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Impact of Major Events on Interprovincial Carbon Emissions—Based on PSM-DID Analysis

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Abstract: The success of major events can enhance national image, boost people's confidence, and alleviate the current "three-fold pressure"—contraction in demand, supply shocks and weak expectations. In the context of the carbon neutrality target, it is important to analyze the relationship between major events and carbon emissions as the ecological, social and economic systems become more closely related. To study the extent and persistence of the impact of major events on the carbon emissions of the hosting provinces, this paper collects annual carbon emission data from 2015 to 2019 for 30 provinces in China. The propensity score matching Difference in Difference model (PSM-DID) is used to explore the impact of major events, such as political conferences, sports events and cultural exchanges, at the national level on inter-provincial carbon emissions. The empirical study shows that (1) the carbon emissions of the provinces involved in major events significantly increase in the year when the major event is held, (2) the carbon emissions of the province significantly decrease in the year after the conclusion of the major event, and (3) the decrease is higher than the increase in carbon emissions in the year when the event is held. Finally, the model results are analyzed in the context of economic events and macroeconomic policy lags during the preparation period of the event, and policy suggestions are made to incorporate carbon neutrality into the overall layout study of ecological civilization construction, strengthening the construction of legal thinking, enhancing inter-provincial and inter-city pollution synergy control, innovating carbon-related technologies, unifying carbon emission accounting and improving data openness.

Keywords: carbon emissions; propensity score matching; differences-in-differences; major events

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1. Introduction

The successful holding of major events can enhance the national image, boost people's confidence and inject a strong shot into the people under the situation of "three-fold pressure"—contraction in demand, supply shocks, and weak expectations [1]. Taking the 2022 Beijing Winter Olympic Games and Winter Paralympic Games as examples, China ranked third and first in the Winter Olympic Games and Paralympic Games, which greatly improved national pride and self-confidence. Moreover, many new green technologies have been developed and applied, and the carbon emissions of venues have been neutralized. 5G mobile internet, cloud computing, big data, satellite navigation, and artificial intelligence will play a great role in the Olympic Games to further promote the development and application of technology. As the construction of a healthy China has become a national strategy, the "300 million people on the ice sports" can not only call for national sports, but also directly promote the development of ice and snow cause and stimulate industrial vitality. In the context of the dynamic world situation and the spread of the global COVID-19, major events such as the Winter Olympic Games have ignited the enthusiasm of the whole people, and promoted economic development. It also alleviated the downward pressure on the economy caused by "three-fold pressure".

Under the severe situation of climate warming, international turmoil and the continued spread of the global COVID-19, China's carbon neutrality goal has a long way to go [2]. China is a big country in energy production and consumption, and the carbon dioxide emissions from energy events account for about 30% of the world. At present, China is still in the development stage of industrialization and urbanization, and the manufacturing industry is still in the middle and low-end position in the international industrial value chain. With the development of the economy and society and the acceleration of the construction of new industrialization and new urbanization, the energy demand will increase and the related carbon emissions will continue to increase in the future.

In order to cope with challenges and overcome difficulties together with countries around the world, maintain international image, improve international influence and improve people's happiness, China, as an international power, regularly holds major international and domestic events.

Scholars have conducted research on major events and air pollution around international events, national events, international cultural exchange activities, national policy meetings and major economic events. Wang [3], Zhao [4], Guo [5], Wang [6], Zhao [7], Liu [8], Cheng [9], Wen [10] studied the air environment quality during major events in China. These studies focus on concentration of $PM_{2.5}$ and CO. All studies show that major events have an impact on the change in pollutant concentration, which has decreased significantly during the holding stages of events. However, after the activity, the pollutant concentration may rise or continue to decline. There is no consensus at this point.

There are relatively few research contents on the theme of "the impact of major events on holding carbon emissions". Taking the case of the 2014 Nanjing Youth Olympics (NYO), Zhang et al. think the NYO has increased carbon emissions during the "preparatory-hosting-after" stages of a mega sporting event [11]. Taking the case of the 2008 Beijing Olympics, Worden et al. [12] and Wang et al. [13] think the Beijing Olympics has reduced carbon emissions during the hosting stages of a mega sporting event. Taking the case of Shanghai Expo, Zeng thinks that carbon emissions increase during the hosting of an event [14].

In the above study, there is no standard for delimiting the boundary between major events and non-major events. Secondly, the above research focuses more on the relationship between $PM_{2.5}$ concentration and major events. There are few studies on the relationship between carbon emissions and major events. Third, in the existing research on the relationship between carbon emissions and major events, only one major event is selected as the research. There may be cases where individual phenomena influence the overall conclusion.

Therefore, this paper explores the impact of major events on China's inter-provincial carbon emissions, and provides policy suggestions according to the analysis results, so as to promote China's carbon neutral development.

The layout of this paper is as follows: the Section 2 is regarding the theoretical basis and the latest research at home and abroad. The Section 3 is regarding PSM-DID model setting, variable selection and data sources. The Section 4 is regarding the analysis of the model results based on the inter-provincial annual data from 2015 to 2019. The Section 5 contains the conclusion and policy suggestions.

2. Theoretical Basis

2.1. Major Events

Roche divided events into four categories: Mega-events, special events, hallmark events and community events, shown in Table 1 [15].

Table 1. Public events: types and dimensions [15].

Type of Events	Example	Target Attendance/Market
Mega-Event	Expos; Olympics; World Cup	Global
Special Event	Grand Prix; World Regional Sport	Global; National
Hallmark Event	National sport event; Big City Sport/Festival	National; Regional
Community Event	Rural Town Events; Local Community Event	Regional; Local

Based on the study of Roche, Malfas et al. think a mega-event can be viewed in two main respects: first, with regard to its internal characteristics—that is, primarily its duration and its scale (i.e., number of participants and spectators, number of individual sessions, and levels of organizational complexity); and second, in respect to its external characteristics, which mainly take account of its media and tourism attractiveness, and its impact on the host city [16].

Müller thinks a mega-event should have visitor attractiveness, mediated reach, costs and transformative impact [17]. Such as the Expo, Summer and Winter Olympics, and Football World Cup.

When studying the relationship between major events and pollutant concentrations or carbon emission, Guo used various national economic conferences as major events [5]. Zhang [11] and Wang [13] used Olympics as major events. However, major events are not defined.

We synthesize the research of the above scholars. The criteria for selecting major events are: Global events or national events, or regional events with great economic and social significance.

The reasons why we did not follow Roche's definition [15] results are because:

(1) Our research focus on major events, not mega-events. Roche focuses more on sports events.
(2) The regional unit we study is the province. According to the Table 1, only a few provinces have held events. Too few samples may affect the accuracy of the study.
(3) Although the study of Guo et al. [5–9] did not define major activities, they chose many national economic policy meetings and international cultural exchange events.

2.2. Major Events and Carbon Emissions

With China's commitment to the world to achieve the "30·60" goal, and do a good job in the "double control" of air pollution prevention and carbon emission, it is related to the image of the country and the government and the health of the people. The CPC Central Committee and the State Council have successively issued policy plans and road maps. Previously, China's rules and regulations on holding provincial carbon emissions were more focused on air pollution prevention and control and energy "double control". In the face of major political conferences or major events, governments at all levels took various measures to control air pollution, and cities took coordinated control of provincial carbon emissions and pollutant control, including some temporary measures to ensure the implementation of major events, for example, the 2014 APEC Beijing and 2008 Olympic Games.

Based on this, many scholars have analyzed the problem of improving the air environmental quality of the host province (city) during major events, but there are few studies on the change in carbon emissions in the host province (city). In the research on the relationship between major events and air environmental quality, Zhong Yisheng took the "9.3" military parade in 2015 and the two early red warnings of heavy air pollution in winter of the same year as an example, made a comparative analysis on the variation characteristics of meteorological elements and pollutant concentration, estimated the proportion of pollutant emission reduction under different emission reduction measures, and used a WRF CAMX model to estimate the $PM_{2.5}$ brought by emission reduction five. The pollution improvement effect is quantitatively evaluated and compared. Compared with the red warning during the military parade, $PM_{2.5,}$ the higher proportion of concentration reduction is due to the greater coordinated emission reduction in regional pollutants, and the meteorological conditions that are easy to diffuse pollutants during the military parade. The intensity of pollution reduction, the implementation timing of emergency control measures, and meteorological conditions are important factors that may affect the pollution improvement effect of emergency pollution control measures [18]. Zhou Derong used the Lagrangian diffusion model to evaluate the atmospheric characteristics of Hangzhou during the G20 summit. The results show that $PM_{2.5}$ in Northern Zhejiang during the opening of the G20 summit five, the potential contribution of primary emissions are reduced by 15% [19]. Xia Chongming's research shows that since taking the opportunity of holding the "Youth Olympic Games" in 2014, Nanjing has adopted a series of "Sports" treatment means, such as strengthening coal pollution, enterprise emission pollution, dust and motor vehicle exhaust pollution, volatile organic compound pollution control and regional joint prevention and control, which has provided good environmental protection for the holding of the event, and the air environmental quality has achieved the expected goal in the short term. After the event, Nanjing's air pollution control still maintained a high-pressure situation, issuing nearly 20 policy documents every year to control environmental pollution, encouraging all kinds of social subjects and the public to actively participate, innovating the environmental supervision and law enforcement mechanism, strengthening the construction of environmental monitoring capacity, key season management and control, publicity and education and information disclosure, and achieving further results in air pollution control [20]. Wang et al. Used an OSPM model to calculate the impact of traffic control on the concentration of pollutants, such as CO during the 2008 Olympic Games. By comparing the modeling results with the measurements on representative streets, i.e., CO presents a double peak similar to the traffic flow, and the air quality is improved through traffic control during major events [21]. In addition, Zhao [4], Guo [5], Wang [6], Zhao [7], Liu [8], Cheng [9], Wen [10], etc. also studied the air environment quality during major events in China. The studies concluded that the pollutant concentration decreased during the events. However, there was no agreement on the change in pollutant concentrations after the events.

In the research on the impact of holding provincial (municipal) carbon emissions, the research of Cao Linhui and others on the Shanghai World Expo shows that the organization and holding of large-scale events is often accompanied by a significant increase in travel traffic. The travel of traffic carbon emission sources has become one of the main reasons for the increase in carbon emissions during major events. They believe that taking corresponding traffic management measures can effectively implement carbon emission reduction and provide sustainable promotion [14,22]. Meng et al. quantified Beijing's carbon emissions. Taking the Beijing Olympic action plan as an example, they pointed out that the improvement of the relationship between carbon emissions in Beijing in recent years may be closely related to urban planning policies, but there was no in-depth analysis on the relationship between carbon emissions and major events [23]. Li H's research shows that the Beijing Olympic Games will bring about 1.18 million tons of carbon dioxide equivalent greenhouse gases, most of which come from audience events. However, the urban landscaping built in the preparatory period can reduce 60,000 tons, and the renewable energy products such as solar photovoltaic in Olympic venues can reduce about 1000 tons, which can be used sustainably after the Olympic Games [24]. Taking the case of the 2014 Nanjing Youth Olympics (NYO), Zhang et al. examined the impacts on the host's local carbon emissions during the 'preparatory-hosting-after' stages of a MSE. By adopting a synthetic control method and logarithmic mean Divisia index decomposition, the following findings were reached from 2010, when the city of Nanjing announced the decision to bid to host the NYO, the NYO increased the carbon emissions of Jiangsu (the province to which Nanjing belongs) in every year from 2010 to 2019 [11]. Worden et al. use the WRF-Chem model and satellite observations data to estimate changes in carbon emissions during the 2008 Beijing Olympics [12]. They conclude that carbon emissions have decreased relatively.

The above research did not consider the lag or quantitative analysis of some major policy-making and democratic consultation events after the introduction of policies. At the same time, the construction of some events in the preparatory period will increase the current pollution and carbon emissions, and the effectiveness of policies and infrastructure in the preparatory period may play a significant role in the subsequent improvement of air quality and reduction in carbon emissions. Secondly, most studies focus on the duration of major events lasting for several weeks and days, while the impact of the construction of the preparatory period is often long-term, so it is ignored in short-term studies. Finally, most of the above studies focus on air quality and air pollutant concentration, and pay little attention to carbon emissions. Therefore, this paper focuses on the research on the impact of major events on the carbon emission of the host province, and explores the role of the current and lagging period of major events on the carbon emissions of the host province from the perspective of inter-provincial and annual, so as to put forward targeted suggestions conducive to the development of carbon neutralization.

3. Materials and Methods

The main content of this paper is the impact of major events on inter-provincial carbon emissions. It compares the provinces that have held major events in the same period with those that have not held major events, and compares the carbon emissions of major events in the same province with those held during non-major events. In this way, a double contrast is formed, which is in line with the idea of the Differences-in-Differences method. Therefore, a Differences-in-Differences model can be used. On this basis, in order to eliminate the characteristic differences between active and inactive cities as much as possible, it is analyzed and combined with the propensity score matching method.

3.1. PSM-DID and Data

3.1.1. PSM-DID

The Differences-in-Differences method approach was first proposed by Ashenfelter and Card [25]. It is widely used to evaluate the effectiveness of public policy implementation in econometrics, due to its ability to avoid possible endogenous problems by comparing the differences between the experimental group and the control group before and after the policy. Existing studies widely use the DID approach when evaluating the environmental and economic effects of China's carbon emission trading policy [26,27].

The basic idea of DID is that randomized controlled experiments are the gold standard for establishing causality. The double difference method can be understood as an analogue for random assignment experiments, where causality is verified in the absence of randomized experiments. The standard steps are as follows:

Step1: Grouping.

For a natural experiment, it divides the entire sample data into two groups: one group is affected by the intervention, the experimental group, and the other group is not affected by the same intervention, the control group.

Step2: First differencing.

Two differences (subtractions) are made before and after the intervention to obtain two sets of differences, representing the relative relationship between the experimental group and the control group before and after the intervention, respectively.

Step3: Second difference score.

The second difference is performed on the two sets of differences, thus eliminating the original difference between the experimental group and the control group, and finally obtaining the net effect of the intervention.

The DID is generally used to evaluate the effect of major events, random experiments or natural experiments (such as the adjustment of laws and regulations), and its standard form is [28]

$$y_{it} = \alpha + \gamma D_t + \beta \mathrm{Treat}_i + \delta D_t \times \mathrm{Treat}_i + \varepsilon_{it} (i = 1, \ldots n; t = 1, 2) \quad (1)$$

where y_{it} is the explanatory variable, D_t is the grouping dummy variable, characterizing the period when the major event is held or after. Treat_i is the major event dummy variable, characterizing whether the major event is held. $D_t \times \text{Treat}_i$ is the interaction term between the grouping dummy variable and the major event. The regression coefficient δ characterizes the net effect of major events. The residual term ε_{it}.

The propensity score matching (PSM) was performed by statistical modeling of the combined propensity score of each observation for each covariate, and then matched according to the proximity of the propensity scores [29]. Logistic regression was performed with the grouping variables as explanatory variables and other variables that might affect the results as covariates. A propensity index was calculated for each observation with an index range between 0 and 1, reflecting the probability of an individual being assigned to the experimental group. This method is commonly applied to overcome endogeneity in sample selection and to perform model robustness tests in a wide range of applications [5,30–32].

3.1.2. Model Setting and Inspection Method

In the process of building the model, considering the sustainability of the impact of major events on the carbon emission of the province, the impact of factors other than major events on the carbon emission of the province, and the fixed effect of region and time, multiple control variables and dummy variables are introduced:

$$CE_{it} = \beta_0 + \beta_1 \, \text{event}_i Periods_{it1} + \beta_2 \, \text{event}_i Periods_{it2} + \lambda C_{it} + T_i + S_t + \varepsilon_{it} \quad (2)$$

where CE_{it} is a numerical variable characterizing the carbon emissions of province i in year t; event_i is a dummy variable characterizing whether or not a major event is held in province i; $Periods_{it1}$ is a dummy variable characterizing the year in which the ith major event is held, examining the duration effect of the event, and $Periods_{it2}$ is a dummy variable that characterizes the year after the ith provincial event is held, and examines the subsequent effect of the event, i.e., the coefficient β_1 examines the current effect of the major event on carbon emissions in the province, and the coefficient β_2 examines the subsequent effect of the major event on carbon emissions in the province. Second, C_{it} is a set of control variables containing the average temperature, average precipitation and average wind speed in year t of province i; T_i and S_t are year and province dummy variables characterizing the fixed effects in time and space.

The robustness of the model conclusions were judged based on the consistency of the conclusions of PSM-DID and DID [5].

3.1.3. Sample Selection and Data Sources

The research sample of this paper is the annual data of 30 provinces in China from 2015 to 2019. Carbon emission data are obtained from the China Carbon Accounting Database (Carbon Emission Accounts and Datasets, CEADs), and meteorological data are obtained from the U.S. National Centers for Environmental Information (NCDC). Major events are mostly held by cities, but considering that CEADs data are annual inter-provincial data, as well as including the radiation and siphoning effects of major events [33–35], and the increasing intra-provincial economic ties [36,37], it was decided to still aggregate major events by provinces, selected with reference to Guo and Xu et al.'s study [5,38]. The events include cultural exchange events, policy planning meetings, sports events, etc. Limited by the scope of provincial carbon emissions data, the most recent data is only available up to 2019. However, it is still possible to give economic development policies based on the study of past phenomena.

In the above data, there are missing values in precipitation of meteorological data. For the missing data, firstly we adopted linear interpolation, and for remaining data still missing, we adopted mean interpolation. Finally, 150 samples containing 40 variables were obtained. The 40 variables included 3 meteorological variables, 4 time dummy variables, 29 province dummy variables, a dummy variable for whether a major event was held, a dummy variable for year of hosting, a dummy variable for one year after holding, and the carbon emissions variable.

4. Results and Discussion

4.1. Basic Descriptive Analysis of Sample Data

According to the contents of Table 2, the 30 provinces from 2015 to 2019 can be divided into a major event holding group that has held major events (hereinafter referred to as the experimental group) and a control group that has not held major events, as shown in Table 3.

Table 2. Major events in China from 2015 to 2019.

Major Events	Year	Provinces
The Second Session of the Thirteenth National Committee of the Chinese People's Political Consultative Conference	2019	Beijing
The Second Session of the Thirteenth National People's Congress	2019	Beijing
World Horticultural Expo	2019	Beijing
World Oceans Day International Events	2019	Guangdong
Celebration of the 100th anniversary of the founding of the Communist Party of China	2019	Beijing
Commemorating the 100th anniversary of the May Fourth Movement	2019	Beijing
The Second International Import Expo	2019	Shanghai
Yangtze River Delta Regional Integrated Development	2019	Shanghai, Jiangsu, Zhejiang, Anhui
The First Session of the 13th National Committee of the Chinese People's Political Consultative Conference	2018	Beijing
The First Session of the Thirteenth National People's Congress	2018	Beijing
The new session of the Forum on China-Africa Cooperation	2018	Beijing
Opening of the Hong Kong-Zhuhai-Macao Bridge	2018	Guangdong
The 18th Meeting of the Council of Heads of State of the Shanghai Cooperation Organization	2018	Shandong
The first China International Import Expo	2018	Shanghai
Standing Committee of the Political Bureau of the CPC Central Committee	2017	Beijing
The 19th National People's Congress of the Communist Party of China	2017	Beijing
The Fifth Session of the Twelfth National Committee of the Chinese People's Political Consultative Conference	2017	Beijing
The Fifth Session of the Twelfth National People's Congress	2017	Beijing
Belt and Road International Cooperation Summit Forum	2017	Beijing
International Standards Organization General Assembly	2017	Beijing
Xiamen International Marathon-Xiamen	2017	Fujian
BRICS Summit	2017	Fujian
BRICS Games	2017	Guangdong
The Thirteenth Games of the People's Republic of China	2017	Tianjin
The Thirteenth Hangzhou National Student Games	2017	Zhejiang
The Fourth Session of the Twelfth National Committee of the Chinese People's Political Consultative Conference	2016	Beijing
The Fourth Session of the Twelfth National People's Congress	2016	Beijing
Boao Forum for Asia	2016	Hainan
G20 Summit	2016	Zhejiang
The Fifth Plenary Session of the Eighteenth Central Committee	2015	Beijing
The Third Session of the Twelfth National Committee of the Chinese People's Political Consultative Conference	2015	Beijing
The Third Session of the Twelfth National People's Congress	2015	Beijing
Beijing International Federation of Nations World Athletics Championships	2015	Beijing
The 70th Anniversary Parade of the Victory of the War of Resistance	2015	Beijing
The First National Youth Games	2015	Fujian
The Council of Heads of Government of the Shanghai Cooperation Organization	2015	Henan
The Fourth China-Central and Eastern European Leaders' Meeting	2015	Jiangsu
The Second World Internet Conference	2015	Zhejiang
The seven national carbon emission trading pilots	2014	Beijing, Hubei, Shanghai, Guangdong, Chongqing, Tianjin
Nanjing Youth Olympic Games	2014	Jiangsu
APEC Summit	2014	Beijing

Note 1: 2014 data is used as $Periods_{it2}$ for 2015 data. Note 2: Selected as international, national or major events around low carbon. Note 3: Limited by inter-provincial data on carbon emissions, the study model is as of 2019.

Table 3. Group of provinces.

Experimental Group	Control Group
Beijing, Guangdong, Shanghai, Jiangsu, Zhejiang, Anhui, Shandong, Fujian, Hubei, Chongqing, Tianjin, Hainan, Henan	Yunnan, Inner Mongolia, Jilin, Sichuan, Ningxia, Shanxi, Guangxi, Xinjiang, Jiangxi, Hebei, Hunan, Gansu, Guizhou, Liaoning, Shaanxi, Qinghai, Heilongjiang

The experimental group includes 13 provinces, including Beijing, Guangdong and Shanghai; the control group contains 17 provinces, including Yunnan, Jilin and Inner Mongolia. The descriptive analysis of carbon emissions and meteorological data of the two groups is shown in Table 4.

Table 4. Descriptive analysis of carbon emissions and other variables.

Variables	Unit	Experimental Group			Control Group		
		Max	Min	Mean	Max	Min	Mean
Carbon Emission	Million tons of CO_2	937.12	39.85	359.10	914.21	51.36	329.22
Temperature	degrees Celsius	25.62	13.25	17.55	22.12	1.27	11.36
Wind speed	m/s	3.38	1.98	2.70	3.33	1.71	2.44
Precipitation	mm	5.20	1.30	2.75	3.65	0.63	2.04

Observing the carbon emission variables, the maximum and mean values of carbon emission data for the experimental group were 937.12 and 359.10 Mt CO_2, respectively, which were 22.91 and 29.88 Mt CO_2 higher than the control group. This may be due to the production pressure from transportation [39], venue construction, and production of venue building materials in the year of the event, which leads to higher carbon emissions in the hosting province; secondly, there is an internal and external lag in the effect of the policies introduced for the policy-designated type of conference; again, carbon emissions are different from carbon dioxide concentrations, which are influenced by inter-provincial development, geographical location, etc., and may be out of a higher level of carbon emissions in the hosting province itself. These two points explain to a certain extent the high carbon emissions in the cities hosting the events in Table 3, and also indicate that the introduction of control variables, such as regional fixed effects, and weather the variables in the model setting of this paper are extremely necessary.

In addition, some existing studies point out that major events have a positive effect on reducing pollutant concentrations, which is different from the above results in Table 3. In addition to the difference in the study subjects being carbon emissions and CO_2 concentrations, respectively, the preliminary judgment is that it may be due to the daily and temporal granularity of CO_2 concentration data that major events have a significant reduction effect on CO_2 concentrations (high frequency data) in the short term, which may be a result of "political blue sky" (it refers to the excellent air quality that occurs as a result of the prevention and control measures taken during the meeting to further reduce pollution), due to further strengthening of environmental protection measures in the days or weeks of the event, and therefore not significant on an annual basis. In fact, the benefits of technological updates, infrastructural improvements, and better policy systems from major events should be observed over a longer time horizon.

The descriptive analysis of the in-depth experimental group, with the year in which the major event was held, the year after it was held, and the remaining years as the dividing line, is shown in Table 5 for the two groups of carbon emissions and meteorological data.

Table 5. Mean values of variables in different periods of the experimental group.

Year	Year of Hosting	One Year after Holding	Others
Variables		**Mean**	
Carbon Emission	339.54	318.39	370.89
Temperature	17.36	17.32	17.67
Wind speed	2.82	2.73	2.61
Precipitation	2.57	2.65	2.87

Observing Table 4, the provinces that have hosted major events have differences in carbon emissions in different periods. The average value of carbon emissions in the year of hosting and the year after are 339.54 and 318.39 Mt CO_2, which is 8.45% and 14.2% lower compared to the rest of the years. Secondly, the average value of carbon emissions in the year after the event is even lower, from 339.54 Mt CO_2 in the year of the event to 318.39 Mt CO_2, a reduction of 6.23%. Preliminarily, it can be judged that the impact of major events on the carbon emissions of the hosting province has some continuity or lag. This impact is more significant than the current impact of the carbon emissions on the hosting province in the hosting year.

4.2. Results of DID

Using panel-corrected standard errors, there are four models according to the type of fixed effects shown in Table 6.

Table 6. DID regression results.

Fixed Effect Type	Time + Region	Time	Region	None
	coef	coef	coef	coef
β_0	346.55 ***	195.76	292.45 ***	174.00
Year of hosting	16.74 **	111.63	20.59 *	114.32
One year after holding	−19.11 *	−169.02	−20.69	−170.74 *
Temperature	5.48	−8.78	14.21 *	-8.51
Wind speed	−25.30	65.12	−22.21	65.22
Precipitation	−0.71	52.17	−2.99	49.97
adjustR^2	0.991	0.02	0.98	0.04
AIC	1408	2053	1445	2046
BIC	1525	2083	1550	2064

Note 1: The year of holding is substituted for $event_i Periods_{it1}$ for the convenience of description. The year after holding is substituted for $event_i Periods_{it2}$. Same as below. Note 2: ***, **, * denote significant at the 1%, 5%, and 10% levels, respectively. Same as below.

Observing Table 5, it can be seen that the model with time fixed effects and area fixed effects (dual fixed effects model) was selected as the optimal model based on the decidable coefficients, AIC, BIC and variable significance, which has the smallest AIC and BIC values, as well as excellent goodness of fit. The model was tested to pass the Breush-Pagan heteroskedasticity test, D.W. autocorrelation test, and F-test.

From the results of the double fixed-effects model, the effects of the year in which the major event is held and the year after it is held on the carbon emissions of the hosting province are significant. Among them, the year of hosting has a positive effect on the increase in carbon emissions in the hosting province, and the year after hosting has a positive effect on the decrease in carbon emissions in the hosting province.

In terms of coefficients, the carbon emissions of the province in the year of the major event are dating to increase by 16.74 Mt CO_2, an increase equivalent to 5.3% in the year after the hosting, and equivalent to 4.5% in the remaining years. This may be due to the fact that the provinces carry out site construction, road renovation, production of building materials, and transportation of goods [40–42] in preparation for the event. Also this type of event behavior lasts relatively longer in the year of hosting relative to the duration of the event, with an event often taking weeks or even months to prepare. The potential high carbon emissions during the preparation period occupies most of the period in a year. There is also a part of major events are national policy planning meetings, due to the existence of a certain lag in macroeconomic policies [43,44], the adjustment of carbon emissions of the hosting province in the year of the event cannot be fully reflected. Second, major events are often held using many new and popular technologies for communication, transportation, etc. The 5G technology that has become popular in recent years is also often used. 5G energy consumption per bit is one-fifth of 4G. But because 5G peak rates have increased 20 times compared to 4G, high energy consumption has become a key issue for 5G [45]. This also leads to an increase in carbon emissions. The development of mobile communication technology has helped in personal carbon footprint and carbon emission monitoring. However, it has not been promoted yet.

In contrast, the carbon emissions of the province in the year after the major event is held will be reduced by 19.11 Mt CO_2, an increase equivalent to 5.6% in the year of the event and equivalent to 5.2% in the remaining years. Both the percentage and the absolute amount of the reduction are larger than the increase in carbon emissions due to the year of hosting, where the absolute amount is about 14 percentage points higher. This may be due to the effectiveness of policy planning meetings in the year after the conference, especially the synergy brought about by the formation of a system due to the continuous improvement of carbon-related policies and regulations. Secondly, it is the multiplier effect brought about by technological upgrading and infrastructure construction after the preparation period for major events, and the economic, sustainable and available impact of such pre-construction has a certain degree of permanence and has an obvious driving and supporting effect on social development. Therefore, it may have played an important role in clean energy development, industrial transformation and upgrading, and carbon emission regulation, which in turn influenced the carbon emission performance and achieved energy saving and emission reduction.

In addition, that none of the meteorological variables are significant may be due to: meteorological data mainly have a large impact on AQI and its related pollutants, and have little impact on carbon emissions in the provinces held, instead, there is a significant relationship between the increase in carbon emissions and temperature rise; some studies have shown that extreme weather has a significant impact, and limited by the granularity of carbon emissions data, extreme weather samples are smoothed out [46,47]. Secondly, the statistical method of data leads to insignificance; NCDC is sensor monitoring data, while carbon emission data is accounting data based on energy inventory, blurring the causal relationship. Again, the meteorological data may be influenced mainly by whether or not a major event is held or the timing of the event [5], with a relatively weak effect on the carbon emissions of the hosting province. Finally, it is possible that the estimation bias is due to sample selection bias, which will also be overcome in the following when using PSM.

4.3. Robustness Test Based on PSM-DID

In order to overcome the sample selection bias and reduce the estimation bias of the Differences-in-Differences method, this paper further uses the propensity score matching method (PSM) and then Differences-in-Differences using the matched samples. Meanwhile, PSM-DID is a test for the robustness of DID analysis results [5].

Referring to the grouping settings of the significant activity group (experimental group) and the control group in Table 3, several provinces from the control group were selected to match with those in the experimental group. The specific matching idea was to seek the sample with the most similar control variables, and the model was a logit regression with whether a major event was held as the explanatory variable, and the control variable as the explanatory variable, and the matching method was nearest neighbor matching using a 1-to-1, no-relaxation, minimum difference caliper method.

Observing Table 7, the control variables are all significant at the 1% level, indicating that weather factors influence whether a major event is held or not, which is consistent with the findings of studies under fine granularity [5,47]. The PSM-based data matching can be continued and 130 samples were obtained by matching, and the mean values of control variables before and after matching are shown in Table 8, and after excluding the mismatched samples, the change in the mean values of the control group occurred more relative to the experimental group.

Table 7. Result of Logit regression.

	Coef	Std.err	z	$p > \|z\|$	[0.025	0.975]
Temperature	0.40	0.11	3.81	0.00	0.20	0.61
Wind speed	2.82	0.69	4.06	0.00	1.46	4.18
Precipitation	−1.52	0.57	−2.67	0.01	−2.63	−0.40

Table 8. Mean values of sample data after PSM matching.

	Variables	Before PSM	After PSM	Differences
Experimental group	Temperature	17.55	17.88	−1.85%
	Wind speed	2.69	2.71	−0.74%
	Precipitation	2.75	2.82	−2.48%
Control group	Temperature	11.36	11.97	−5.10%
	Wind speed	2.44	2.38	2.52%
	Precipitation	2.04	2.18	−6.42%

DID with time and region fixed effects was performed on the matched data, and the regression results are shown in Table 9.

Table 9. PSM-DID regression results.

	Coef	Std.err
β_0	393.31 ***	71.24
Year of hosting	16.90 **	6.92
One year after holding	−17.29 *	9.09
Temperature	−0.59	5.37
Wind speed	−36.27	22.80
Precipitation	0.15	7.23
adjust R^2	0.995	
F	508.30 ***	
Breush-Pagan	76.59 ***	
D,W	1.96	
AIC	1162	
BIC	1262	

Note 1: ***, **, * denote significant at the 1%, 5%, and 10% levels, respectively. Same as below.

Comparing the DID results with the PSM-DID results.

(1) In terms of significance, the results are consistent with DID. The year of hosting and the year after the hosting year are significant, and the meteorological variables are not significant. That is, the year of hosting and the year after hosting have significant effects on carbon emissions in the hosting province.

(2) In terms of coefficient size, the results are consistent with DID. The carbon emissions of the province in the year of the major event will increase by 16.90 Mt CO_2, which is 0.16 Mt CO_2 higher than the DID result; the carbon emissions of the province in the year after the major event will decrease by 17.29 Mt CO_2, which is 1.82 Mt CO_2 lower than the DID result. However, both the DID and PSM-DID results support the conclusion that the year of hosting has a positive effect on the increase in carbon emissions in the province, the year after hosting has a positive effect on the decrease in carbon emissions in the hosting province and the decrease in carbon emissions is greater than the increase in carbon emissions.

(3) From the fitting effect, comparing Tables 5 and 8, the goodness of fit, AIC and BIC of PSM-DID are smaller than the DID results. From the model test, compare Tables 5 and 8. The PSM-DID passed the F-test and heteroskedasticity test, D.W. was close to 2, and passed the autocorrelation test by checking the table.

Combined with the conclusions of (1–3), the PSM-DID and DID results are highly consistent and the model conclusions are robust.

5. Conclusions and Policy Insights

5.1. Conclusions

Based on the annual data of carbon emissions and meteorology of 30 Chinese provinces from 2015 to 2019, the relationship between major events and provincial carbon emissions was analyzed by DID and PSM-DID. The results obtained indicate that the holding of major events has a significant effect on the change in provincial carbon emissions. The year of hosting has a positive effect on the increase in carbon emissions in the hosting province, and the year after hosting has a positive effect on the decrease in carbon emissions in the hosting province, and the reduction in carbon emissions is greater than the increase in carbon emissions. This result confirms Zeng's conclusion that carbon emissions will increase during the hosting of event [14]. Contrary to the conclusion that carbon emissions will be reduced during the hosting of event [11–13]. Secondly, the analysis in Section 4.2 also supports the conclusion that carbon emissions increase during the preparation of events. Finally, changes in carbon emissions and pollutant concentrations may not be consistent. The results of the pollutant concentration study show that pollutant concentration is lower during the hosting of an event [5–8], in most cases. However, this study shows that during the hosting of an event, carbon emissions increased. This may be due to the fact that the carbon emission data are annual data. This issue will also be studied in the follow-up study.

In terms of the division of major events and non-major events, a larger range of significant events are selected relative to reference [15]. A smaller range of major events are selected relative to reference [5]. This is because the study area unit is the province. Too strict a qualification of major events leads to too little data, too loose a qualification leads to unconvincing results. Such problems are also due to the lack of a uniform definition of a major event. The distinction between major events is a vague range [5–8].

5.2. Policy Insights

5.2.1. Government

Incorporate carbon neutrality into the overall layout of ecological civilization construction, and achieve the goal of carbon neutrality using rule of law thinking and rule of law. First, the 19th Party Congress proposed the general goal of socialism with Chinese characteristics, which has been written into China's constitutional amendment and become the basic idea guiding China's development. Xi's Thought on Ecological Civilization is also the guiding ideology for achieving the carbon neutrality vision goal. Achieving the carbon neutrality vision goal is not only a work requirement for addressing climate change, but also a clear requirement for high-quality economic development and ecological civilization construction, and should be understood from a political perspective. Secondly, the "Guidance on Building a Modern Environmental Governance System", "Guidance on Deepening the Reform of Comprehensive Administrative Law Enforcement for Ecological Protection" and the 14th Five-Year Plan call for accelerating the construction of a multi-departmental comprehensive administrative law enforcement system and forming an integrated law enforcement mechanism with clear boundaries of authority, clear responsibilities, information sharing, and coordination, and a comprehensive law enforcement pattern. Considering the impact of the macro policy lag and system synergy on the carbon emission of the province, it is necessary to establish a regulatory mechanism involving accounting, planning, testing, and monitoring, and in this mechanism, to clarify the administrative subjects, law enforcement management standards and law enforcement management measures, to improve the frequency of carbon emission performance assessment and supervision, to strengthen the role of assessment feedback on the layout and planning adjustment of industries and enterprises, and to promote carbon neutrality with a sound carbon emission management system. Promote carbon neutrality.

Unify carbon emission accounting and improve the openness of data. The emission sources of greenhouse gases and conventional air pollutants are homogeneous, but the current carbon emission and ecological environment and air pollutant emission monitoring and statistical systems are not yet connected, and they are still separate and independent statistical monitoring systems, and communication needs to be strengthened in data sharing [48]. The working group on carbon emission statistics and accounting are mainly in charge of the National Bureau of Statistics, while the competent department for addressing climate change and pollutant emission reduction is the ecological environment department, and different departments need to strengthen coordination and communication in terms of synergistic regulation of greenhouse gases and local pollutants. Secondly, the granularity of the current year's database is mostly concentrated in inter-provincial data and annual data, and it is necessary to actively promote the refinement of carbon accounting granularity, improve the update frequency, and form a comprehensive and reliable database to provide strong support for industry research. Finally, there are five main methods of carbon emission measurement: actual measurement method, material balance method, inventory method, life cycle method, and input-output analysis method, and the appropriate method is selected according to the carbon source in practice. The five methods have their advantages and disadvantages, and the differences in the results may have opposite effects on the situation judgment. The unification of carbon accounting system can be tried by piloting them first, further improving the carbon emission statistics mechanism, and perfecting and forming a unified carbon emission accounting system.

5.2.2. Enterprise

Strengthen inter-provincial and inter-city pollution synergy control and innovate carbon-related technologies. It is inevitable that the 14th Five-Year Plan period and even a longer period in the future will focus on pollution reduction and carbon synergy to fight the battle against pollution. Considering the positive effect of the preparatory period on the increase in carbon emissions in the host province and the synergistic effect of "pollution reduction and carbon reduction" in cities, the construction of inter-provincial and inter-city synergistic control and linkage mechanisms for air pollution during the preparation of major events should be strengthened [49], and cities are encouraged to carry out relevant planning, and to analyze and explore the effect of synergistic control and linkage mechanisms for carbon reduction by means of industry and enterprise piloting first. The effect of the pilot control mechanism is analyzed and explored, and an assessment and evaluation system is formed to make adjustments to the formulation of relevant policies. Second, the preparatory period involves circulation, construction, production and other links, the technology involved in these processes to further green transformation, reduce the unit carbon emissions; the use of energy gradually replaced by clean energy; the ability and conditions of the industry, enterprises to introduce CCS, CCUS and other decarbonization technologies [50,51], or joint research institutions to overcome breakthroughs in high energy consumption, high consumption and other advanced technical problems, and then strengthen the low-carbon, intensive use of science and technology innovations, to achieve a higher level of energy saving and emission reduction, effectively improving the "double control", so as to alleviate energy saving and emission reduction, production slowdown on the speed of economic development hindrance.

5.2.3. General Public Peoples

Green travel. Individuals need to take the concept of green travel deep into their hearts. Green travel not only eases traffic congestion to a certain extent, but also reduces environmental pressure. Individuals can reduce carbon emissions by using various means of transportation, such as bicycles, electric buses, subways, electric cars, as well as carpooling and sharing.

Eco-friendly office. Eco-friendly office means reducing the amount of printing and copying in the office process, developing good habits for saving paper, choosing recyclable office stationery, and speeding up the adaptation to a paperless office. At the same time, reduce business travel and try to use remote video conferencing and other means of communication.

Reduce energy consumption. In the selection of electrical appliances, choose to use energy-saving appliances as much as possible. Installing photovoltaic distributed energy is a good choice, which can meet the household energy demand and is also in line with the low energy consumption of electricity. At the same time, the habit of saving electricity is also essential. You can use the smart home control center to coordinate the energy consumption in the house and turn off the appliances that are not in use in time. In the selection of decoration materials, the use of environmentally friendly materials with low energy consumption in the production process, for example, the use of recycled steel, through the insulation of concrete formwork, roof radiation barriers, foundation insulation panels, etc. to improve the energy efficiency of homes.

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