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Spatial differences in the influence of science popularization resources development on the energy consumption carbon footprint in provincial regions of China

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Abstract

Background: Science popularization resources development is an important means to improve public scientific literacy and has a crucial influence on the formation of public consumption habits, patterns and concepts, and ultimately on the energy consumption carbon footprint.

Methods: Based on panel data from the provincial regions in China from 2010 to 2014, this paper measures the energy consumption carbon footprint in provincial regions using Intergovernmental Panel on Climate Change (IPCC) methods and builds a geographically weighted regression (GWR) model to evaluate the levels of science popularization resources development in provincial regions by using the global entropy method. Then, the mechanisms of influence on the energy consumption carbon footprint and the levels of science popularization resources development in the provincial regions of China are analyzed and measured.

Results: The results showed that science popularization resources development could significantly lower the energy consumption carbon footprint; from 2010 to 2014, the lowering effect of science popularization resources development on the energy consumption carbon footprint in the major east, middle, and west provincial regions showed a weakening trend, with a greater lowering amplitude in the east than in the middle and west regions and narrowing spatial differences among them; at present, this influence works best in the west region followed by the middle and east regions.

Conclusions: The results imply that we should give full attention to science popularization resources development to lower the energy consumption carbon footprint in China. In addition, focus should be given to the west region of China and construction mechanisms for science popularization resources that are built with flexible adoptions of means such as a combination of government guidance and market mechanisms, as well as joint construction by government and society.

Keywords: Science popularization resources development, Energy consumption carbon footprint, Spatial difference

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Background

In recent years, the effect of climate change caused by emissions of greenhouse gases such as CO_2 has become more prominent and has attracted wide attention from the international community. Currently, carbon emissions are no longer limited to production links, but instead, they have extended into the entire consumption system. The concept of energy consumption carbon footprint was derived from the term "ecological footprint" [1]. The concept reveals the influence of human life in terminal consumption areas on climate change and is an important symbol of green development studies shifting from the level of production to consumption. Additionally, energy consumption carbon footprint can effectively measure environmental pollution caused by excessive emissions of greenhouse gases and objectively reflect the environmental pressure changes in certain regions caused by carbon emissions.

Needless to say, the level of scientific literacy of the public will influence their consumption habits and patterns and ultimately their energy consumption carbon footprints. Science popularization refers to the activities of popularizing knowledge of natural and social sciences, spreading scientific thoughts, promoting scientific spirit, advocating for scientific methods, and widening the application of scientific technologies in a way easy for the public to understand, accept, and participate [2]. Generally, science popularization resources include a resource system consisting of essential elements and their combinations for various science popularization practices, including science popularization input and output systems. The input system consists of resources related to science popularization abilities such as human, finance, and site resources, while the output system consists of science popularization event resources and media resources produced from creating and managing the above input system. The former serves as the foundation for science popularization outputs, while the latter serves as the concrete content of science popularization outputs, jointly forming the complete science popularization resource system. Science popularization resources development undoubtedly serves as an important means for improving the scientific literacy and environmental protection awareness of the public [3]. Moreover, science popularization resources development could help cultivate public green consumption views, promote and deepen the carbon emission reductions of various enterprises, and enhance and promote green development outlooks at all levels of government. In addition, the development of these resources is conducive to practicing low-carbon consumption and development strategies featuring policy guidance, corporate dominance and public participation [4–6], and ultimately effectively lowering the energy consumption carbon footprint [7–10]. The relevant influence mechanisms are shown in Fig. 1.

As for the subject of ecological protection, human beings play a decisive role in the construction of ecological systems. Therefore, the fundamental motive for promoting carbon reduction and environmental protection work lies in effectively uplifting the environmental protection awareness of the public [11]. Science popularization resources development undoubtedly serves as an important means for improving the scientific literacy and environmental protection awareness of the public [3]. Science popularization event resources can be constructed by holding various science popularization events for environmental protection (such as science popularization exhibitions, competitions, and lectures on promoting ecological civilization and green consumption), where there is a wide public participation and environmental protection is also promoted to the public. Science popularization media resources can be created by providing vivid green consumption services with image-text and sound-image combinations with carriers such as books, magazines, radio, TV, and websites. The construction of science popularization input resources, such as human, finance, and site resources, can provide a foundation and guarantee the output of resource elements such as events and media and deeply root the green consumption view into the daily life and behaviors of the public.

Enterprises are the subject of energy consumption, so a shift of the corporate consumption view is crucial to reducing carbon emissions. Low-carbon developments are the only way to upgrade and transition Chinese enterprises. In addition, science popularization resources can help and enhance the awareness of corporate ecological protection concepts and push enterprises to promote carbon emission-reduction work. Science popularization resources development can help promote enterprises to carry out energy-saving and emission-reduction technological developments. Enterprises could uplift the productivity of low-carbon products by improving production technologies and enhancing the R&D and application of low-carbon technologies to meet low-carbon consumption demands [12]. In addition, the development of popular science resources can help shift the corporate development goal from purely pursuing economic benefits to giving equal consideration to social responsibility. The flexible popularization of scientific knowledge, method, spirit, and environmental protection concepts with carriers such as holding science popularization themed events, exhibitions, and bulletin boards can help enterprises shoulder social responsibility when creating profit and ultimately win social respect through contributing to society with reduced carbon emissions.

As the formulator and regulator of energy production and consumption policies, the government plays an irreplaceable role in energy production and consumption.

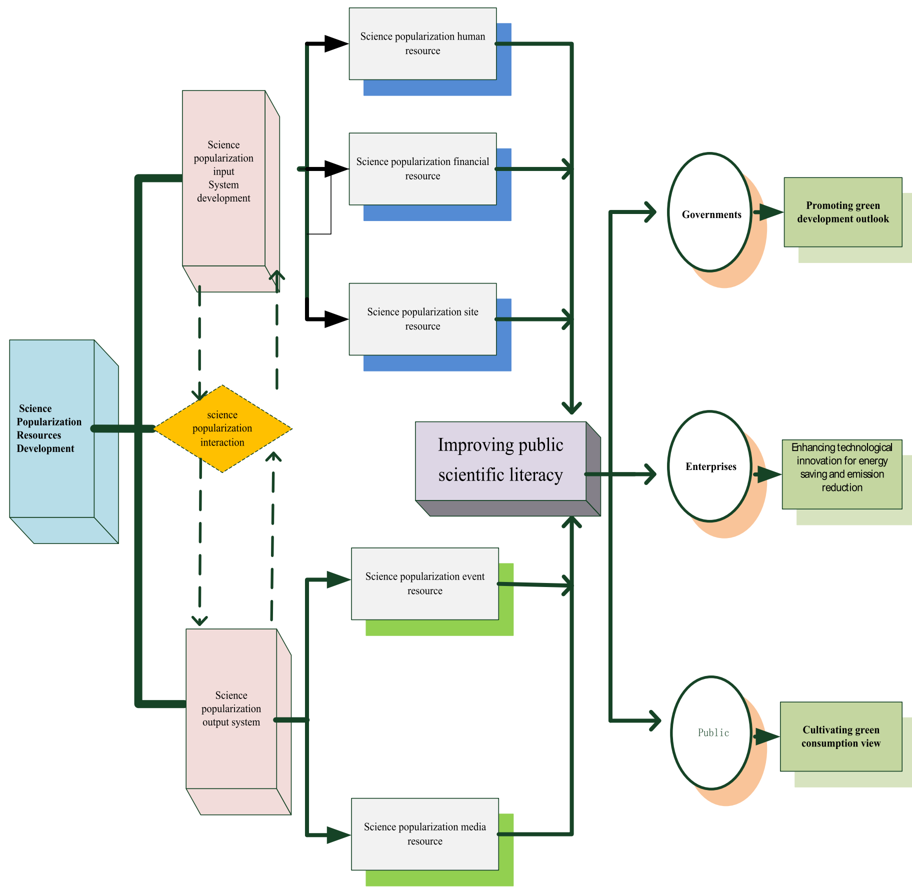

Fig. 1 Mechanisms of the influence of science popularization resources development on energy consumption carbon footprint

The multi-functionality and high penetration of science popularization resources development will undoubtedly help form low-carbon consumption and development concepts in governments and ultimately enhance and promote the green development outlook. Green low-carbon consumption serves as the core of sustainable living while stimulating green consumption in families with economic means turns out to be the precondition of green low-carbon consumption [13]. First, science popularization resources development can help governments regulate consumption behaviors of residents and lower energy consumption intensity with economic means such as adjusting resource tax rates and levying methods as well as providing financial subsidies. In addition, science popularization resources development can help governments reform the outlook of economic development and form a scientific performance concept by shifting from pursuing quantity and scale to uplifting quality and efficiency as well as including indexes reflecting environmental resources, such as unit GDP occupancy of resources and energy consumption, into political performance evaluations. Moreover, science popularization resources development is conducive for governments to scientifically guide the optimization and adjustment of industrial structure and population structure, lowering the proportion of high energy consumption industries and optimizing energy production and consumption layout. Finally, science popularization resources development can act in favor of governments enhancing the construction of ecological civilization systems and guiding entire societies to practice low-carbon, energy-saving, and environmentally friendly living styles.

Since the implementation of the Outline of the Action Plan for the Nation's Science Literacy, the process of Chinese regional science popularization resources has constantly been deepened, and the forms and means for the public-targeted popularization of scientific technologies have been increasingly enriched, hence positively uplifting the scientific literacy of the public. Most scholars at home and abroad have discussed the influence on the regional energy consumption carbon footprint from the angles of economic development, population growth [14, 15], and energy consumption [16, 17], and there is no literature has included science popularization resources development in the scope of research. Whether in terms of the influence mechanism or empirical analysis, there are no arguments supporting whether the influence exists or not, or what the intensity of the influence is if it exists, i.e., whether science popularization resources development can lower the energy consumption carbon footprint or not. If it exists, are there any differences among regions?

To this end, considering that there can be differences in the influence of science popularization resources development on the energy consumption carbon footprint among different provincial regions, this paper is based on dynamic comprehensive measurements of the levels of energy consumption carbon footprint and science popularization resources development in provincial regions and attempts to use the panel data of provincial regions from 2010 to 2014 and then adopt a GWR (geographically weighted regression) model that could effectively reflect the interregional differences of regression coefficients to reach the goal of analysis [18]. Through empirical analysis, the following questions will be answered: (1) Can regional science popularization resources development effectively lower the energy consumption carbon footprint? (2) If it can, are there any spatial differences among the different Chinese provincial regions in terms of intensity? The remainder of the paper is arranged as follows: section 1 analyzes the mechanisms of the influence of science popularization resources development on the energy consumption carbon footprint; section 2 empirically explores the influence of science popularization resources development on the energy consumption carbon footprint; section 3 presents the provincial comparison based on the results of the above empirical analysis; and section 4 presents the main conclusions of this paper.

In terms of research content, the current literature has mostly studied the factors that influence the energy consumption carbon footprint based on economic indicators such as GDP and population. However, few articles have studied the impacts of science popularization resources development on the spatial differences in the energy consumption carbon footprint from the perspective of consumers; in terms of research methods, the literature often uses constant coefficient measurement models to analyze the impacts of economic indicators on carbon footprint. However, there is little research that uses variable coefficient measurement models to study the impacts of provincial science popularization on the energy consumption carbon footprint. This undoubtedly indicates a new direction for the research of this article, which also indicates the innovation and originality of this article.

Methods

Empirical model

Considering that there can be differences in the influence of science popularization resources development on the energy consumption carbon footprint among different provincial regions, this paper adopts a GWR model for analysis that can effectively reflect interregional differences of regression coefficients [19, 20]. A GWR model fully considers the spatial non-stationarity of regression coefficients, as shown in Formula (1):

$$y_i = \alpha_{i0}(u_i, v_i) + \sum_{k=1}^{p} \alpha_{ik}(u_i, v_i) X_{ik} + \varepsilon_i \quad \mathrm{i} = 1, 2, \cdots, n \tag{1}$$

where y is the explained variable, which is the linear combination of explaining variables x_k ($k = 1,2,\ldots,$p) and $i = 1,2,\ldots,$ n is the number of observed values. ε_i is the stochastic error term that satisfies the features of a normal distribution. In the model, the estimated parameters are the functions of the spatial position i, which changes with the change in spatial position. (u_i, v_i) are the spatial position coordinates of the sample i, and $\alpha_{ik}(u_i, v_i)$ is the value of the coefficient of independent variable x_k at the point of i. In model (1), the regression coefficient of the region i is the variate $\alpha_{ik}(u_i, v_i)$ obtained through local regression estimation of a data subsample of approximate observed values. The weighted least squares method is used for estimation of Formula (2):

$$\alpha^*(u_i, v_i) = \left(X^T W(u_i, v_i) X\right)^{-1} X^T W(u_i, v_i) Y \tag{2}$$

where W is the spatial weight matrix of $n \times n$, in which all non-diagonal elements are 0, and all diagonal elements are the distance functions between the observed value at location j and point i that are used to measure the influence of the spatial locations of observed values of j ($j = 1,2,\ldots,n$) on the parameter estimation of point i. To estimate the parameters in Formula (2), a suitable criterion is selected to determine the spatial weight matrix W. The commonly used method to calculate a spatial weight matrix include Gaussian distance, exponential distance, and tricube distance, and the first one is adopted in this paper to determine the weight:

$$W(u_i, v_i) = e^{-1/2\left(d_{ij}/b\right)^2} \tag{3}$$

where b is the bandwidth of the smoothing parameter, and the higher the value, the better the smoothing effect. The selection of a suitable bandwidth has an important influence on the efficiency of model operation. This paper selects the Akaike information criterion (AIC) to determine the optimal bandwidth using the formula shown in Formula (4):

$$A_c = 2n\ \ln(\hat{\sigma}) + n\ \ln(2\pi) + n\left[\frac{n + tr(s)}{n-2-tr(s)}\right] \quad (4)$$

where A is the value of AIC, and the subscript c is the corrected estimated value; n is the sample size; $\hat{\sigma}$ is the standard deviation of the error term estimation; $tr(s)$ is the trace of the matrix S in the GWR; that is, the function of the bandwidth.

On the basis of Formula (1), the GWR model is built to measure the influence of science popularization resources development on the energy consumption carbon footprint in provincial regions. It is assumed that apart from the factors such as economic development, population growth, and energy consumption, science popularization resources development is also an important factor that influences the energy consumption carbon footprint, and the expected effect is negative, i.e., it can effectively lower the energy consumption carbon footprint. The variable explained by this model is the energy consumption carbon trace in provincial regions; the explaining variable is the level of science popularization resources development in provincial regions; the control variables are the per capita GDP (reflecting the factor of economic development), population density (reflecting the factor of population growth), and energy consumption per 10,000 yuan of added industrial value (reflecting the factor of energy consumption). Detailed information is shown in Table 1.

Table 1 Selection of the factors that influence the energy consumption carbon footprint

Variable	Index	Symbol	Unit
Explained variable	Energy consumption carbon footprint	EnerFP	hm^2/person
Explaining variable	Level of science popularization resources development	PCR	
Control variable	Per capital GDP	PerGDP	Yuan/person
	Energy consumption per 10,000 yuan of added industrial value	IndEC	Tons of standard coal/ten thousand yuan
	Population density	PopD	Person/square km

Data

Explained variable: energy consumption carbon footprint in provincial regions The energy consumption carbon footprint variable is represented in units of land area, representing the cost of ecological resources required to absorb the CO_2 emissions caused by energy consumption; carbon emissions of major energy types can be calculated by the IPCC method [21, 22], while the conversion coefficient between the carbon emissions from energy consumption and ecological footprint can be determined by measuring the forest absorption of CO_2, which can then be converted into land area, and the energy consumption carbon footprint value can be obtained through summation [23]. The specific calculation is as shown in Formula (5) [24]:

$$C_{fj} = \sum_{i=1}^{8} C_{fij} = \sum_{i=1}^{8} \frac{C_{ij}}{P \times F_{CL}} \quad (5)$$

where C_{fj} is the energy consumption carbon footprint of the j^{th} province, C_{ij} is the i^{th} type of energy consumption carbon emissions (including eight main types of energy that consist of coal, coke, crude oil, gasoline, kerosene, diesel, fuel oil, and natural gas) of the j^{th} province, P is the total population, and F_{CL} is the ratio of the conversion coefficient between carbon emissions and forest area. This paper adopts the conversion coefficient between energy consumption carbon emissions and ecological footprint released by the WWF (measured by the quality of CO_2 absorption by forests), namely 6.49 t/hm^2 [25]. The formula converts the substantial consumption of various types of energy into released heat by averaging c, which can be used to obtain specific values of the energy consumption carbon footprint for provinces. The index data are sourced from the China Statistical Yearbook and China Energy Statistical Yearbook over all years. Through measurements and calculations, the energy consumption carbon footprints for 30 provinces in China (Xizang, Hong Kong, Macao, and Taiwan not included due to data constraints) are obtained, as shown in Table 2.

The level of science popularization resources development can be obtained through calculation using the global entropy method.

Explaining variable: the level of science popularization resources development in provincial regions This paper holds that the level of science popularization resources development cannot be measured with a singular index, so on the basis of drawing upon [26, 27], a comprehensive evaluation index system is built, as shown in Table 3, covering five layers of criteria of science popularization human resources, event resources, financial resources, media resources, and site resources, which can be broken down into 22 evaluation indexes.

Table 2 Comprehensive evaluation scores of the energy consumption carbon footprint and level of science popularization resources development in provincial regions

Region	Province	Energy consumption carbon footprint score 2010	Energy consumption carbon footprint score 2014	Comprehensive evaluation score of the level of science popularization resources development 2010	Comprehensive evaluation score of the level of science popularization resources development 2014
Eastern region	Beijing	0.2685	0.1851	53.208	49.041
	Shanghai	0.4952	0.4279	31.838	41.870
	Tianjin	0.6437	0.5954	24.483	15.657
	Zhejiang	0.3792	0.3740	18.097	13.939
	Jiangsu	0.4296	0.5012	14.695	12.681
	Guangdong	0.2491	0.2550	12.927	7.768
	Shandong	0.5683	0.6210	9.420	11.573
	Fujian	0.2939	0.3450	10.032	7.482
	Liaoning	0.7066	0.7376	16.735	14.119
	Hainan	0.2076	0.2565	17.474	11.072
	Hebei	0.5946	0.6287	10.251	8.064
Central region	Heilongjiang	0.4441	0.4805	9.200	9.502
	Jilin	0.4743	0.5103	8.642	3.609
	Hubei	0.3269	0.3030	13.557	13.220
	Henan	0.3538	0.3497	11.443	6.341
	Hunan	0.2363	0.2292	11.283	6.711
	Anhui	0.2889	0.3425	10.084	7.912
	Jiangxi	0.2015	0.2363	9.401	7.047
	Shanxi	1.0567	1.2595	8.169	5.926
Western region	Shaanxi	0.4482	0.6577	10.487	10.254
	Sichuan	0.2035	0.2155	10.605	7.431
	Inner Mongolia	1.3581	1.7680	8.873	8.003
	Guangxi	0.1933	0.2324	10.206	5.936
	Yunnan	0.2809	0.2573	11.748	9.587
	Xinjiang	0.5777	0.9934	13.514	10.462
	Ningxia	1.1266	1.6701	10.307	8.463
	Gansu	0.3252	0.3973	9.343	7.418
	Guizhou	0.3792	0.4520	8.275	5.894
	Chongqing	0.2804	0.2664	16.741	10.332
	Qinghai	0.3341	0.4589	14.871	8.058

Data source: carbon footprint is obtained through IPCC calculations

On the basis of building a comprehensive evaluation index system, this paper adopts the global entropy method [28, 29] that features objective weighting and dynamic comparability to obtain data on the level of science popularization resources development in provincial regions. The steps are as follows:

Build a global evaluation matrix and standardize it. n indexes are used to evaluate the science popularization resources development of m provincial regions over a duration of T years and ultimately build an initial global evaluation matrix for the evaluation system, which is recorded as X:

$$x = \left(x_{ij}^{t}\right)_{mT*n} = \begin{bmatrix} {x_{11}}^{1} & {x_{12}}^{1} & \dots & {x_{1n}}^{1} \\ {x_{21}}^{1} & {x_{22}}^{1} & \dots & {x_{2n}}^{1} \\ \dots & \dots & & \dots \\ {x_{m1}}^{1} & {x_{m2}}^{1} & \dots & {x_{mn}}^{1} \\ \dots & & \dots & \\ {x_{11}}^{T} & {x_{12}}^{T} & \dots & {x_{1n}}^{T} \\ {x_{21}}^{T} & {x_{22}}^{T} & \dots & {x_{2n}}^{T} \\ \dots & \dots & \dots & \\ {x_{m1}}^{T} & {x_{m2}}^{T} & \dots & {x_{mn}}^{T} \end{bmatrix} \quad (6)$$

where x_{ij}^{t} is the assigned value of the j^{th} evaluation index of the i^{th} provincial region at the t^{th} year, and

Table 3 Comprehensive evaluation index system to determine the levels of science popularization resources development in provincial regions

Target layer	Criterion layer	Specific indexes
Level of science popularization resources development in provincial regions	Science popularization human resource	Number of science popularization personnel (person/ten thousand persons)
		Proportion of professionals among science popularization personnel (%)
		Proportion of persons with above-intermediate titles or above-undergraduate credential among professionals (%)
		Proportion of registered volunteers among part-time personnel (%)
		Proportion of creation personnel among professionals (%)
	Science popularization event resource	Total number of three types of events (time)
		Proportion of participating person-time in three types of events among the regional population (person-time/ten thousand persons)
		Proportion of participating person-time during event weeks among the regional population (person-time/ ten thousand times)
		Proportion of participating person-time in international exchanges among the regional population (person-time/ten thousand persons)
		Proportion of participating person-time in openness to the society of colleges, universities and research institutions among the regional population (person-time/ten thousand persons)
	Science popularization financial resource	Average fundraising amount (yuan/person)
		Proportion of regional fundraising amount in GDP (%)
		Average fund use amount (yuan/person)
	Science popularization site resource	Number of sites per million persons (number/ one million persons)
		Exhibition area per ten thousand persons (sqm/ten thousand persons)
		Number of promotion facilities per ten thousand persons (number/ten thousand persons)
	Science popularization media resource	Number of books circulated per ten thousand persons (volume/ten thousand persons)
		Number of journals circulating per ten thousand persons (volume/ten thousand persons)
		Number of discs circulating per ten thousand persons (piece/ten thousand persons)
		Number of newspapers circulating per ten thousand persons (piece/ ten thousand persons)
		TV program duration (hour)
		Number of websites (number)

$n = 24$, $m = 30$, and $T = 5$. Given that the dimension, magnitude, and positive and negative assignment of each index vary, X has to be standardized to make $x_{ij}^{t} \in [0, 100]$, as shown in Formula (7) and Formula (8). $(x_{ij}^{t})'$ is the equally standardized index value, $x_{j\min}$ is the minimal value of the j^{th} index, $x_{j\max}$ is the maximal value of the j^{th} index. Formula (7) and Formula (8) are respectively for the standardization of the positive index and negative index.

$$\left(x_{ij}^{t}\right)' = \frac{x_{ij}^{t} - x_{j\ \min}}{x_{j\ \max} - x_{j\ \min}} \times 99 + 1 (i = 1, 2, \ldots, m; j = 1, 2, \ldots, n; t = 1, 2, \ldots T) \tag{7}$$

$$\left(x_{ij}^{t}\right)' = \frac{x_{j\ \max} - x_{ij}^{t}}{x_{j\ \max} - x_{j\ \min}} \times 99 + 1 (i = 1, 2, \ldots, m; j = 1, 2, \ldots, n; t = 1, 2, \ldots T) \tag{8}$$

The formula for measuring the information entropy of the j^{th} index is as follows:

$$e_j = -K\sum_{t=1}^{T}\sum_{i=1}^{n} y_{ij}^t \ \ln y_{ij}^t \quad (9)$$

where $y_{ij}^t = \frac{(x_{ij}^t)'}{\sum_{t=1}^{T}\sum_{i=1}^{m}(x_{ij}^t)'}$, constant $K = \frac{1}{\ln mT}$, which is related to the number m of the samples in the system. When the information in the system is distributed disorderly, then the degree of order is 0 and information entropy e_j=1. When samples are all in a disorderly state, $y_{ij}^t = 1$.

According to information entropy index, the weight w_j of the j^{th} index can be calculated. When $0 \le w_j \le 1$, $\sum_{j=1}^{n} w_j = 1$ as follows:

$$w_j = \frac{1-e_j}{n-\sum_{j=1}^{n} e_j} \quad (10)$$

After obtaining the results of the index weight, Formula (11) can be used to calculate the comprehensive evaluation score:

$$s_i = \sum_{j=1}^{n} w_j \left(x_{ij}^t\right)' \quad (11)$$

The index data are sourced from the China Statistical Yearbook and China Energy Statistical Yearbook over all years. Through the calculation, the data on the level of science popularization development for provincial regions across the country are obtained, as shown in Table 2.

Control variable There are three control variables, namely, per capita GDP, population density, and energy consumption per 10,000 yuan of added industrial value. The index data are sourced from the China Statistical Yearbook and China Energy Statistical Yearbook over all years.

Results and discussion

Before starting the GWR modeling, we need to detect whether there is an obvious spatial correlation of the sample data. If there is, it is suitable to adopt the GWR model for analysis; otherwise, it is more suitable to adopt a constant coefficient model (such as OLS). GeoDa 9.5 software is adapted to detect the spatial correlation of the energy consumption carbon footprint in provincial regions of China from 2010 to 2014. The results from Moran's I statistical analysis show that the values are 0.2860, 0.2406, 0.2641, 0.2834, and 0.2989, and the normal statistical magnitude Z is lower than the significant level (1.96) of the normal distribution function 0.01, indicating that there is relatively strong positive spatial correlation among the levels of the energy consumption carbon footprint in provincial regions, and the GWR model needs to be introduced to offset the shortcomings of traditional constant coefficient models. With SAM4.0 software, the values estimated by the GWR model in 2010 and 2014 in the provincial regions are calculated and compared with those from an OLS model, which is a typical example of traditional constant coefficient models (see Table 4).

From Table 4, it can be seen that after introducing the GWR model, the fitting degree and regression effect are significantly improved. Hence, it is suitable for this paper to adopt the GWR model for empirical analysis. Further results from testing the significance of the regression coefficient show that when the significance level $S = 0.05$, the regression coefficients of the three variables of PCR, PerGDP, and IndEC all passed significance testing except for the control variable PopD. The GWR-estimated results and the spatial distribution of the GWR coefficient of the influence of science popularization resources development on the energy consumption carbon footprint in Chinese provincial regions are as shown in Table 5. Generally, the GWR-estimated results of the influence of science popularization resources development on the energy consumption carbon footprint in Chinese provincial regions from 2010 to 2014 are all negative, indicating that it is negatively correlated with the energy consumption carbon footprint with obvious interprovincial differences; the absolute values of the GWR-estimated coefficient for the east, middle, and west regions in 2010 are 0.874, 0.785, and 0.702, respectively. The values slightly declined in 2014, and they were 0.542 (the west), 0.571 (the middle), and 0.640 (the east). From 2010 to 2014, the influence of science popularization resources development on the energy consumption carbon footprint in three regions displayed a weakening trend, but the lowering amplitude in the east is higher than that in the middle and west regions, yet the imbalance is narrowing.

By the spatial quintile method, the participating provincial regions of China can be divided into five arrangement levels according to the coefficient of the influence

Table 4 Comparison of detection results between GWR and OLS estimation models

Detection analysis	2010		2014	
	GWR	OLS	GWR	OLS
AICC	6.950	14.130	14.772	19.125
R^2	0.764	0.608	0.699	0.530
Adjusted R^2	0.725	0.579	0.642	0.496
Residuals	0.57	0.92	1.44	2.19

Data source: obtained by SAM software

Table 5 GWR-estimated results of the influence coefficient of science popularization resources development on the energy consumption carbon footprint in Chinese provincial regions

Region	Province	2010	2014
Eastern region	Beijing	– 0.805	– 0.602
	Tianjin	– 0.889	– 0.592
	Hebei	– 1.281	– 0.594
	Liaoning	– 0.966	– 0.590
	Shanghai	– 0.819	– 0.516
	Jiangsu	– 0.789	– 0.538
	Zhejiang	– 0.842	– 0.506
	Fujian	– 1.021	– 0.489
	Shandong	– 0.770	– 0.564
	Guangdong	– 0.751	– 0.488
	Hainan	– 0.681	– 0.479
	Mean	– 0.874	– 0.542
Central region	Shanxi	– 0.768	– 0.603
	Jilin	– 0.795	– 0.605
	Heilongjiang	– 0.804	– 0.650
	Anhui	– 0.888	– 0.538
	Jiangxi	– 0.750	– 0.509
	Henan	– 0.714	– 0.570
	Hubei	– 0.718	– 0.557
	Hunan	– 0.844	– 0.533
	Mean	– 0.785	– 0.571
Western region	Inner Mongolia	– 0.769	– 0.660
	Guangxi	– 0.785	– 0.528
	Chongqing	– 0.668	– 0.578
	Sichuan	– 0.710	– 0.612
	Guizhou	– 0.674	– 0.561
	Yunnan	– 0.777	– 0.582
	Shaanxi	– 0.751	– 0.613
	Gansu	– 0.644	– 0.689
	Qinghai	– 0.690	– 0.714
	Ningxia	– 0.614	– 0.643
	Xinjiang	– 0.638	– 0.855
	Mean	– 0.702	– 0.640
	The overall mean	– 0.787	– 0.584

of science popularization resources development on the energy consumption carbon footprint (as per the average value from 2010 to 2014).

Level I region: six provincial regions of Shanghai, Zhejiang, Fujian, Jiangxi, Guangdong, and Hainan with the lowest absolute values of the influence coefficient;

Level II region: six provincial regions of Jilin, Beijing, Hebei, Shanxi, Shaanxi, and Sichuan with relatively low absolute values of the influence coefficient;

Level III region: six provincial regions of Liaoning, Shandong, Henan, Tianjin, Chongqing, and Yunnan with average absolute values of the influence coefficient;

Level IV region: six provincial regions of Jiangsu, Anhui, Hubei, Hunan, Guizhou, and Guangxi with relatively high absolute values of the influence coefficient;

Level V region: six provincial regions of Heilongjiang, Inner Mongolia, Ningxia, Qinghai, and Xinjiang with the highest absolute values of the influence coefficient.

Conclusions

The results of the empirical analysis showed that the level of science popularization resources development and the energy consumption carbon footprint are obviously negatively correlated. From 2010 to 2014, there were certain spatial differences in the influence of science popularization resources development on the energy consumption carbon footprint in the three major regions of the east, the middle, and the west. In 2014, the influence reached the highest level in the west followed by the middle and the east, yet the imbalance among the regions began to narrow.

This study has theoretical value and practical significance. At present, we should fully understand the influence of science popularization resources development on the energy consumption carbon footprint. Science popularization resources development can help cultivate the views of green consumption by the public, promote and deepen the carbon emission-reduction work of various enterprises, and enhance the outlook on green development at all levels of government. In addition, it is also conducive to practicing low-carbon consumption, developing strategies featuring public participation, corporate dominance and policy guidance, and ultimately effectively lowering the energy consumption carbon footprint.

The practical significance of this study lies in establishing regional policies. Focus should be given to the west region, and resource construction mechanisms built with flexible adoptions of means, such as a combination of government guidance and market mechanisms, as well as joint construction by government and society. In addition, it is necessary to optimize policies related to the environment and cultural environment and establish evaluation and feedback frameworks with focus on performance evaluations and feedback evaluations, with a view of fully utilizing science popularization resources development to lower the energy consumption carbon footprint and ultimately assisting in promoting low-carbon society construction and green economic development.

Although this research strives to be rigorous and objective, there are still some shortcomings due to the author's own research ability and data availability. For example, although this paper selects the construction of the evaluation index system as comprehensively as possible, it can reflect the development of popular science resources. However, the evaluation index system to be constructed still needs further improvement, and the operability of the proposed countermeasures has yet to be improved. Some propositions and conclusions related to this study still need to be further discussed and improved in the future.

Abbreviations
GWR: Geographically weighted regression; IPCC: Intergovernmental Panel on Climate Change

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Availability of data and materials
Data are available from Figshare: DOI 10.6084/m9.figshare.5501314.

Authors' contributions
YD conducted the literature review and some quantitative analyses. GD guided the direction and ideas of the project. PW analyzed the data and edited the manuscript. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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