pilot zones reduce carbon emissions in Chinese cities, focusing on energy consumption reduction, green technological innovation, and industrial structure upgrading, providing theoretical support for the government to formulate corresponding targeted policies. Third, by employing a multi-period difference-in-differences (DID) approach and instrumental variable methods, it can avoid measurement errors and endogeneity problems associated with reverse causality, thus providing more reliable research conclusions.

Literature Review

Studies on the Economic Effects of Cross-Border E-Commerce

The literature on cross-border e-commerce mainly focuses on its economic effects.

Some scholars concentrated on its macroeconomic effects and have found that it can promote regional economic growth [7], international trade [8] and reduce trade costs [9]. Scholars have also conducted research at the micro-level and discovered that cross-border e-commerce can improve firm performance [10], facilitate exports [11], and enhance consumer welfare [12]. In recent years, with the continuous reform of cross-border e-commerce and the acceleration of the establishment of CBECPZs, some scholars have begun to use the DID method to study the effectiveness of cross-border e-commerce. At the macro level, the establishment of CPECPZs has been proven to promote economic growth, inbound tourism, trade upgrading and export growth, and internationalization of the manufacturing industry [13–15], reducing supply chain risks [16]. At the meso level, the establishment of CPECPZs can promote urban entrepreneurial vitality, urban carbon emissions efficiency, and urban residents' tourism consumption [17–19]. At the micro level, the establishment of CPECPZs can increase enterprise exports, risk-bearing levels, and employee salaries, improve environmental performance, etc. [20, 21], as well as household consumption levels and welfare [22].

Studies on Carbon Emissions

Many existing studies focused on carbon emissions reduction. Under the constraint of the "dual carbon" targets, achieving carbon emissions reduction has become a research hotspot in academia. In recent years, research on carbon emissions reduction has mainly concentrated on three aspects. First, the feasibility and potential of achieving the "dual carbon" targets are assessed [23]. Second, the driving factors for carbon emissions reduction are explored. Numerous scholars have reached a consensus on the carbon reduction effects of three major factors: technological progress [24], industrial structure upgrading [25], and energy structure adjustment [26]. Studies have also indicated that green finance [27], economic agglomeration [28], trade openness [29], and infrastructure development [30], among others, can also contribute to carbon emissions reduction. Third, there is the evaluation of the effectiveness of carbon emissions reduction policies. To achieve the "dual carbon" targets, the Chinese government has implemented various policies to control carbon emissions, such as conducting low-carbon province and city pilot projects and establishing a carbon emissions trading system. Most studies suggested that the establishment of low-carbon pilots and a nationwide carbon emissions trading market are conducive to carbon emissions reduction [18, 31].

In summary, as a significant driving force in China's current economic transformation, cross-border e-commerce will undoubtedly have an effect on green and low-carbon transitions. However, there is a lack of empirical research precisely assessing the effect of cross-border e-commerce on urban carbon emissions reduction. Existing literature primarily provides theoretical explanations or analyzes sub-topics related to carbon emissions reduction, such as technological innovation and industrial structure upgrading in the context of cross-border e-commerce development.

Theoretical Mechanisms and Hypothesis Testing

The Direct Effect of Cross-Border E-Commerce On Carbon Emissions

First, from the production side, cross-border e-commerce can effectively reduce carbon emissions by optimizing supply chain management and promoting green production. Reijnders and Hoogeveen [32] pointed out that cross-border e-commerce typically utilizes data analysis and forecasting technologies to adjust production scales based on market demand, thereby reducing resource waste and energy consumption caused by overproduction.

Second, from the consumption side, cross-border e-commerce can influence consumer behavior through digital platforms, promoting low-carbon consumption. For example, cross-border e-commerce platforms can use algorithms, personalized marketing, and other strategies to recommend environmentally friendly products and advocate for green consumption concepts, encouraging consumers to choose low-carbon products. More importantly, the model of online purchasing combined with offline delivery in cross-border e-commerce can reduce carbon emissions associated with frequent consumer travel [33].

Third, from the distribution side, cross-border e-commerce can effectively reduce carbon emissions by integrating logistics resources, optimizing delivery routes, and promoting green logistics. Cross-border e-commerce platforms often use advanced logistics management systems that precisely calculate transportation routes and cargo loadings, reducing ineffective transportation and empty running rates. Additionally, cross-border e-commerce actively promotes the use of new energy vehicles and environmentally friendly packaging materials, lowering carbon emissions in the logistics process [34]. Based on the comprehensive analysis above, we propose the following hypothesis.

Hypothesis 1: Cross-border e-commerce can reduce urban carbon emissions.

The Effect of Green Technological Innovation

Green technological innovation is a crucial force in achieving low-carbon development [35]. Many studies have found that green technological innovation can promote carbon emissions reduction in cities through channels such as eliminating outdated production capacity and reducing energy consumption intensity [36]. From the supply side perspective, cross-border e-commerce companies, while developing their businesses, also need to consider environmental issues. They can achieve this by improving production methods, transportation modes, and packaging methods, as well as reducing environmental pollution and resource waste. From the demand side perspective, the use of green technology to produce green products activates public demand for green consumption. This not only fosters more sustainable and low-carbon lifestyles but also provides positive feedback to the production side, further driving enterprises to apply green and low-carbon production models. At the policy level, the CBECPZ encouraged companies to participate in carbon emissions trading within the zones, internalizing the cost of carbon emissions reduction and thereby incentivizing or pressuring enterprises to reduce carbon emissions through green technological innovation in their production processes. Considering that enterprises often need to invest significant amounts of research and development (R&D) funding in green technological innovation [37] but often face significant uncertainties, the financial institutions within the pilot zones have issued a large number of green financial instruments to support the achievement of the "dual carbon" targets. These instruments provide financial support for enterprise R&D, help share the risks of R&D failures, and provide guarantees for green innovation. Based on the comprehensive analysis above, we propose the following hypothesis.

Hypothesis 2: Cross-border e-commerce can reduce urban carbon emissions levels through green technological innovation.

The Effect of Industrial Structure Upgrade

The establishment of CBECPZ promotes the application and development of cross-border e-commerce. On one hand, it stimulates the application and diffusion of new technologies. The intense competition in the Internet era compels enterprises to increase their investment in technology, enhancing their technological innovation capabilities and levels. Technological progress and productivity improvement are the core driving forces behind upgrading the industrial structure. On the other hand, the application and development of e-commerce significantly reduce search costs between producers and consumers, increasing channels of information communication and promoting consumer diversity and personalization. This leads to changes in the social supply-demand structure and further drives industrial upgrading. Additionally, The establishment of CBECPZ promotes the development of cross-border e-commerce while also extending the relevant industry chains. It drives the growth of productive service industries in areas such as financial payment, information technology, scientific and technological services, warehousing, and logistics. This optimizes the division of labor and expands the coverage of the cross-border e-commerce industry chain, accelerating the integration of upstream and downstream sectors in the industry chain. It transforms the original structure of the service industry, increases the share of productive service industries in the national economy, and promotes industrial structure upgrading. Clearly, the industrial structure resulting from the application and development of cross-border e-commerce exhibits a "service-oriented" green transformation model. It helps replace energy-intensive and polluting industrial sectors, accelerates the process of "retreating from the second industry and advancing to the third industry" in cities, reduces energy consumption and environmental pollution, improves production efficiency, and promotes the green and low-carbon development of cities. Based on the comprehensive analysis above, we propose the following hypothesis.

Hypothesis 3: Cross-border e-commerce can reduce urban carbon emissions levels through industrial structure upgrading.

The Effect of Energy Consumption Reduction

The policies of CBECPZ can potentially reduce energy consumption and carbon emissions through economies of scale. Economies of scale refer to the larger scale of economic activities and the increased demand for resources and energy brought about by economic development, resulting in higher levels of pollution and negative environmental impacts [38]. As a commercial transaction activity conducted on open networks, cross-border e-commerce inevitably has important environmental implications. In reality, e-commerce is widely used in production, consumption, distribution, and other fields. Data from a joint research team composed of scientific research institutions and companies[1], as presented in the "Environmental Impact Report on E-commerce" in 2009, showed that the energy consumption generated by online retail in China in 2009 was equivalent to a reduction of 393 tons of standard coal per 100 million yuan of sales (compared to traditional retail). However, it is worth noting that the application of e-commerce may also have potential negative environmental impacts as it increases resource consumption in other aspects, such as packaging materials and electricity consumption [39]. Mills' study found that internet usage increased electricity consumption by 8% in the United States. Nevertheless, overall, e-commerce has evident energy-saving and efficiency-improving effects. Therefore, the development of cross-border e-commerce can not only promote economic efficiency but also have a positive impact on improving urban energy consumption, ultimately driving the green and low-carbon development of Chinese cities. Based on the comprehensive analysis above, we propose the following hypothesis.

Hypothesis 4: Cross-border e-commerce can reduce urban carbon emissions levels by lowering energy consumption.

1 The joint research group composed of the China Academy of Social Sciences China Circular Economy and Environmental Evaluation Forecasting Research Center and Alibaba Research Center.

Materials and Methods

Model Specification

Given the endogeneity issues present in previous studies, this research intends to use the Difference-in-Differences (DID) method to examine the effect of the establishment of CBECPZ on the carbon emissions levels of Chinese cities. As of the end of 2022, a total of 165 cities across seven batches have been approved as CBECPZs in China. These batches include the second batch of 12 cities in January 2016, the third batch of 22 cities in July 2018, the fourth batch of 24 cities in December 2019, the fifth batch of 46 cities in May 2020, and the sixth and seventh batches of 27 and 33 cities, respectively, in January 2022 and November 2022. Due to data availability at the city level and to avoid the interference of the COVID-19 epidemic on the macroeconomic environment, the time period for this study is from 2009 to 2019, focusing on the first three batches of Pilot Zones as the treatment events. Considering that the establishment of CBECPZ occurred in multiple periods, this study employs a multi-period Difference-in-Differences approach for regression analysis, as shown in Equation (1).

$$CE_{it} = \alpha_0 + \alpha_1 Policy_{it} + \alpha_2 \Sigma Controls_{it} + V_i + \mu_t + \varepsilon_{it} \quad (1)$$

Where i and t represent the city and year, respectively. CE_{it} is the dependent variable representing the carbon emissions level of city i in year t. $Policy_{it}$ represents the effect of establishing CBECPZ and is composed of the interaction between $Treat_i$ and $Post_t$ dummy variables. If a city is selected as a Pilot Zone, $Treat = 1$; otherwise, $Treat = 0$ for cities not included in the Pilot Zones. Similarly, Post is a time dummy variable: $Post = 0$ for years before the establishment of Pilot Zones and $Post = 1$ for the year of establishment and subsequent years. $Controls_{it}$ refers to a set of city-level control variables. α_0 represents the constant term, V_i and μ_t denote city and time fixed effects, and ε_{it} represents the error term.

Variable Description

Dependent Variable

City carbon emissions level (CE): This study measures the carbon emissions performance of each city by the logarithm value of their carbon emissions. The calculation of carbon emissions for each city is based on the energy consumption of electricity, natural gas, liquefied petroleum gas, etc., following the approach proposed by Han and Xie [40]. The calculation formula is as follows:

$$I = C_n + C_P + C_e = kE_n + \gamma E_P + \varphi(\eta \times E_e) \quad (2)$$

Where I represents the city's carbon emissions; C_n, C_p, and C_e represent the carbon emissions from natural gas, liquefied petroleum gas, and electricity consumption in the city, respectively; E_n, E_p, and E_e represent the consumption of natural gas, liquefied petroleum gas, and electricity in the city; k and γ are the CO_2 emission coefficients of natural gas and liquefied petroleum gas, respectively[2]; φ is the greenhouse gas emission coefficient for the coal-electricity fuel chain, converted to equivalent CO_2 of 1.3203 kg/(kW·h); η represents the proportion of coal-fired power generation to total power generation[3]. The data is sourced from the "China Electric Power Yearbook".

Core Explanatory Variable

The core explanatory variable is the impact variable of the policy regarding the establishment of Cross-Border E-commerce Pilot Zones ($Treat_i$*$Post_t$). Based on whether the cities in the sample are designated as pilot zones and the timing of their establishment, policy dummy variables $Post_t$ and time dummy variable $Treat_i$ are created. The interaction term Policy is generated by multiplying $Treat_i$ and $Post_t$ after assigning values to them.

Control Variables

This study controls for various variables based on the research of scholars such as Li and Xu [41], Zhang et al. [42], etc. The control variables include the level of economic development, population size, degree of government intervention, level of financial development, foreign direct investment, infrastructure level, urban technological innovation level, and industrial structure. Table 1 presents the definitions and descriptive statistics of the variables.

Results and Discussion

Baseline Regression Analysis

Table 2 presents the baseline results of the impact of the CBECPZ policy on urban carbon emissions. Columns (1) and (2) report the estimation results for the entire sample, where Column (1) represents the estimates when only controlling for regional fixed effects and time fixed effects without including other control variables, and Column (2)

2 According to the data from China Energy Management Contracting Network (http://www.emcsino.com/html/news_info.aspx?id=9267), the CO_2 emission factor for natural gas is 2.1622 kilograms per cubic meter, and the CO_2 emission factor for liquefied petroleum gas is 3.1013 kilograms per kilogram.

3 According to the "China Electric Power Yearbook" for the years 2004–2014, the average proportion of coal-fired power generation in the total power generation was as follows: 82.9%, 82.5%, 81.8%, 83.3%, 83.3%, 81.2%, 81.8%, 80.8%, 82.5%, 78.6%, 79.2%, and 80.3%.

Table 1. Variable definitions and descriptive statistics.

Variables	Variable Definitions	Obs	Mean	SD	Min	Max
CE	The logarithm of urban carbon emissions	3100	6.243	1.165	0	9.533
Policy	If a city is approved to become a CBECPZ in a certain year and onwards, it is assigned 1. Otherwise, it is assigned 0.	3100	0.030	0.171	0	1
Pgdp	Logarithm of per capita GDP	3100	10.594	0.632	4.605	13.056
Pop	Logarithm of population density (population per square kilometer)	3100	5.886	0.693	3.020	8.137
Finance	Logarithm of the balance of financial institution deposits and loans	3100	17.228	1.123	14.383	21.590
Foreign	Logarithm of foreign direct investment	3007	9.974	1.888	1.386	14.941
Gov	Proportion of local government fiscal expenditure to GDP	3100	0.195	0.105	0.044	1.485
Tech	Percentage of scientific research and technical services and geological exploration professionals in the total employed population	3094	0.016	0.012	0.002	0.099
Lnrinfra	Logarithm of per capita road area	3100	3.372	0.497	0.289	5.198
Indstru	Proportion of value added by the secondary industry to GDP	3100	0.475	0.107	0.117	0.897

includes the estimates with additional control variables. The results show that regardless of whether control variables are included or not, the coefficient for "policy" is consistently negative. In Column (2) with control variables, the estimated coefficient for "policy" is 0.398%, which is statistically significant at the 1% level. Columns (3) and (4) present the estimation results after excluding municipalities directly under central government administration. Similar to the previous findings, the coefficient for "policy" remains significantly negative, even when control variables are included. In Column (4) with control variables, the estimated coefficient for "policy" is -0.372, passing the significance test at the 1% level. Columns (5) and (6) show the estimation results after further excluding provincial capital cities. Once again, the coefficient for "policy" is consistently negative, regardless of the inclusion of control variables. In Column (6) with control variables, the estimated coefficient for "policy" is -0.342, which is statistically significant at the 1% level. These results indicate that the policy of establishing CBECPZ has played an important role in reducing carbon emissions. Thus, Hypothesis 1 is confirmed.

Robustness Check

Parallel Trends and Dynamic Effects Test

The key assumption for applying the difference-in-differences (DID) method is to satisfy the parallel trends assumption, which states that in the absence of the CBECPZ policy, the green development trends in the treatment group and the control group should be parallel. Following the approach of Beck et al. [43], this study replaces the variable "Post" in the baseline regression model (1) with yearly dummy variables ("$Year_t$"). Considering the limited data for the 7 years before policy implementation and the 3 years after policy implementation, this study combines the data for the 7 pre-policy years into period -7 and the data for the 3 post-policy years into period 3. All other variables remain the same as in Equation (1). To avoid multicollinearity, this study sets the initial year of the sample as the base period in the regression. The specific model establishment is as follows:

$$CE_{it} = \beta_0 + \sum_{t=-6}^{3} \delta_t \, Policy_{it} + \beta_2 Controls_{it} + V_i + \mu_t + \varepsilon_{it} \quad (3)$$

For clarity, the estimated coefficient δt of the interaction term "Policy" is depicted in Fig. 1. The solid dots in Fig. 1 represent the marginal effects of the pilot implementation of the CBECPZ, and the short vertical lines represent the 95% confidence intervals. Based on the results in Fig. 1, it can be observed that the coefficient estimates for each period before the implementation of the CBECPZ policy are not significant. This indicates that there is no significant difference between the treatment group and the control group, passing the parallel trend assumption test. The reason for the significantly negative coefficient in the period immediately preceding the policy implementation could be attributed to the presence of policy anticipation effects. Many regions had already implemented policies

Table 2. Baseline regression analysis.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample results	Full sample results	Samples excluding direct-controlled municipalities	Samples excluding direct-controlled municipalities	Samples excluding both direct-controlled municipalities and provincial capital cities	Samples excluding both direct-controlled municipalities and provincial capital cities
Policy	-0.461***	-0.398***	-0.435***	-0.372***	-0.436***	-0.342***
	(0.058)	(0.051)	(0.061)	(2.380)	(0.104)	(0.083)
Controls	NO	YES	NO	YES	NO	YES
City FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Obs	3,100	2,057	3,056	2,026	2,770	1,833
R^2	0.895	0.893	0.886	0.883	0.868	0.864

Standard errors clustered at the city level are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

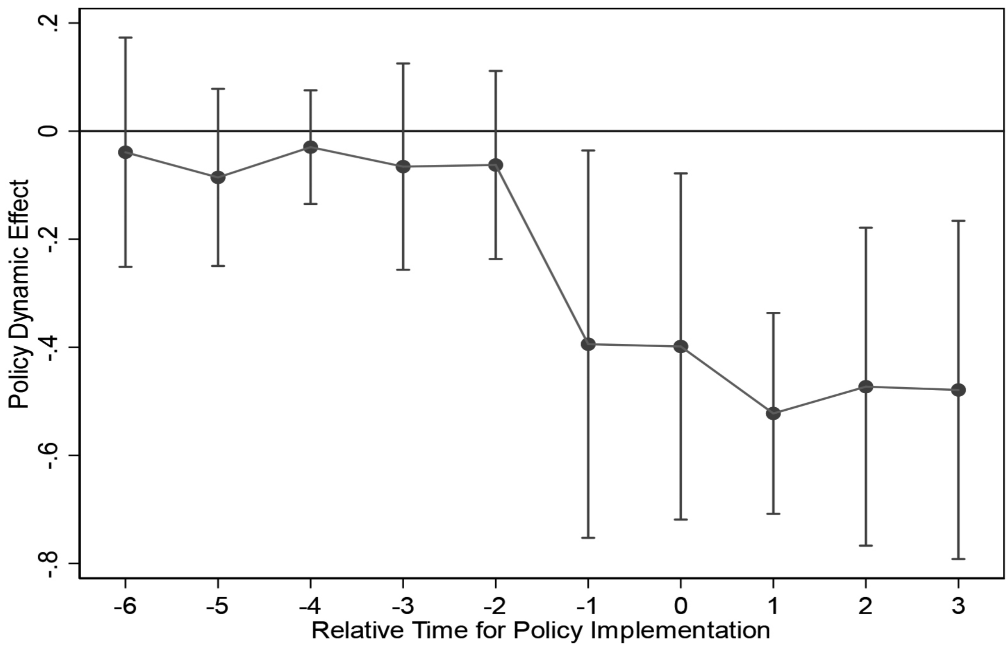

Fig. 1. Parallel trend test.

and embarked on cross-border e-commerce transformation before being designated as comprehensive pilot zones, leading to an early release of policy effects. However, after the implementation of the comprehensive pilot zone policy, the coefficients for each year are consistently and significantly negative, aligning with the baseline regression results. Overall, the regression results indicate that the difference-in-differences method can be applied to examine the impact of comprehensive pilot zone establishment on urban carbon emissions. Moreover, these findings validate the main conclusion of this study, which asserts that the development of comprehensive pilot zones has a positive influence on urban green and low-carbon development.

Placebo Test

In order to mitigate the influence of omitted variables or unobservable factors on the estimation results, this study conducted a placebo test. The purpose of this test is to eliminate spurious regressions caused by omitted variables or unobservable factors, ensuring the validity of the estimated policy treatment effect. Drawing from the research of Li et al. [44], a placebo test was performed by constructing fake

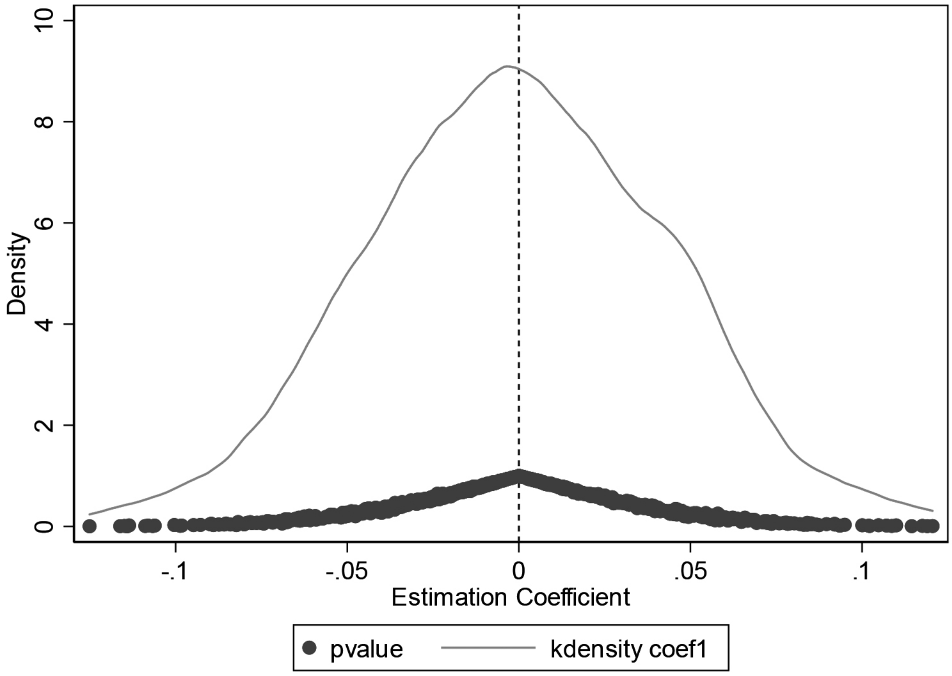

Fig. 2. Placebo test.

policy shocks. Specifically, an equal number of cities were randomly selected as the treatment group, which did not actually become CBCEPZ. Fake policy dummy variables were generated and included in the baseline model for estimation. Theoretically, if the baseline regression is not affected by omitted variables or other random factors, the estimated coefficients of the fake policy dummy variables should not significantly differ from zero. This implies that the randomly designated CBECPZ would not have a significant impact on urban carbon emissions levels. This process was repeated 500 times, and Fig. 2 presents the distribution of estimated coefficients after regressing the fake policy dummy variables for these 500 iterations. It can be observed that the estimated coefficients are very close to zero and follow a normal distribution. In contrast, the estimated coefficient for the "Policy" variable in the baseline regression is clearly outside this coefficient distribution. Therefore, the estimation results of this study are robust and not influenced by omitted variables or random factors. The green and low-carbon promotion effect of the CBECPZ establishment is reliable.

Instrumental Variables Method

Considering the potential endogeneity problems caused by reverse causality and omitted variable bias in the baseline regression, this article follows the approach of Nunn and Qian [45], using the product of the number of Chinese internet users in the previous year and the number of post offices in 1984 as the instrumental variable[4]. Regression analysis is performed using two-stage least squares (2SLS), and the specific results are shown in Table 3, where Columns (1) and (2) report the regression results of the instrumental variable (IV). The regression results show that there is a significant positive correlation between the instrumental variable and the pilot policy variable, regardless of whether control variables are included, and the validity of the instrumental variable in this article is verified through weak instrumental variable tests. Columns (3) and (4) report the results of the 2SLS regression. The results show that the coefficient of the core explanatory variable policy is consistent with the baseline regression results.

Other Robustness Tests

In addition to the aforementioned tests, this study also conducted several robustness tests:

(1) Alternative Dependent Variable. Firstly, the dependent variable, measured as carbon emissions, was replaced with per capita carbon emissions, and the estimation was

4 The main reasons for selecting this instrumental variable are as follows: (1) Cross-border e-commerce is highly related to logistics infrastructure. A high density of post offices means that the logistics infrastructure in that area was relatively well developed and advanced in the early days, and regions with good logistics infrastructure have well-developed cross-border logistics and express delivery industries. Thus, the development of cross-border e-commerce is also better in those areas, making this instrumental variable meet the relevance condition. (2) The correlation between historical infrastructure and modern urban economic development is relatively low, and the impact of traditional postal and telecommunications facilities on urban employment is minimal. Therefore, this instrumental variable meets the exogeneity condition.

Table 3. Instrumental variables (IV) estimation results.

Variables	(1)	(2)	(3)	(4)
	Policy	Policy	CE	CE
IV	2.96e-08***	2.76e-08***		
	(5.98e-09)	(1.73e-09)		
Policy			-0.910***	-0.949***
			(0.250)	(0.149)
Control variable	NO	YES	NO	YES
City FE	YES	YES	YES	YES
Kleibergen-Paap rk LM statistic (P Value)	13.075(0.000)	252.165(0.000)		
Cragg-Donald Wald F statistic	334.249[16.38]	254.164[16.38]		
Obs	2218	2165	2218	2165
R^2			-0.018	0.012

Standard errors clustered at the city level are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

re-conducted, as shown in Table 4, Column (1). Secondly, while total carbon emissions can provide an intuitive measure of carbon emissions variations, it overlooks regional differences in economic levels. Therefore, this study selects the ratio of regional carbon emissions to regional Gross Domestic Product (GDP), known as carbon intensity, as the outcome variable, and the estimation results are presented in Table 4, Column (2). Regardless of whether per capita carbon emissions or carbon intensity is considered, the estimated results consistently show a significant negative relationship.

(2) PSM-DID Estimation. The selection of pilot cities by the Chinese government for cross-border e-commerce development may be biased towards cities with better infrastructure. This selection bias could potentially affect the estimated results of this study. Therefore, this study further employs the Propensity Score Matching Difference-in-Differences (PSM-DID) method to address the issue of selection bias. Specifically, city-level carbon emissions are used as the outcome variable, while government interventions, degree of openness, infrastructure, economic development level, population density, technological innovation level, and industrial structure are used as matching variables. The cities in the experimental group and control group are matched based on nearest neighbor matching within a caliper. Regression tests are then conducted using the matched sample based on propensity score matching. The results of the regression analysis, presented in Table 4, Column (3), show that the coefficient of the policy intervention of the CBECPZ (Policy) is significantly negative, consistent with the baseline regression results.

(3) Controlling for macro policy effects at the provincial level. This study focuses on the city level, but during the same period, there are macro policies implemented at the provincial level that can influence regional carbon emissions. To account for the potential impact of these macro policies, this study controls for province-level time trends to capture the different time trajectories across provinces. The results of the regression analysis, as shown in Table 4, Column (4), indicate that the coefficient of the policy intervention of the CBECPZ (Policy) remains significantly negative, consistent with the baseline regression results, after controlling for the provincial time trends.

(4) Consider the spatial correlation of the error term. Taking into account the potential spatial correlation of carbon emissions, this article follows the approach of Nunn and Wantchekon [46] by using spatial HAC standard errors. The model is specified to have spatial correlation within a 2° range, and the results are presented in Table 4, Column (6). The coefficient of Policy remains significantly negative, consistent with the baseline regression results.

(5) Exclude the influence of other policies. Considering that many similar or correlated policies are implemented simultaneously or in conjunction across regions, there may be a certain policy overlap effect. Therefore, this article takes into account other policies implemented during the sample period that have significant relevance to urban carbon emissions, which could affect the regression results. To control for the impact of other concurrent policies, we include virtual variables for carbon emission trading pilot programs [47], low-carbon city pilot programs [48], and innovative city pilot programs [49] in the baseline regression. Specifically, this article examines the causal relationship between the CBECPZ and urban carbon emissions after controlling for interference from other policies. Among them, "carbontrade" indicates whether the city is a carbon emission trading pilot city in a given

Table 4. Robustness tests.

Variables	(1) Replace dependent variable with per capita carbon emissions	(2) Replace dependent variable with carbon emission intensity	(3) PSM-DID	(4) Control province-time trend	(5) Consider spatial correlation	(6) Excluding other policy effects
Policy	-0.189***	-0.212***	-0.353***	-0.355***	-0.464***	-0.437***
	(0.043)	(0.033)	(0.077)	(0.066)	(0.044)	(0.061)
Control variable	YES	YES	YES	YES	YES	YES
Carbontrade						YES
Lowcarbon						YES
Innocity						YES
Year FE	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES
Obs	2978	2978	1063	2,942	2999	2958
R^2	0.051	0.059	0.074	0.903	0.062	0.069

Standard errors clustered at the city level are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

year (1 if yes, 0 otherwise), "lowcarbon" indicates whether the city is a low-carbon pilot city in a given year (1 if yes, 0 otherwise), and "innocity" indicates whether the city is an innovative pilot city in a given year (1 if yes, 0 otherwise). The estimation results after excluding the interference from these three policies are shown in Column (7) of Table 4. All results indicate that even after controlling for other policy shocks, the coefficient of Policy remains significantly negative, and its magnitude does not show significant change compared to the baseline results. This suggests that the causal relationship between the CBECPZ and urban carbon emissions remains valid, unaffected by other policy interferences, as examined in previous research findings.

Heterogeneity Test

Heterogeneity in Digital Infrastructure

In regions with more advanced digital infrastructure, businesses have greater opportunities to engage in cross-border e-commerce and find it more convenient to conduct such activities. Some regions may even have accumulated experience in this field. After the approval of the CBECPZ, enterprises in these regions can seize the opportunity and quickly obtain institutional advantages. Therefore, the level of digital infrastructure plays a role in moderating the impact of the CBECPZ on regional carbon emissions. In this study, internet penetration rate is used as a proxy variable for digital infrastructure. Based on the initial-year internet penetration rates of each city in the sample, the entire sample is divided into two groups: high-level digital infrastructure and low-level digital infrastructure. The results of the test are shown in Columns (1) and (2) of Table 5. It can be observed that, whether in regions with high-level or low-level digital infrastructure, the coefficients of the impact of the CBECPZ on regional carbon emissions are significantly negative. Furthermore, the absolute value of the coefficient is larger for regions with low-level digital infrastructure. One possible reason is that, after long-term development, the level of digital infrastructure across different regions in China is relatively high and not significantly disparate.

Heterogeneity in Environmental Regulatory Intensity

Government environmental regulations can alter the resource allocation of businesses and significantly impact the relationship between emerging foreign trade formats such as cross-border e-commerce and regional green and low-carbon transformation capabilities. Therefore, this study measures the environmental regulatory intensity of a region using the comprehensive utilization rate of general industrial solid waste. The entire sample is divided into two groups based on the median: cities with high-level environmental regulations and cities with low-level environmental regulations. The results of the group comparison are reported in Columns (3) and (4) of Table 5. The estimation results show that, whether in cities with high-level or low-level environmental regulations, the coefficient of the Policy variable is significantly negative. Furthermore, the absolute value of the coefficient is larger for cities with low-level environmental regulations. This indicates that the establishment of the CBECPZ can change or even reverse the unfavorable situation of low-level environmental

Table 5. Heterogeneity test.

Variables	Different digital infra-structure		Different environmental regulatory intensity		Different geographical location		Different urban hierarchy	
	High	Low	Different	Different	Eastern cities	Central/western cities	High-level cities	Ordinary cities
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Policy	-0.319***	-0.442***	-0.423***	-0.556***	-0.334***	-0.436***	-0.017	-0.340***
	(0.068)	(0.048)	(0.075)	(0.086)	(0.026)	(0.077)	(0.033)	(0.142)
Controls	YES	YES	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Obs	1,519	1,480	1,956	976	1,056	1,902	284	2,674
R^2	0.904	0.854	0.929	0.868	0.908	0.879	0.966	0.875

Standard errors clustered at the city level are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

regulation in terms of green and low-carbon transformation and bridge the gap in carbon emissions between these two types of regions.

Heterogeneity in Geographic Location

In this study, the sample cities are divided into eastern cities and central-western cities based on their geographic location. The regression results are reported in Columns (5) and (6) of Table 5. The estimation results show that, whether in eastern cities or central-western cities, the coefficient of the Policy variable is significantly negative. Furthermore, the absolute value of the coefficient is larger for central-western regions compared to eastern regions. Compared to central-western cities, eastern cities have a strong foundation in foreign trade. They started implementing cross-border e-commerce early and have shown high enthusiasm in this area. Moreover, governments at various levels in the eastern region have introduced policies in a timely manner to encourage and promote the development of cross-border e-commerce. Therefore, the marginal effect of the pilot zone policy on regional carbon emissions is not so big in the eastern region. In contrast, the central-western region had a weaker foundation in foreign trade, and the level of policy support was insufficient. The pilot zone policy provides rare development opportunities and various preferential policies for the central-western region, making its effects more pronounced.

Heterogeneity in City Tier

In this study, the sample cities are classified into high-tier cities and ordinary cities based on their city tier. Direct-controlled municipalities, sub-provincial cities, and centrally administered municipalities are categorized as high-tier cities, while other cities are classified as ordinary cities. The regression results are reported in Columns (7) and (8) of Table 5. The estimation results show that the coefficient of the Policy variable is negative but not significant for high-tier cities. However, for ordinary cities, the estimated coefficient is significantly negative. High-tier cities have a higher level of development, a highly service-oriented industrial structure, strong technological innovation capabilities, and higher requirements for environmental quality. Therefore, the carbon emission effects of the pilot zone policy are no longer significant for these cities. On the other hand, ordinary cities have a lower level of development, with an industrial structure mainly focused on manufacturing and limited technological innovation capabilities. The introduction of the pilot zone policy has attracted various upstream and downstream service industries to settle in these cities, promoting the optimization of their industrial structures. This, in turn, stimulates an increase in technological innovation capabilities and facilitates the green and low-carbon transformation of these cities.

Mechanism Test

In the examination of causal mechanisms, existing research commonly employs the mediation effect model for regression analysis. However, the major drawback of the mediation effect model is its inability to address endogeneity issues when the dependent variable regresses on the mediator variable. Therefore, this article directly regresses the mechanism variable on the core explanatory variable and utilizes 2SLS estimation to mitigate potential endogeneity concerns in the mechanism examination. The proposed model for mechanism examination in this study is specified as follows:

Table 6. Mechanism test.

Variables	Gpa		Upgrade		Pelec		Elec	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Policy	0.492***	0.421***	0.074	0.141***	-0.013	-0.004	-0.044**	-0.018
	(0.050)	(0.053)	(0.052)	(0.046)	(0.016)	(0.018)	(0.017)	(0.018)
Controls	NO	YES	NO	YES	NO	YES	NO	YES
City FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Obs	3,017	2,932	3,017	2,932	816	775	870	770
R^2	0.876	0.893	0.868	0.893	0.984	0.983	0.980	0.977

Standard errors clustered at the city level are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

$$Mech_{it} = \phi_0 + \phi_1 Policy_{it} + \gamma X_{it} + \lambda_i + \mu_i + \varepsilon_{it} \quad (4)$$

In Equation (4), *Policy* represents the estimated results of the first-stage regression model from the instrumental variable (IV) test, specifically the predicted values of the IV obtained by regressing the core explanatory variable (Policy) on the instrument. *Mech* is the mechanism variable representing the city's green innovation capability, industrial structure upgrading, and energy consumption. Considering that invention patents serve as important carriers of knowledge elements and direct outputs of innovation activities, and the threshold for applying for green invention patents is relatively high, the number of green invention patent applications in a city can reflect its green innovation capability. Therefore, following the approach of Tao et al. [50], this study uses the number of green invention patent applications (Gpa) as a substitute indicator for a city's green innovation capability. For industrial structure upgrading, we adopt the ratio of the output value of the tertiary industry to the output value of the secondary industry (Upgrade) as a measure of the dynamic transformation pattern of "retreat from the second industry and advance to the third industry". As for energy consumption, since there is a lack of data on energy consumption at the city level and considering the high correlation between electricity consumption and energy consumption, this study refers to the approach of Li and Xu [41] and focuses on the perspective of city's electricity consumption, using the logarithm of per capita electricity consumption (Pelec) and the logarithm of total electricity consumption (Elec) as measures.

The results of the mechanism test are shown in Table 6. Columns (1) and (2) present the test results for the impact pathway of the city's green technological innovation. The results indicate that the policy dummy variable, "Policy," is significant at the 1% level regardless of whether control variables are considered. This suggests that the establishment of CBECPZ can effectively promote green technological innovation and enhance the city's green innovation capability. A higher green innovation capability is associated with a reduction in regional carbon emissions [24]. Thus, Hypothesis 2 is confirmed. Columns (3) and (4) report the test results for the impact mechanism of industrial structure upgrading. Based on Column (4) with control variables, the establishment of CBECPZ significantly promotes the transformation and upgrading of regional industrial structures, increasing the service-oriented nature of the economic structure. Previous studies have shown that the transformation and upgrading of the industrial structure can reduce regional carbon emissions [51]. Thus, Hypothesis 3 is confirmed. Columns (5) and (6) present the test results for the impact mechanism of energy consumption. Based on Column (6) with control variables, the establishment of CBECPZ did not have a significant effect on regional energy consumption. This indicates that the pilot policies of CBECPZ have not yet influenced carbon emissions by reducing energy consumption. Thus, Hypothesis 4 is not confirmed. In summary, the above results demonstrate that the establishment of CBECPZ suppresses carbon emissions by enhancing green technological innovation and promoting industrial structure transformation and upgrading. However, the pathway of energy consumption has not yet shown an effect.

Conclusions

This article is based on the policy background and mechanism analysis of China's pilot program for CBECPZ. Using data from 283 Chinese cities at or above the prefectural level from 2009 to 2019, the study employed a multi-period Difference-in-Differences (DID) method to examine the impact and underlying mechanisms of the pilot program on urban carbon emissions. The results show a significant reduction in urban emissions after becoming a CBECPZ. Therefore, the establishment of CBECPZ significantly promotes the green and low-carbon transformation of cities. Various robustness tests confirm the stability of the baseline result. The findings also indicate that green technological innovation capability and industrial structure transformation and upgrading are important mechanisms through which the pilot program influences urban carbon emissions. However, the pathway of reducing energy consumption has not yet shown a significant effect. Furthermore, heterogeneous treatment effect analysis suggests that the effects of the cross-border e-commerce pilot program are more pronounced in cities with lower levels of digital infrastructure and weaker environmental regulations, as well as in the central and western regions and ordinary cities.

Policy Implications

Based on the aforementioned conclusions, this article proposes the following policy recommendations:

(1) Expand the pilot scope of CBECPZ. Continue to expand the pilot program by including more eligible cities, allowing a greater number of cities to benefit from the radiating effects of the pilot policies and stimulate the green and low-carbon development of cross-border e-commerce.

(2) Improve evaluation and supervision of the establishment of CBECPZ. The central government should establish a system for evaluating and supervising the establishment process, ensuring reasonable oversight and strict assessment. Implement dynamic adjustment and exit mechanisms, provide greater support in terms of funding and policies to the zones with favorable assessment results, and promote survival of the fittest.

(3) Develop preferential policies to enhance the green leadership role of CBECPZ in ordinary cities, central and western regions, areas with inadequate digital infrastructure, and regions with lower environmental regulatory intensity. Provide greater support in terms of finance and human resources to these regions, leveraging their advantages as latecomers. Additionally, increase investment in cross-border e-commerce in rural areas so that they can catch up with urban areas in terms of infrastructure and talent development.

(4) Respect market laws in the cities where the comprehensive pilot zones are located, recognizing the fundamental role of the market in resource allocation. Minimize unnecessary blind interventions and improve resource allocation efficiency.

(5) Developing countries, represented by China, should continuously improve support policies for cross-border e-commerce development. Innovatively address deep-seated contradictions and institutional issues, create a favorable environment for the development of cross-border e-commerce, enhance cross-border infrastructure and supporting services, promote high-quality development of cross-border e-commerce, and ultimately facilitate the green and low-carbon transformation of urban development.

Limitations and Future Research

The first limitation is the data interval. Due to data availability, the data in this article are available only up to 2019. Thus, we focus on the first three batches of Pilot Zones as the treatment events. In the future, with the updating of the data, the sample period can be extended to after 2019 to capture the effects of the other batches of CBECPZs. The second limitation is the research method. This article mainly uses DID and instrumental variable methods to avoid the estimation bias caused by endogeneity problems, but estimation errors caused by spatial correlation cannot be ruled out. Therefore, spatial econometric methods can be used to exclude spatial correlation and test spatial spillover effects and siphon effects to obtain more accurate estimation results in the future. The third limitation is the research level. This article focuses on the carbon emissions at the urban level, but enterprises are the micro foundation for economic activities. Therefore, it is necessary to delve deeper into the enterprise level and further explore the effect on the carbon emissions structure of enterprises, clarifying the micro mechanism of cross-border e-commerce on enterprise carbon emissions.

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Conflict of Interest

The authors declare that they have no conflict of interest.

Data Availability Statement

Data will be made available on request.

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