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Original Research

The Impact of the Digital Economy on the Carbon Emissions of the Sports Industry – Based on Panel Data on 30 Provinces in China

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Abstract

The digital economy (DE) is characterized by high efficiency and being green, intelligent and innovative, which means that it can reduce carbon emissions and empower the green development of the sports industry. Therefore, exploring the relationship between digital economy and carbon emissions in the sports industry holds great significance. Based on 2010-2021 panel data covering 30 provinces in China, the digital economy development level (DEL) and carbon emissions of the sports industry (CESI) are measured. Then, a two-way fixed effect model, threshold effect model and spatial Durbin model are used to examine the impact of the digital economy on the carbon emissions of the sports industry. The results show the following: (1) After multiple tests, the development of the digital economy has a significant inhibitory effect on the CESI; in other words, the development of the digital economy can drive the low-carbon development of the sports industry. (2) The influence of the development of the digital economy on the CESI has a nonlinear feature of an increasing marginal effect and a spatial spillover effect. (3) From the perspective of regional heterogeneity, the development dividend of the digital economy in the developed eastern region of China is greater than that in the less developed central and western regions, having a more significant impact on the low-carbon development of the sports industry. Therefore, it is necessary for China to speed up the construction of digital infrastructure, build an integrated layout of digital infrastructure, give full play to the radiating role of the digital economy, and implement differentiated development paths based on regional comparative advantages.

Keywords: digital economy, carbon emissions of the sports industry, fixed effect model, threshold model, spatial Durbin model

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Introduction

Carbon emissions and the resulting climate problems have become the focus of global attention. In the past 40 years, with China's sustained rapid economic growth and accelerated urbanization process, the demand for energy consumption has been increasing, and environmental risks and ecological pressures have become increasingly severe [1]. According to data released by the International Energy Agency, as early as 2007, China's carbon emissions exceeded those of the United States, ranking first in the world [2]. Thus, in September 2020, China proposed the strategic goal of reaching a carbon peak by 2030 and carbon neutrality by 2060 (also known as the "double carbon" goal). China is actively taking responsibility to promote the building of a community with a shared future for humankind and the harmonious coexistence between humans and nature, which is also an inherent requirement for China's economy to achieve green and sustainable development [3].

Statistics show that China's sports industry has maintained rapid growth in recent years, and there is still much room for growth in the future. From 2012 to 2020, the scale and value added of China's sports industry increased from 952.6 billion Yuan and 313.6 billion Yuan to 2.74 trillion Yuan and 1.07 trillion Yuan, respectively, with average annual growth rates of 14.1% and 16.6%, much higher than the growth rates of other industries in the same period [4]. The proportion of the value added of the sports industry in GDP in the same period rose from 0.60% in 2012 to 1.06% in 2020, and the rate of contribution of the sports industry to GDP continued to increase [5]. The sports industry is a complex industry spanning the secondary and tertiary industries. The output of the sporting goods manufacturing industry has long been dominated by low-end manufacturing, such as sports shoes and clothing, and in the production process, it is deeply related to other high-carbon-emission industrial categories, such as the rubber, textile, and chemical industries. Large stadiums generate large-scale carbon emissions during operation to meet the needs of competition. With the continuous expansion of the scale of the sports industry and the development trend of the global low-carbon economy, the issue of carbon reduction and the green development of the sports industry has been widely considered. More than 280 sports organizations, including the International Olympic Committee (IOC), FIFA and others, have joined the "Race to Zero Carbon" campaign launched by the United Nations, which aims to reduce carbon emissions by 50% by 2030 and reach zero carbon emissions by 2040 [6]. In 2019, China's Ministry of Ecology and Environment issued a carbon-neutral pilot plan for large-scale events, which included carbon emissions from large-scale sports events in the macro management system. The "Carbon Peak Action Plan before 2030" issued by The State Council in China clearly states that it is necessary to accelerate the optimization of the industrial structure and the green and low-carbon transformation of traditional industries and to promote the integrated development of digitalization, intelligence and greenness in the industrial field to promote carbon peaking in this field. In addition, since China's sports industry still has large room for growth, the value added of China's sports industry will account for more than 4% of GDP by 2035, and the value added of the sports industry may exceed 8 trillion Yuan [7]. Thus, it is increasingly important to adhere to low-carbon development in the process of high-quality development demand and the linear growth in scale of the sports industry.

According to the White Paper on the Global Digital Economy (2022) released by the China Academy of Information and Communications Technology, the value added of the digital economy in 47 major countries around the world reached US $38.1 trillion in 2021. The scale of China's digital economy reached 7.1 trillion US dollars, accounting for 18.5% of the total of the 47 countries, ranking second in the world behind only the United States [8]. Today, digital technology innovation is still a global strategic focus. With the development of the digital economy, China has introduced relevant policies to support the integrated development of the sports industry and the digital economy. The report of the 20th National Congress of the Community Party of China clearly pointed out that it is important to "accelerate the development of the digital economy, promote the deep integration of the digital economy and the real economy, and build an internationally competitive digital industrial cluster". In 2019, the General Office of the State Council issued the Outline for the Construction of a Sports Power, proposing to promote the intelligent development of national fitness. The Opinions of the State Council on Accelerating the Development of the Sports Industry and Promoting Sports Consumption in China pointed out that it is necessary to improve innovation-driven strategies, strengthen sports brand building, develop sports products with high scientific and technological content and independent intellectual property rights, and increase the value added of products.

The accelerated integration of the digital economy based on digital technology and the sports industry promotes the transformation of the sports manufacturing industry into service-oriented manufacturing, enables the sports service industry to produce new formats [9], improves the level of digital governance of the sports industry [10], drives the high-quality development of the sports industry, and accelerates the sports industry in becoming a pillar industry [11]. Most related studies focus on the digital economy and evaluating scientific and technological innovation and the linear economic growth of the sports industry, and research has not yet examined how digital technology enables the low-carbon development of the sports industry. The multi-dimensional computing and analysis ability and intuitive decision-making efficiency of digital technology make it play an enormous role in production management, order service, process optimization, energy consumption monitoring, storage and transportation, emission accounting and other links of the sports industry, and production efficiency improvement and service process optimization will also reduce the carbon emissions of all aspects of industrial development. However, there is no evidence on an empirical level in this regard. Can the digital economy affect the carbon emissions of the sports industry? What are the characteristics of this effect? The answers to these questions will help clarify the relationship between the digital economy and the low-carbon development of the sports industry and provide references for exploring the path of green development of the sports industry. Accordingly, this paper tries to expand research in the following ways. First, based on the provincial scale, an evaluation index system is constructed to measure the digital economy development level (DEL) and the carbon emissions of the sports industry (CESI) in China. Second, the relationship between the two is demonstrated to test the effect of the development of the digital economy on the carbon emissions of the sports industry. Third, considering the Metcalfe law, the nonlinear effect and spatial spillover effect of the development of the digital economy on the carbon emissions of the sports industry are verified. Fourth, based on the regional differences in location and the level of economic development, this paper further discusses whether there is heterogeneity in the effect among different regions of China.

The possible contributions of this paper are as follows. (1) This paper measures the level of low-carbon development of the sports industry by calculating the CESI in 30 provinces of China from 2010 to 2021, providing a basis for objectively evaluating the development quality of the sports industry. (2) Based on Chinese panel data, a two-way fixed effect model is used to analyze the effect of the DE on the CESI to provide a reference for realizing the green development of the sports industry and to expand the effect analysis framework for the digital economy. (3) A threshold effect model is used to demonstrate the characteristics of the influence of the digital economy on the CESI and to reveal the nonlinear effect of the digital economy on the green development of the sports industry.

Literature Review

The Digital Economy

At present, the digital economy (DE) has entered a period of rapid development, and research on the digital economy has gradually been enriched. First, the connotation of the digital economy has drawn much attention from researchers. The digital economy is based on digital technology to realize the reshaping of the production mode and process, achieve revolutionary efficiency improvement, and trigger the sustainable development of digital transformation in the economic and social fields. The China Digital Economy Development Report (2022) pointed out that the digital economy is a new economic form that specifically involves digital knowledge and information as production factors, digital technology as a driver, the modern information network as a carrier, digital technology and the integration of the real economy as a direction, and the reconstruction of the governance mode as a guarantee. This concept highlights the role of data elements, digital technologies, modern information networks, and the integration of digital technologies and the real economy in the development of the digital economy. At the same time, digital technology is characterized by high innovation, high permeability and high growth, and these characteristics are conducive to breaking the dependence on traditional production factors and constantly integrating with the primary, secondary and tertiary industries, thus giving birth to a large number of new products and new business forms. In addition, scholars have measured the level of development of the digital economy by constructing an evaluation index system. For example, Zhao et al. (2019) built an indicator system based on the internet and digital finance [12]. Wang et al. (2021) built an index system from four dimensions: the digital economy development carrier, digital industrialization, industrial digitalization and the digital economy development environment [13]. Pan et al. (2021) constructed an evaluation index system based on four aspects: digital economic infrastructure, digital industrialization, industrial digitalization and digital governance [14].

The Sports Industry

The sports industry (SI) is constantly exploring and developing in the process of economic system reform, its concept is constantly evolving, and its connotation is constantly being enriched. According to the Statistical Classification of the Sports Industry (2019), the sports industry refers to the collection of production activities that provide various sports products (goods and services) and sports-related products to society [5]. Based on the effective supply of sports, the characteristics of the development of the sports industry include the following: 1) With the continuous improvement in the external environment for the development of the sports industry, the scale of the sports industry and its contribution to the national economy will continue to increase. 2) With the acceleration of the transformation and upgrading of the sports industry, the structure of the sports industry will continue to optimize. 3) With the upgrading of the mass consumption structure and the continuous promotion of sports industry policies, mass sports consumption will be significantly increased, and infrastructure such as the per capita sports venue area will continue to grow. 4) With the continuous improvement in the sports business environment, sports market players will continue to grow.

Low-Carbon Development of the Sports Industry

Low-carbon development means minimizing greenhouse gas emissions under the condition of ensuring healthy, rapid and sustainable economic and social development. Low-carbon development requires a reduction in total carbon emissions and unit emissions through technological innovation to improve the energy structure, adjust the industrial structure, and improve energy efficiency and production efficiency while maintaining the current economic development speed and quality or even improving them [15].

Based on the connotation and requirements of low-carbon development, the low-carbon development of the sports industry refers to improving production efficiency, energy efficiency and resource use efficiency through technological innovation, improving the energy structure, optimizing the industrial structure to reduce the carbon emission intensity of the sports industry and reducing greenhouse gas emissions under the condition that the development speed and quality of the sports industry remain unchanged or even improving. To reduce the carbon emission intensity of the sports industry, it is necessary to reduce both the total carbon emissions of the industry and the carbon emission intensity per unit of GDP of the industry [16]. The total carbon emissions of an industry are determined by the level of industrial development and unit carbon emission intensity. The higher the level of industrial development and economic growth is, the greater the relative energy consumption and CO_2 emissions [17]. Therefore, while ensuring the level of industrial development, it is necessary to continuously reduce the unit carbon emission intensity of the industry.

Impact of the DE on the Low-Carbon Development of the Sports Industry

To date, scholars have analyzed the relationship between the digital economy and the development of the sports industry. Pan et al. (2021) pointed out that the scale effect and long tail effect of the digital economy are conducive to the cross-border integrated and innovative development of the sports industry [14]. Shen et al. (2022) and Lin and Shen (2022) argued that the development of the digital economy has broken the mode of the traditional sports service industry and has improved the stability and competitiveness of the sports industry chain and supply chain [18, 19]. Krämer et al. (2018) took the high-quality development of the sports industry as a perspective, holding the view that the digital economy can promote the digital transformation of the sports industry by improving the efficiency of this industry, optimizing the allocation of resources, strengthening market supervision, and promoting the high-quality development of the sports industry [20].

Compared with traditional economic activities, the digital economy based on digital technology has a fast response to the market, a low marginal cost, less resource consumption and less environmental pollution. The digital economy has many advantages, such as innovation, greenness and sharing, which meet the requirements of the new development concept, can continuously improve output efficiency, and are conducive to the long-term sustainable development of the economy and society [21]. Digital technology enables the development of the sports industry, which promotes the upgrading of the sports industry structure, process optimization, supply and demand matching, and the integration of formats through the application of digital technology and reduces the carbon emission intensity per unit GDP of the sports industry while improving the efficiency of resource utilization to control and influence total carbon emissions in the linear growth process of the scale of the sports industry [22].

The literature review found that there have been few empirical analyses of the impact of the digital economy on the low-carbon development of the sports industry. Whether the digital economy can reduce carbon emissions and promote the low-carbon development of the sports industry remains to be further tested. Based on the analysis above, this paper analyzes the impact of the digital economy on the carbon emissions of the sports industry to demonstrate the impact of the digital economy on the green development of the sports industry.

Theoretical Analysis and Research Hypotheses

Direct Effect of the DE on the CESI

The digital economy reduces the carbon emissions of the sports industry (CESI) by exerting network effects, innovation effects and efficiency improvement effects. First, the digital economy promotes the integration and network coordination of all links of the industrial chain through network effects, realizes the dynamic matching of supply and demand, promotes the precise, intelligent, green and low-carbon development of the sports industry, and reduces the carbon emissions of this industry [21]. The digital economy can optimize the allocation of resources, thereby reducing energy consumption and achieving carbon emission reduction. The digital economy mainly realizes digital industrialization through the use of data elements, unblocks the orderly flow and transmission of information, and improves the efficiency of inter-industry resource allocation. At the same time, the digital economy can realize the digitalization and intelligence of the sports industry through the integration of data elements on data platforms [22]. Second, the digital economy drives the development and application of advanced technologies in related industries, improves the level of green, low-carbon and energy-saving technologies, and reduces carbon emissions in the sports industry. Digital technology can enhance knowledge accumulation, information integration and resource sharing, reduce the cost of knowledge search, storage, processing and transmission, lay the foundation for science and technology to reduce carbon emissions, use digital platforms and digital technologies to optimize the allocation of innovation resources, reduce the irrational behavior of technology research and development, predict innovation risks, reduce innovation costs, improve innovation speed and the research and development success rate, and promote technological progress. The carbon emission reduction of the sports industry is driven by technology linkage and technology spillover [23].

On this basis, Hypothesis H1 is proposed as follows: The digital economy has an active role in reducing the CESI.

Nonlinear Effect of the DE on the CESI

The digital economy is regarded as a revolutionary product of the continuous development of software and the internet in the era of information technology, and it follows the law of an increasing marginal effect of information and knowledge exchange and production. In the early stage of the development of the digital economy, the acquisition and feedback costs of information and knowledge are high, the diffusion ability of intelligent equipment is relatively weak, and the conceptual innovation of industrial intelligence is a new test for the comprehensive ability of enterprises [24, 25]. At this time, the impact of the digital economy on the CESI is weak and has not even begun to manifest itself. With the continuous development of the digital economy, the analysis and decision-making costs of intelligent production equipment and intelligent service facilities in the sports industry have gradually decreased, and the green contribution of intelligent systems has been continuously improved [26]. As a result, the digital economy has begun to have a positive impact on the CESI. When the development of the digital economy exceeds a certain scale, the information linkage with the sports industry chain will be closer, and the digital economy will become an important driving factor for enhancing the CESI.

On this basis, Hypothesis H2 is proposed as follows: The impact of the DE on reducing the CESI will be enhanced with the increase in the level of development of the digital economy, showing a nonlinear feature of an increasing marginal effect.

Spillover Effect of the DE on the CESI

Due to the platform-type and externality characteristics of the digital economy, it can produce spatial spillover effects on the carbon emissions of the sports industry in neighboring and related regions. First, the development of the digital economy has realized a digital trading platform, broken through regional restrictions, intensified intra-regional and inter-regional competition, promoted the coordination and development of the sports industry across time and space, and strengthened the spatial spillover effect of carbon emission reduction in the sports industry [27]. Second, the unique externalities of the digital economy promote the deep integration and development of the sports industry and its industrial chain across regions, fields and technologies so that the impact on the carbon emission reduction of the sports industry can be realized as a spatial spillover effect.

Therefore, Hypothesis H3 is proposed as follows: The development of the digital economy has a significant spatial spillover effect on the CESI in neighboring regions.

Materials and Methods

Variable Selection

Explained Variable

The explained variable of this study is the carbon emissions of the sports industry (CESI), which are measured based on the practice of Chai et al. [28]. First, the raw coal, gasoline, kerosene, diesel, fuel oil, natural gas, electricity, etc., consumed by the sports industry are included in the total energy consumption of the sports industry as standard coal. Second, the equivalent carbon dioxide emissions of the sports industry are calculated using the carbon emission formula as the carbon emission value of the industry.

$$CESI = \sum_{i=1}^{7} A_i B_i \tag{1}$$

Where in Formula (1), CESI represents the equivalent carbon dioxide emissions of the sports industry, i is the *ith* energy consumed by the sports industry ($1<i\leq7$), A_i represents the consumption of the *ith* energy of the sports industry, and B_i represents the carbon emission coefficient of the *ith* energy of the sports industry. According to the IPCC2006 National Greenhouse Gas Emission Inventory Guide, the carbon emission factors of raw coal, gasoline, kerosene, diesel, fuel oil, natural gas and electricity are 0.7559, 0.5538, 0.5741, 0.5821, 0.6185, 0.4483 and 2.2132 kg of carbon/kg of standard coal, respectively.

Explanatory Variable

The digital economy development level (DEL) is the explanatory variable in this study. The digital economy indicators in this paper refer to the practices of Pang et al. [29], and they are composed of digital infrastructure, digital industrialization, industrial digitalization and the digital environment. Digital infrastructure mainly includes hardware facilities, such as long-distance cables, mobile phone capacity, internet broadband access ports,

Table 2. Measurement index system for the DEL.

Types	Primary indicators	Secondary indicators
Digital infrastructure	Hardware facilities	Telecom mobile phone exchange capacity
		Length of long-distance cable lines per square kilometer
		Internet broadband access ports per square kilometer
	Network resources	Number of domains
		Number of IPv4 address
		Number of pages
		Internet broadband access users
Digital industrialization	Digital Financial Inclusion Index	Digital Financial Inclusion Index
	Enterprise e-commerce situation	E-commerce exchange activities for businesses
		Information-based enterprise
		E-commerce sales
		E-commerce purchases
	Digital application	Number of websites per 100 companies
		Number of computers per 100 people

Types	Primary indicators	Secondary indicators
Digital industrialization	Communication traffic	Total volume of telecommunication services
		Mobile phone call duration
		Mobile SMS traffic
	Communication service level	Telephone penetration rate
		Mobile phone penetration rate
	Software and information technology services	Software revenue
		Software product revenue
		Information service revenue
Digital environment	Intellectual support	R&D personnel full-time equivalent
		Number of master's students
		Number of students enrolled in ordinary institutions of higher education
		Number of doctoral students
	Research input	Internal expenditure of national R&D funds
		Internal R&D applied research expenditure

internet communication base stations, smart sensors, and network resources, such as domain names, web pages, and internet users [29]. Digital industrialization refers to the value added mode of information products. That is, the information industry, which includes basic telecommunications, software services and the internet, organizes and analyzes the data contained in it to form physical products, which are used by enterprises or sold to the market. Industrial digitalization refers to the process of applying information systems to traditional industries and collecting and organizing large amounts of data resources through information systems to enhance the digitalization, networking and intelligence of industrial development and to increase industrial output and improve efficiency. The digital environment includes both human capital and financial input for the development of the digital economy. All indicators are shown in Table 2.

There are many multi-criteria decision-making (MCDM) methods, of which the technique for order preference by similarity to an ideal solution (TOPSIS) method is effective at ranking and selecting a number of possible alternatives. For MCDM, the weight of the index is crucial for measuring the importance of the index. In this paper, the entropy weight is defined and constructed based on the information entropy and data. Therefore, the TOPSIS method with the EW is used to determine the DEL.

(1) Standardize the evaluation matrix:

If the evaluation index is positive:

$$y_{ij} = \frac{x_{ij} - \min x_j}{\max x_j - \min x_j} \tag{2}$$

If the evaluation index is negative:

$$y_{ij} = \frac{x_{\max} - x_j}{\max x_j - \min x_j} \tag{3}$$

(2) Calculate the information entropy:

$$H_j = -k\sum_{i=1}^{m} p_{ij} Inp_{ij} \text{ (Where } p_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}, k = \frac{1}{Inm} \tag{4}$$

Define the weight of the *jth* indicator as:

$$W_j = \frac{1-H_j}{\sum_{j=1}^{n}(1-H_j)} \text{ (Where } W_j \in [0,1] \text{, and } \sum_{j=1}^{n} W_j = 1 \tag{5}$$

(3) Construct the weight normalization matrix:

$$R=(r_{ij})_{m\times n},\ r_{ij}= W_j \cdot y_{ij}\ (i = 1, 2, \ldots, n; j =1, 2, \ldots, m) \tag{6}$$

(4) Determine the positive and negative ideal solutions S_J^+ and S_J^-, respectively:

$$S_J^+ = \max(r_{1j}, r_{2j}, \cdots, r_{nj}) \tag{7}$$

$$S_J^- = \min(r_{1j}, r_{2j}, \cdots, r_{nj}) \tag{8}$$

(5) Calculate the Euclidean distance between each scheme:

$$d_i^+ = \sqrt{\sum_{j=1}^{n}(S_i^+ - r_{ij})^2} \tag{9}$$

$$d_i^- = \sqrt{\sum_{j=1}^{n}(S_i^- - r_{ij})^2} \tag{10}$$

(6) Calculate the degree of closeness to the comprehensive level of the digital economy DEL_i:

$$DEL_i = d_i^- \big/ (d_i^- + d_i^+) \tag{11}$$

In the formula above, $DEL_i \in$ (0,1). The closer the value of DEL_i is to 1, the better the evaluation object is, that is, the higher the level of evaluation object is, and vice versa.

Control Variables

To accurately measure the effect of the development of the digital economy on the green development of the sports industry and to minimize the errors caused by interference from other factors, the following control variables are selected: population density (*Ped*) is represented by population per unit area. The higher the population density of an area is, the more intensive the economic activities, and the greater the consumption of resources, thereby increasing carbon emissions. At the same time, places with a high population density have more complete public facilities and effectively reduce carbon emissions. (2) The industrial structure (*Str*) is measured by the proportion of the output value of the tertiary industry in the total output value. Industrial structure upgrading affects carbon emissions through the scale effect, structural effect and technology effect. Xi et al (2023) noted that optimizing the primary and secondary industries and vigorously developing the tertiary industry are the only way for China to develop a low-carbon economy [30]. (3) Technological innovation (*Tec*) is represented by per capita financial expenditure on science and technology. Improving the level of technological innovation is conducive to improving energy efficiency, which leads to a reduction in carbon emissions. Wang et al (2020) found that an improvement in the technological level can reduce the cost of carbon emission reduction through the learning effect [31]. (4) Environmental regulation (*Env*) is measured by the ratio of total investment in pollution control to GDP. Zhang (2022) pointed out that with the increasingly significant policy effects of environmental regulation; environmental regulation is conducive to curbing the emission of pollutants. (5) Foreign direct investment (*Fdi*) is measured by the indicator of FDI actually utilized in the provincial statistical yearbook. Since the FDI data obtained are all in USD 10,000, this paper uses the average annual price of the RMB exchange rate to convert the USD data into RMB and then calculates this index.

Model Elaboration

Fixed Effect Model

Unobserved factors in a model may cause omitted variable bias, which can be effectively addressed by using a fixed effect model. Therefore, we use a two-way fixed effect panel model to test the linear relationship between the *DEL* and the *CESI*. The model is set as Formula (12):

$$CESI_{it} = \alpha_0 + \beta_1 DEL_{it} + \sum_{k=1}^{n} \lambda_k Col_{it,k} + \mu_i + \upsilon_t + \xi_{it} \tag{12}$$

In the formula above, the explained variable is $CESI_{it}$, the explanatory variable is DEL_{it}, and $Col_{it,k}$ is the set of control variables. Subscripts *i* and *t* represent the province and the year, respectively, and μ_i is the individual fixed effect. ξ_{it} represents the random error term, which is subject to a normal distribution.

The Panel Threshold Model

The influence of the *DEL* on the *CESI* may be enhanced with an improvement in the *DEL*. Therefore, the influence of the digital economy on the *CESI* may have a nonlinear relationship; thus, we take the *DEL* as the threshold variable to test the nonlinear relationship. The dynamic panel threshold regression model is finally established as follows (Formula (13)):

$$CESI_{it} = \alpha_0 + \beta_{11}DEL_{it}I(DEL_{it} \le \theta_1) + \beta_{12}DEL_{it}I(\theta_1 < DEL_{it} \le \theta_2)$$
$$+ \cdots + \beta_{1,n}DEL_{it}I(\theta_{n-1} < DEL_{it} \le \theta_n) + \beta_{1,n+1}DEL_{it}I(DEL_{it} > \theta_n) +$$
$$\sum_{k=1}^{n} \lambda_k Col_{it,k} + \mu_i + \xi_{it} \tag{13}$$

In the formula above, the explained variable is $CESI_{it}$, the explanatory variable is DEL_{it}, and $Col_{it,k}$ is the set of control variables. I(•) is the indicative function. θ_1, θ_2,…, and θ_n are threshold values, and there are n+1 threshold intervals. β_{11}, β_{12},…, and $\beta_{1,n}$ are regression coefficients under different threshold intervals.

The Spatial Durbin Model

Spatial econometric models mainly include the spatial lag model (SLM) and the spatial error model (SEM). If both the explained variable and the explanatory variable are spatially dependent, the spatial Durbin model (SDM) is used [32]. In view of the spatial dependence of the explained variable (*CESI*) and explanatory variable (*DEL*), the spatial Durbin model is constructed in this study as follows (Formula (14)):

$$CESI_{it} = \alpha_0 + \rho\sum_{j=1}^{n} W_{ij}CESI_{jt} + \beta X_{it} + \theta\sum_{j=1}^{n} W_{ij}X_{jt}$$
$$+ \phi Col_{it} + \varphi\sum_{j=1}^{n} W_{ij}Col_{jt} + \upsilon_t + \varepsilon_{it} \tag{14}$$

In the formula above, the explained variable is $CESI_{it}$, the explanatory variable is DEL_{it}, and $Col_{it,k}$ is the set of control variables. Where ρ is the spatial correlation coefficient and W_{ij} is the spatial weight matrix. β, θ, ϕ, and φ are the parameters to be estimated, u_i is the spatial fixed effect, v_t is the time fixed effect, and ε_{it} is the spatial error term.

Regarding the spatial weight matrix, there are two types: (1) The first is the geographical distance spatial weight matrix (*W1*). It is usually calculated by the reciprocal of the square of the actual geographical distance between two regions, that is, $W_{ij} = 1d_j^2/(i \neq j)$. d_{ij} is represented by the direct distance between two provincial capitals. *W1* is selected as the benchmark spatial weight matrix. (2) The second is the economic geographic nested spatial weight matrix (*W2*). It is calculated by the following formula: $W_{ij} = 1d_j^2/|\bar{Y}_i - \bar{Y}_j + 1|\, e^{-d_{ij}}$, $(i \neq j)$. $\bar{Y}_i$ and $\bar{Y}_j$ represent the per capita GDP of the *ith* and *jth* provinces, respectively. d_{ij} is also represented by the direct distance between two provincial capitals. *W2* is used for model robustness testing.

Data Sources and Descriptive Statistics

The empirical analysis is based on 2010-2021 panel data covering 30 provinces in China. Hong Kong, Macao, Taiwan and the Tibet Autonomous Region are excluded because data on these areas are missing. The data on the energy consumption of the sports industry mainly come from the China Industrial Statistics Yearbook, the China Energy Statistics Yearbook, provincial statistical yearbooks, and the official websites of the provincial sports bureaus. The indicators of the digital economy are mainly derived from the EPS database, the China Statistical Yearbook, the China Economic and Social Big Data Research Platform and the Peking University Digital Financial Inclusion Index. Some missing data were filled in through interpolation. All data measured in monetary units are deflated using 2010 as the base, and quantitative analysis and model estimation are performed using SPSS and R language software. To eliminate data heteroscedasticity and make the data more stable during the empirical analysis, the natural logarithmic form was taken for all variables. The descriptive statistical results of the variables are shown in Table 3.

Results and Discussion

Results and Analysis of the Fixed Effect Model

Results of the Whole Study Area

The estimation results of the impact of digital economy development on the CESI are shown in Table 4. In Model (1), there are no control variables added, and in Models (2)-(6), the control variables are added

Table 3. Descriptive statistics of the variables in the specified model.

Variables	Observations	Mean	Std. Dev.	Min	Max
InCESI	360	2.856	0.738	0.765	4.552
InDEL	360	-0.320	-2.551	-1.158	-0.082
InEnv	360	0.996	0.521	0.664	5.113
InPed	360	5.452	1.274	2.032	8.123
InTec	360	10.318	1.537	6.213	13.583
InStr	360	3.776	0.194	3.353	4.394
InFdi	360	14.726	1.546	6.821	16.876

Table 4. Benchmark regression results of the effect of the DEL on the CESI.

Variables	*CESI*					
	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
InDEL	-0.198** (-2.579)	-0.271** (-2.760)	-0.252** (-3.111)	-0.243** (-2.564)	-0.221** (-2.875)	-0.217** (-3.116)
InPed		0.063* (-2.110)	-0.051 (-1.760)	-0.043 (-1.132)	-0.040 (-1.070)	-0.033 (-1.125)
InStr			-0.216*** (-2.998)	-0.198*** (-3.245)	-0.184*** (-2.754)	-0.157*** (-3.276)
InFdi				-0.167** (-2.811)	-0.129** (-2.961)	-0.113* (-2.060)
InTec					-0.161** (-2.920)	-0.153** (-2.605)
InEnv						-0.206*** (-3.604)
N	360	360	360	360	360	360
Constant	-0.008 (-0.579)	-0.073** (-2.613)	-0.651 (-0.111)	-0.240** (-2.564)	-0.826** (-2.875)	-0.135* (-2.116)
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Province fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.655	0.659	0.664	0.674	0.679	0.684

Note: ** and *** represent significance at the 5% and 1% levels, respectively, with t values shown in brackets.

successively. When no control variables are added, the estimated coefficient of the *DEL* as the core explanatory variable is 0.308 and is significant at the 5% level. After the control variables are added to Models (2)-(6), the regression parameters of the effect of digital economy development on the *CESI* are all approximately -0.2 and are significant at the 5% level. These results indicate that digital economy development had a significant inhibitory effect on the carbon emissions of the sports industry during the study period, verifying Hypothesis H1.

In Model (6) with all control variables included, the estimated coefficient of the effect of *Ped* on *CESI* is negative but not significant, indicating that increasing population density does not significantly reduce carbon emissions. The estimated coefficient of the effect of *Str* on *CESI* is significantly negative. That is, the current industrial structure has a significant inhibitory effect on the *CESI*. Industrial structure upgrading affects carbon emissions through the scale effect, structural effect and technology effect. At the same time, the estimated coefficient of the effect of *Fdi* on *CESI* is significantly negative. This result indicates that the introduction of foreign investment can promote the innovation of the production technology of enterprises and improve the level of green development of the sports industry to a certain extent. The regression coefficients of the effect of *Tec* and *Env* on the *CESI* are negative and significant at the 5% and 1% levels, respectively. It can be seen that technological innovation can improve resource utilization efficiency, reduce carbon emissions, and enhance the green development level of the sports industry. Increased environmental regulations have also forced companies to reduce pollutant emissions and improve the cleanliness of the production process in the sports industry.

Results of Different Areas

In reality, there are differences in the resource endowment and industrial development mode among different regions, which may affect the effect of the digital economy on the carbon emissions of the sports industry. In view of the large differences in different regions of China, the whole research region is divided into four regions, namely, the eastern, central, western and northeastern regions, for analysis to test the heterogeneity of different regions[1]. The regression coefficients of *DEL* in the eastern, central and western regions are significantly negative, indicating that the DEL in these regions has an inhibitory effect on the *CESI*. However, this effect is not significant in the northeast region (Table 5). In terms of the four regions,

[1] The eastern region includes Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan. The central region includes Shanxi, Anhui, Jiangxi, Henan, Hubei and Hunan. The western region includes Chongqing, Sichuan, Guizhou, Guangxi, Yunnan, Shaanxi, Inner Mongolia, Gansu, Ningxia, Qinghai and Xinjiang. Northeast China includes Heilongjiang, Jilin and Liaoning.

Table 5. Estimation results of different areas.

Variables	Eastern region	Central region	Western region	Northeast region
InDEL	-0.342**(-3.181)	-0.214**(-2.732)	-0.169*(-2.116)	-0.084(-1.176)
InPed	-0.095(-1.321)	-0.061(-1.253)	-0.055(-0.986)	-0.157*(-2.232)
InStr	-0.248**(-3.145)	-0.181**(-1.256)	-0.122**(-1.643)	-0.043(-1.094)
InFdi	-0.151**(-3.214)	-0.117**(-2.981)	-0.101**(-2.763)	-0.094*(-1.965)
InTec	-0.287**(-2.802)	-0.154**(-2.917)	-0.102*(-2.105)	-0.091*(-2.114)
InEnv	-0.251***(-3.885)	-0.224***(-3.987)	-0.171***(-3.611)	-0.186***(-3.864)
N	120	72	132	36
Constant term	-0.016(-0.653)	-0.093*(-2.123)	-0.435(-0.654)	-0.513(-1.543)
Adj. R^2	0.711	0.702	0.676	0.597

Note: ** and *** represent significance at the 5% and 1% levels, respectively, with t values shown in brackets.

the eastern region has the most prominent effect of the digital economy on reducing the *CESI*. For the eastern region, the development level of the digital economy is relatively high, and the inhibitory effect of digital technology innovation on the carbon emissions of the sports industry has been effectively released.

Results and Analysis of the Panel Threshold Model

To accurately describe the impact of the development of the *DE* on the *CESI*, *CESI* is taken as the dependent variable, and *DEL* is taken as the independent variable for threshold regression. Before threshold estimation, it is necessary to test whether a threshold effect exists and to select single, double and triple threshold hypotheses to estimate Formula (13). As seen from the estimation results in Table 6, the F test statistics of the single threshold and double threshold are 38.213 and 18.054, respectively, and both are significant at the 1% level. However, the triple threshold is not significant. Thus, there is a double threshold effect. The impact of digital economy development on the CESI has a threshold effect; that is, there is a nonlinear influence relationship.

The threshold estimation results of the effect of the *DEL* on the *CESI* are shown in Table 7. According to the estimation results, when *DEL* is less than 0.737 (In*DEL* = -0.305), the coefficient of the effect of digital economy development on the *CESI* is positive but not significant. When the digital economy development index crosses 0.737 and is between 0.737 and 0.794 (In*DEL* = -0.243), the estimated coefficient of the effect of digital economy development on the CESI is 0.269 and significant at the 10% level. When the digital economy development index exceeds 0.794, the regression coefficient of the effect of digital economy development on the *CESI* is 0.315 and is significant at the 5% level. It can be seen that an improvement in *DEL*

Table 6. Test results of the threshold effect.

Threshold variable	Model test	Threshold estimate	F statistic	P value	Critical values		
					1%	5%	10%
DEL	Single threshold	0.737	38.213***	0.000	24.093	12.865	9.432
	Double threshold	Threshold 1: 0.737 Threshold 2: 0.794	18.054***	0.002	11.977	6.897	3.611
	Triple threshold	0.488	8.221	0.170	7.905	5.558	3.021

Table 7. Estimation results of the threshold effect.

Threshold variable	Threshold and interval	Coefficient	T Value	Standard error
DEL	*DEL*≤0.737	0.074	1.021	0.023
	0.737<*DEL*≤0.794	0.269**	2.927	0.003
	DEL>0.794	0.315***	4.194	0.001

has a greater effect on the improvement in *CESI*. That is, the impact of the development of the digital economy on the *CESI* shows an increasing trend with the increase in the level of development of the digital economy, which shows that the development of the digital economy has a nonlinear impact on the *CESI*. Thus, Hypothesis H2 is verified.

Results and Analysis of the Spatial Durbin Model

Spatial Autocorrelation Test

Before estimating the spatial effect, it is necessary to conduct a spatial autocorrelation test on the carbon emissions of the sports industry and the development level of the digital economy. Methodologically, Moran's I is used to calculate the spatial correlation based on the geographical distance spatial weight matrix (W1), and the results are shown in Table 8. Table 8 shows that the global Moran's I values of *DEL* and *CESI* over the years are positive and are all significant. These results indicate that *DEL* and *CESI* have significant spatial correlation. From the perspective of the time dimension, the mean values of the global Moran's I values of *DEL* and *CESI* basically increased year by year. It can be concluded that the spatial agglomeration trends of *DEL* and *CESI* are constantly strengthening.

Identification of Spatial Estimation Models

From the spatial autocorrelation test above, it can be seen that both the *DEL* and the *CESI* have strong spatial correlation characteristics. Therefore, spatial factors should be considered when studying the relationship between them [33]. First, we determine whether the spatial panel model is suitable. The LM-lag, robust LM-lag, LM-error and robust LM-error test statistics are all significant, indicating that the null hypothesis that the SPM or the SEM does not exist can be rejected. That is, the spatial panel model is applicable. The Wald and LR statistics are then combined to determine which spatial model is more appropriate. Using the SDM as the matrix for estimation, both the Wald and LR statistics are significant, indicating that the SDM is more suitable for data fitting. Two kinds of spatial weight matrices are used in each test, and the results are shown in Table 9. In the spatial Durbin model, the Hausman test rejects the null hypothesis (P<0.01); thus, the fixed effect model is more suitable. At the same time, to avoid the influence of unobserved time-varying factors on the estimation results, the two-way fixed effect spatial Durbin model is selected for empirical analysis.

Table 9. Test results of the spatial models.

Types of test	W1	W2
LM-lag test	62.653^{***}	59.454^{***}
Robust LM-lag test	38.323^{***}	25.872^{***}
LM-error test	53.241^{***}	25.543^{***}
Robust LM-error test	67.764^{***}	45.554^{***}
Wald-spatial lag test	121.987^{***}	33.127^{***}
LR-spatial lag test	91.543^{***}	71.974^{***}
Wald-spatial error test	76.651^{***}	46.871^{***}
LR-spatial error test	56.753^{***}	41.653^{***}
Hausman test	61.432^{***}	41.391^{***}

Results of the Spatial Durbin Model

To compare the robustness of the estimation results, Table 10 reports the spatial estimation results of the effect of the *DEL* on the *CESI* under different matrices. At the same time, based on LeSage and Pace [34], the model estimation results are decomposed to investigate whether there is a spatial spillover effect of digital economy development on the *CESI*. According to the estimation results in Table 10, the spatial autoregressive coefficient of *CESI* is positive and significant at the 1% level, indicating that the homogeneous spillover effect of the *CESI* is relatively significant.

From the perspective of spatial effect decomposition, both the direct effect and indirect effect estimation

Table 8. Global Moran's I values of *DEL* and *CESI* from 2010 to 2021.

Global Moran's I values of *DEL*						Global Moran's I values of *CESI*					
Year	Moran's I	P value	Year	Moran's I	P value	Year	Moran's I	P value	Year	Moran's I	P value
2010	0.225^{**}	0.041	2016	0.261^{**}	0.022	2010	0.321^{*}	0.078	2016	0.383^{**}	0.075
2011	0.234^{***}	0.002	2017	0.275^{**}	0.034	2011	0.336^{*}	0.019	2017	0.401^{**}	0.083
2012	0.243^{**}	0.085	2018	0.275^{***}	0.008	2012	0.338^{*}	0.096	2018	0.415^{**}	0.064
2013	0.247^{**}	0.097	2019	0.269^{***}	0.003	2013	0.345^{**}	0.045	2019	0.411^{**}	0.019
2014	0.252^{**}	0.039	2020	0.274^{***}	0.004	2014	0.363^{**}	0.021	2020	0.425^{***}	0.004
2015	0.259^{***}	0.002	2021	0.287^{***}	0.008	2015	0.371^{**}	0.044	2021	0.437^{***}	0.001

Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 10. Estimation results of the spatial Durbin model.

Variables	W1				W2			
	Elasticity coefficient	Direct effect	Indirect effect	Total effect	Elasticity coefficient	Direct effect	Indirect effect	Total effect
In*DEL*	-0.208* (-2.215)	-0.352** (-3.222)	-0.719* (-2.443)	-1.071* (-2.154)	-0.234** (-3.135)	-0.371** (-2.871)	-0.868** (-2.927)	-1.239** (-2.713)
W×In*DEL*	-0.426** (-2.285)				-1.321** (-2.945)			
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ρ	0.485*** (4.261)				0.382*** (3.634)			
Log-Likelihood	143.156				124.654			

Note: ** and *** represent significance at the 5% and 1% level, respectively, with t values shown in brackets.

parameters of the effect of digital economy development on the *CESI* are significantly negative. These results indicate that digital economy development not only contributes to promoting the *CESI* in a local region but also inhabits the *CESI* in neighboring regions. That is, digital economy development has a significant spatial spillover effect on the *CESI* in its neighboring regions; thus, Hypothesis H3 is verified.

Conclusion and Policy Implications

Based on 2010-2021 panel data covering 30 provinces in China, this paper uses a fixed effect model, threshold effect model and spatial Durbin model to empirically test the impact of the digital economy on carbon emissions in the sports industry. Finally, the following conclusions are drawn: (1) The development of the digital economy can effectively restrain the carbon emissions of the sports industry, thus promoting the green development of the sports industry. (2) The inhibitory effect of the development of the digital economy on the carbon emissions of the sports industry presents a nonlinear feature of an increasing marginal effect. That is, as the development level of the digital economy improves, it has a greater impact on the carbon emissions of the sports industry. (3) The development of the digital economy has a significant spatial spillover effect on the carbon emissions of the sports industry in surrounding regions. In other words, the development of the digital economy not only inhibits the carbon emissions of the sports industry in a region but also inhibits the carbon emissions of the sports industry in surrounding areas, which is conducive to the formation of a pattern of coordinated regional development. (4) From the perspective of regional heterogeneity, the development dividend of the digital economy in the developed eastern region of China is greater than that in the less developed central and western regions, having a more significant impact on the carbon emission reduction and green development of the sports industry.

Based on the conclusions above, the following policy implications are obtained:

(1) The government should accelerate the construction of digital infrastructure and further give full play to the role of the digital economy in the low-carbon development of the sports industry. And the government should continue to promote the construction of digital infrastructure such as 5G communications, the Internet of Things, and big data centers. At the same time, it is necessary to comprehensively improve the efficiency of resource utilization, promote the comprehensive development of green industry and green supply chains, achieve efficient output and intensive use of resources, and further give full play to the positive role of the digital economy in the green and low-carbon development of the sports industry.

(2) The government will issue guidelines on the low-carbon development of the sports industry. It should guide the newly joined sports industry to combine digital technology with energy-saving and emission reduction equipment, sustainable energy, and carbon emission management in the planning and design link. The government should require intelligent manufacturing and green energy use in sports manufacturing parks and new plants and encourage sports manufacturing enterprises to use the roof of the plant to establish distributed solar and wind energy devices to meet their own energy needs through the digital development and management of renewable energy. At the same time, it is necessary to encourage large sports events to use digital technology to carry out carbon emission inventories of events and actively achieve carbon neutrality of events.

(3) In view of the spillover effect of the digital economy on the carbon emission reduction of the sports industry, the government should promote the construction of the integrated layout of digital infrastructure and give full play to the radiating role of the digital economy. It is necessary to build an integrated digital infrastructure layout by increasing the coordination of new infrastructure construction in various regions [31]. At the same time, it need

to promote the cross-regional division of labor and cooperation, improve the breadth and depth of the integration of information technology and the real industry, and fully release its spatial contribution to the green transformation of the industry.

(4) Considering that the positive effect of the development of the digital economy on the low-carbon development of the sports industry in less developed areas needs to be further strengthened, the construction of digital infrastructure in less developed areas should be accelerated. Relying on our own competitive industries, we will deepen the construction of digital infrastructure and build a digital industrial chain with regional characteristics [35]. For example, important ecological barrier areas should actively promote industrial digitalization, cultivate and expand energy-saving and environmental protection industries, and build a green and circular industrial system. Energy-and chemical-intensive areas should strengthen the application of digital technology and promote the transformation of industrial production modes.

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Data Availability Statement

The data presented in this study are available upon request from the corresponding author.

Conflicts of Interest

The authors declare no conflict of interest.

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