Pol. J. Environ. Stud. Vol. 32, No. 2 (2023), 1239-1251
DOI: *10.15244/pjoes/156688* ONLINE PUBLICATION DATE: 2023-01-13

Original Research

Research on Carbon Emission Efficiency and Its Improvement Path of China's Provinces Based on SBM-ML Model and fsQCA Model

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Received: 5 October 2022
Accepted: 18 November 2022

Abstract

The realization of the "double-carbon" goal will contribute to the high-quality and sustainable development of China's economy and society, while the improvement of carbon emission efficiency in Chinese provinces will lay a solid foundation for the realization of the "double-carbon" goal. In this paper, 30 Chinese provinces are selected as research cases. MatLab software is applied to build the slacks-based measure Malmquist-Luenberger (SBM-ML) model to measure carbon efficiency. By the analysis of their carbon efficiency with the fuzzy qualitative comparative analysis (fsQCA) method, this paper aims to find new ways to improve carbon emission efficiency. Among the data of all the provinces and municipalities, there are only four are greater than 1, revealing much room for improvement in Chinese carbon emission efficiency. The carbon emission efficiency of each province and municipality is synergistically influenced by five elements: environmental regulation, urbanization rate, marketization level, consumer price index, and government environmental expenditure. Different configurations of the five elements constitute four feasible ways to improve carbon emission efficiency. The total consistency level of 0.822277 indicates that the four paths are sufficient conditions for achieving high carbon emission efficiency. The conclusions of this paper are not only helpful in accurately grasping the carbon emission efficiency in Chinese provinces but also provide theoretical support and practical guidance for improving the carbon emission efficiency in China.

Keywords: carbon emission efficiency, SBM-ML, fsQCA, Promotion Path

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Introduction

Since the reform and opening up, the Chinese economy has been growing rapidly, but the extensive mode of economic growth [1] leads to high consumption of energy and carbon dioxide emissions. The sharp increase in the emission of carbon dioxide and other greenhouse gases intensifies the greenhouse effect and global warming and accelerates the melting of glaciers, giving rise to more severe climate problems [2] which brings more pressure to Chinese resources and the environment. Under the dual pressure, coordinating the coexistence between human beings and nature and reducing the burden of nature has become a priority in the process of high-quality sustainable development in China. Putting green development as the center of economic growth, a green and efficient development path is the only way for urban transformation in China [3].

On September 22, 2020, at the 75th session of the United Nations General Assembly, carbon peaking and carbon neutrality goals were first proposed by Xi Jinping, the president of China [4]. Regarding carbon peaking and carbon neutrality goals, Xi has mentioned the urgency and difficulty in achieving the target many times on different occasions. The proposal of carbon peaking and carbon neutrality goals has pointed out the direction for the high-quality and sustainable development of the Chinese economy and society. Reducing carbon emissions and improving carbon emission efficiency have become the primary task. In The Outline of the 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and the 2035 Vision Target (2021), it is clearly stated that China is going to reach the carbon peak before 2030 and will strive to achieve carbon neutrality before 2060 [5]. The Opinions of the CPC Central Committee and The State Council on Complete, Accurate and Comprehensive Implementation of the New Development Concept to Achieve Peak Carbon and Carbon Neutrality (2021) put forward the requirements of adhering to systematic views and defining a clear roadmap and construction drawing of Chinese carbon peaking and carbon neutrality goals to promote the energy efficiency to an advanced international level [6]. These documents suggest that China is acting with the utmost determination to reduce emissions and move towards carbon peaking and carbon neutrality goals.

The realization of carbon peaking and carbon neutrality goals is closely related to carbon emission efficiency. How to improve carbon emission efficiency and identify the influencing factors of carbon emission efficiency while keeping economic growth are the main concerns of China and the world. In this paper, the slacks-based measure Malmquist-Luenberger (SBM-ML) model is applied to measure the provincial carbon efficiency of 30 Chinese provinces. In addition, the fuzzy qualitative comparative analysis (fsQCA) method is employed to find the influence of the configuration of three factors in carbon emission efficiency including the local government's concern for the environment, urbanization rate, and people consumption behaviors. In doing so, paths to promote the efficiency of carbon emissions in China can be explored. It is helpful to accurately grasp the carbon emission efficiency of all provinces and cities in China, and to provide theoretical support and practical guidance for all provinces and cities in China to improve the carbon emission efficiency.

Literature Review

Research on Carbon Emission Efficiency

Carbon emission efficiency has been a hot topic for scholars at home and abroad. Current research on carbon emission efficiency can be divided into the following two aspects: measurement of carbon emission efficiency and differentiation and analysis of influencing factors of carbon emission efficiency.

As for the first type, the researches on carbon emission efficiency measurement, the measuring methods generally applied are data envelopment analysis (DEA) and stochastic frontier analysis (SFA). The SFA method is limited by artificial parameter setting, so DEA is currently the mainstream tool for measuring carbon emission efficiency. Initially, scholars used the traditional DEA model to find the carbon emission efficiency [7-9]. Still, the traditional DEA model does not consider the influence of undesirable outputs and has problems such as the accuracy can be affected by improper output selection, which does not apply to carbon emission studies where there are non-desired outputs. So the SBM model [10], Malmquist index method [11], and three-stage DEA model [12] are extended and some other methods start to emerge. For example, Haihong Song et al. selected a super-efficient SBM model including non-desired outputs to measure the carbon emission efficiency of the Yellow River Basin in China from 2006 to 2019 [13]. Zilong Wang et al. measured the static and dynamic efficiency of carbon emissions through the global Slack Based Measurement (GSBM) model and the global Malmquist-Luhnberg Productivity Index (GML) [14]. Weizhong Zhou et al. evaluated the carbon emission efficiency of China's construction industry from 2010 to 2019 by a three-stage DEA, and found that the average value of efficiency was low overall and showed an increasing and then decreasing trend [15]. Jianwei Ren et al. proposed a non-radial opportunity-constrained DEA model to evaluate the pure carbon emission efficiency, which effectively solved the problem of uncertain carbon emissions [16]. Only with appropriate methods, can the carbon emission efficiency be obtained and evaluated accurately and be able to provide support for further research on the improvement path of carbon emission efficiency.

In the second research type, to identify the factors influencing carbon emission efficiency, relevant studies have found that human capital, renewable energy development, digital finance, and green technology innovation have influenced carbon emission efficiency to different degrees. Weijun He et al found that human capital could improve carbon emission efficiency after they analyzed of the panel data from 1999 to 2019 of the Yangtze River Economic Belt and established the mediation effect. [17]. Feng Dong used a random forest regression model to explore the impact of renewable energy on regional carbon emission efficiency and found that renewable energy development first inhibits and then enhances carbon emission efficiency [18]. Ming Long Zhang applied a spatial econometric model to empirically analyze the impact of digital finance and green technology innovation on carbon emission efficiency, and the results showed that the synergistic effect of the two played an important role in carbon emission The results show that the synergistic effect of the two plays an important role in the improvement of carbon emission efficiency, but to a certain extent inhibits the carbon emission efficiency of the surrounding cities [19]. Lunchen Ning et al. picked the panel data of 30 provincial-level administrative regions from 2007 to 2016, finding that the level of opening up, energy structure, and intensity can inhibit carbon emission efficiency [20]. Yingqi Xu et al. by constructing a two-way fixed benefit model, discovered that the intensity of foreign investment has negative effects on carbon emission efficiency [21]. In general, many factors affect carbon emission efficiency in different degrees. Only the influencing factors are decided, can we find more scientific ways to improve carbon emission efficiency.

Theoretical Basis

Environmental Regulation, Government Expenditure on Environmental Protection and Carbon Emission Efficiency

In the 11th Five-Year Plan, the Chinese government maps out the regional targets and measures for energy conservation and emission reduction, planning more work in environmental protection to ensure the sustainable economic development of China. The theory of sustainable development refers to a development model in which human beings can meet their current needs without sacrificing the needs of their later generations [22]. The theory emphasizes the importance of "practice" which means replacing "economy and society" with "environment", a new social central goal [23]. Environmental regulation refers to all policies and measures formulated to protect the environment [24]. Government spending on environmental protection reflects the intensity of government investment in environmental protection and discourages polluting behavior [25]. For example, Lu Zhang et al. found that environmental regulations with targeted regulation and adaptive incentives can promote joint emission reduction [26]. Xiaoli Zhao et al. found that market-based environmental regulations and government environmental subsidies type of environmental regulations can improve carbon emission efficiency [27]. Moreover, both environmental regulations and government environmental spending reflect the government's emphasis on sustainable development and affect the efficiency of carbon emissions. Wen Shiyan et al. analyzed 208 low-carbon pilot cities and found that local governments that, paid attention to the intensity of environmental and sustainable development promoted technological innovation and improved industrial structure, thus significantly improving urban carbon emission efficiency [28]. Therefore, environmental regulation intensity and government environmental expenditure are selected as the two antecedent variables in this paper to explore their impact on carbon emission efficiency.

Urbanization Rate, Marketization Level and Carbon Emission Efficiency

Chinese urbanization and marketization are still proceeding. The social and economic development of China is going to take a lot of energy. As the generalized externality theory defines, the movement of one subject can cause certain external effects on another subject [29]. It is true for urbanization which has positive and negative external effects on the environment and two-way effects on carbon emission efficiency [30]. The urbanization rate and marketization level present the development situation of the city, and they also have bidirectional influences on carbon emission efficiency. Urbanization is intrinsically related to carbon emissions, which is mainly reflected by the effects of the scale, speed, quality, stage, mode, and structure of urbanization and the economic changes caused by urbanization [31]. On the one hand, the rapid advancement of urbanization and marketization can bring negative external benefits to the environment, increasing carbon emissions and bringing pressure to the environment [32]. Along with the progress of urbanization and marketization, industrialization develops, leading to an increase in carbon emissions [33]. On the other hand, due to regional differences, urbanization can stimulate the development of local technology, bring external positive benefits to the environment and improve carbon emission efficiency [34]. In addition, Aiping He, adopting the Tobit fixed effects model and panel threshold model, found that marketization level has a complex impact on carbon emission efficiency. To be specific, there is a significant "inverse u" relation between the market segmentation and carbon emission efficiency relevance. As for market potential, it is beneficial to carbon emission efficiency [35]. Therefore, urbanization rate and marketization level are selected as two antecedent variables in this paper to explore their impact on carbon emission efficiency.

Consumer Index and Xarbon Emission Efficiency

Besides the government and social environment, residents' behavior also influences the environment and affects carbon emission efficiency. According to the IPAT theory of environmental economics, consumption can affect the environment [36]. Chen Li et al. studied the influencing factors of carbon emissions of 286 Chinese cities at the prefecture level and above and concluded that residents' savings and consumption can stimulate the increase of carbon emissions and inhibit carbon emission benefits [37]. Moreover, carbon emissions from subsistence consumption account for a large proportion of carbon emissions [38], and changes in residents' consumption behavior can cause changes in carbon emissions. For example, Honghua Yang et al. built a multi-level SD model based on the system dynamics method. After thorough analysis, they found that residents' behavior improvement could reduce carbon emissions [39]. With the PLS-SEM model, Hongcheng Zhu et al. discovered that various consumption behaviors of residents have direct and indirect significant impacts on carbon emissions [40]. The change in residents' consumption behavior leads to the upgrade of the consumption structure which will affect carbon emissions. Dongshen Luo, with the help of the STIRPAT model and mediating effect model, found that the upgrading of consumption structure can promote carbon emission reduction by expanding immaterial consumption and service industry [41]. In addition, the disposable consumption of the residents influences the preferences of the residents and presents the consumption philosophy of the residents [40], which reflects the regional economic level. Chinese economic growth plays a major part in the increase in carbon emissions [42]. Therefore, this paper also selects the residential consumption index as an antecedent variable to explore its impact on carbon emission efficiency.

To sum up, environmental regulation, government expenditure on environmental protection, urbanization rate, marketization level, and consumer consumption index are selected as all the antecedent variables in this paper.

Literature Comments

Present research on carbon emission efficiency mainly focuses on the measurement and the influencing factors of it. In terms of carbon emission efficiency measurement, most researchers chose the traditional DEA model, SBM model, Malmquist index method, and three-stage DEA model to measure the carbon emission efficiency of a certain region or industry. Given the limitations of traditional DEA and the influence of undesirable output, in this paper, the SBM-ML model is decided to measure the carbon emission efficiency. In addition to the measurement, the influence of variables including market, environment, and economy on carbon emission efficiency has also been studied, but most studies only mention one single variable with little exploration of the interaction of these variables. In this paper, from the perspectives of market, environment, and economy, environmental regulation, government expenditure on environmental protection, urbanization rate, marketization level, and consumer consumption index are picked to explore the impact of different combinations on carbon emission efficiency and explore paths to improve carbon emission efficiency.

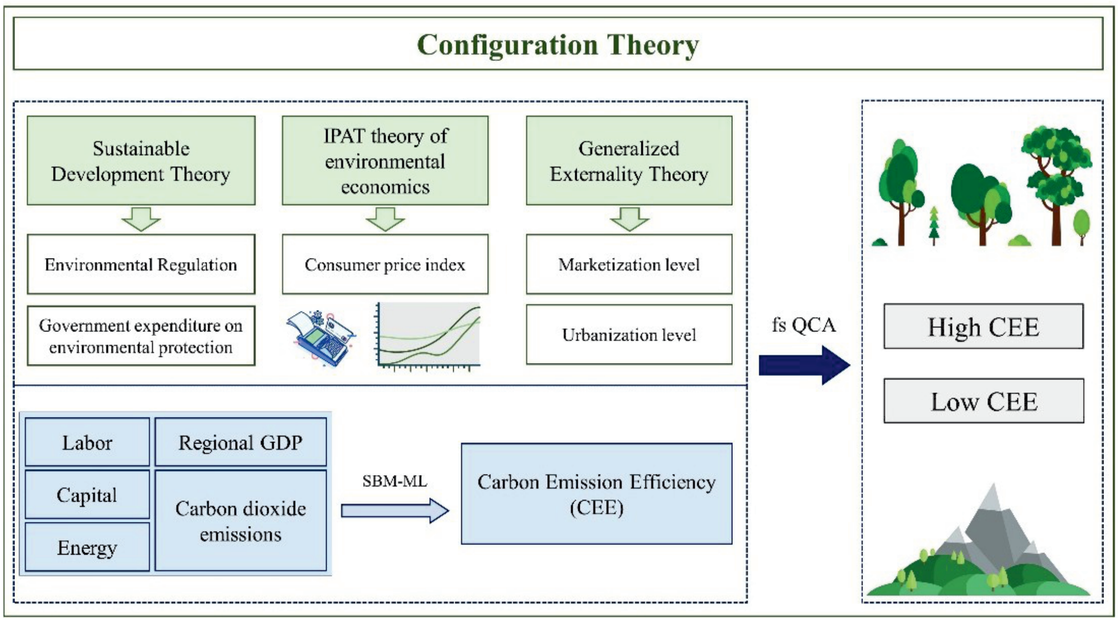

Fig. 1. Theoretical models.

Research Design

Considering all the available factors, this study measures and evaluates the carbon emission efficiency of Chinese provinces with the SBM-ML index model. Afterward, the fsQCA method is applied to explore the influence of different antecedent variable configurations on the carbon emission efficiency of Chinese provinces, to seek the path to improve the carbon emission efficiency.

Research Methods

SBM-ML Index Model

Data Envelopment Analysis (DEA) is one of the most important mathematical methods in the evaluation of carbon emission efficiency. Since 1978, being proposed by Charnes and Cooper, it has been widely used and developed. Even though the DEA method is widely used in efficiency measurement, the traditional DEA is still difficult to distinguish the output, that is, it is unable to deal with the bad output properly. The non-radial and slacks-based DEA (SBM) model proposed by Tone is a modified version of the traditional model. It considers the influence of slack variables of input and output on production efficiency, but can also correctly distinguish between good and bad output. Based on this method, this paper introduces the concept of intertemporal dynamics and applies the SBM-ML index model that includes undesired output to measure the carbon emission efficiency CEE of Chinese provinces under variable returns to scale.

In this paper, the production of 30 provinces in China is taken as one decision-making unit. Assuming that the number of investment type of each province is N, $X = \{x_1, x_2, ..., x_N\} \in R_+^N$, the number of desirable output type is Q_1, $Y = \{y_1, y_2, ..., y_{Q_1}\} \in R_+^{Q_1}$ and the number of undesirable output type is Q_2, $B = \{b_1, b_2, ..., b_{Q_2}\} \in R_+^{Q_2}$. With the variable remuneration, the possibility set of each province in the t_{th} year is $P_t(x) = \{y_t, b_t\}$, so the SEM directional distance function of province i in the same year should be:

$$D_V^t(x_i^t, y_i^t, b_i^t) = \hat{\rho} = min(\frac{1 - \left[\frac{1}{N}\sum_{n=1}^{N}\frac{s_n^x}{x_n^i}\right]}{1 + \left[\frac{1}{Q_1 + Q_2}(\sum_{q_1=1}^{Q_1}\frac{s_{q_1}^y}{y_{q_1}^i} + \sum_{q_2=1}^{Q_2}\frac{s_{q_2}^b}{b_{q_2}^i})\right]})$$

$$s.t. \sum_{i=1}^{I} z_i^t y_{i,q_1}^t - s_{q_1}^y = y_{i,q_1}^t, q_1 = 1,2,\cdots,Q_1,$$

$$\sum_{i=1}^{I} z_i^t x_{i,n}^t + s_n^x = x_{i,n}^t, n = 1,2,\cdots,N,$$

$$\sum_{i=1}^{I} z_i^t b_{i,q_2}^t + s_{q_2}^b = b_{i,q_2}^t, q_2 = 1,2,\cdots,Q_2,$$

$$\sum_{i=1}^{I} z_i^t = 1, z_i^t \geq 0, s_{q_1}^y \geq 0, s_n^x \geq 0, s_{q_2}^b \geq 0, i = 1,2,\cdots,I \quad (1)$$

where min(·) represents the minimum value function, the numerator and denominator of $\hat{\rho}$ respectively represent the average distance between input and output from the production frontier, s_n^x, $s_{q_1}^y$, $s_{q_2}^b$ respectively represent the slack variable, z_i^t represent the weight vector. Next, the SBM-ML index with adjacent reference for two consecutive years is constructed as follows:

$$(SBM - ML)_t^{t+1} = \left[\frac{D_V^t(x^{t+1}, y^{t+1}, b^{t+1})}{D_V^t(x^t, y^t, b^t)} \times \frac{D_V^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})}{D_V^{t+1}(x^t, y^t, b^t)}\right]^{1/2} \quad (2)$$

where $SBM - ML > 1$ represents the improvement of carbon emission efficiency, while $SBM - ML < 1$ denotes the reduction of carbon emission efficiency.

Qualitative Comparative Analysis of Fuzzy Sets

Qualitative comparative analysis, short for QCA, was first proposed by Charles C. Ragin. It is an analytical method to research small and medium-sized sample cases. According to the type of variables, QCA can be classified into the clear set qualitative comparative analysis (csQCA), multi-valued qualitative comparative analysis (mvQCA), and fuzzy set qualitative comparative analysis (fsQCA). In this paper, 30 Chinese provinces are selected as research samples and fsQCA is the chosen method because it compensates for the limitation of the amount of sample and the variety of influencing factor combinations won't affect the results with this method.

Sample Description

From the regional level, this paper selects 30 Chinese provincial-level regions as research cases (excluding Tibet, Hong Kong Special Administrative Region, Macao Special Administrative Region, and Taiwan due to the lack of relevant data). There is a certain lag in the impact of provincial inputs on carbon emission efficiency, which can cause inconsistency between the input and the output. However, it has not been mentioned in relevant statistical reports and yearbooks. In reality, there are also great differences in the influencing factors of carbon emission efficiency, so it is hard to determine a reasonable and unified lag period. DEA is a method that can be applied to investigate the relative efficiency of each sample under the same index system. Although the output of different years differs, relevant studies show that, due to the path dependence, the set of the lag period (1 to 3 years) has little influence on the result of carbon emission efficiency. Therefore, this paper uses the current data to measure the carbon emission efficiency of each region in China in 2019.

Measurement and Data Sources

Result Variables

According to available literature, this paper chooses the urban employment number of each province in 2019

Table 1. SBM-ML index model Input and output variables.

	Input variable	Definition of variables	Source
Input	Labor input	Quantity of urban employment	China Statistical Yearbook
	Capital input	$K_{it} = K_{i,t-1}(1-\delta_{it}) + I_{it}$ (3)	China Statistical Yearbook
	Energy input	Total consumption of energy quantified by the consumption of standard coal	China Energy Statistical Yearbook
Desirable output	Regional GDP	Regional GDP is calculated with the GDP of 2008 as the basis	China Statistical Yearbook
Undesirable output	Carbon dioxide emission	$(CO_2)_{ijt} = \sum_{j=1}^{j} R_{jt} \times \delta_j \times \alpha_j \times \frac{44}{12}$ (4)	China Statistical Yearbook IPCC2006

where K_{it} represents the fixed capital stock of the province i n the tth period, I_{it} represents the fixed capital investment of the province i in the tth period and δ_{it} represents the depreciation rate. In equation (7), R_{jt} represents the consumption of the number j energy in period t, δ_j represents the conversion coefficient of standard energy consumption corresponding to the number j energy, and α_j represents the carbon emission coefficient corresponding to the energy.

as the labor input and the fixed capital stock calculated by the perpetual inventory method as the capital input. Given the depreciation of the fixed capital stock at the rate of 9.6%, the total energy consumption of each province is taken as the energy input. The regional Gross Domestic Prod (GDP) calculated with the GDP of 2008 is taken as the basis of desirable output. And carbon dioxide emissions are regarded as unwanted output. The calculation of this rate is based on the estimation method of the IPCC Guide to National Greenhouse Gas Emission Inventory, 2006 edition. The input and output variables are displayed in Table 1.

Condition Variables

In the process of QCA, the methods that can determine antecedent conditions mainly include a problem-oriented method, research framework method, and theoretical framework method. After the analysis of a large number of kinds of literature, five factors that have an obvious influence on carbon emission efficiency are picked as the antecedents of high carbon emission efficiency. They are environmental regulation, urbanization rate, marketization level, consumer consumption index, and government environmental protection expenditure.

Data Sources

Considering the data availability, 30 provinces (Tibet, Hong Kong, Macao, and Taiwan are excluded due to the lack of data) that respond to the carbon peaking and carbon neutrality goals in China are selected as research samples, and relevant data from 2019 are used to calculate the carbon emission efficiency of each province. The calculation data are from China Statistical Yearbook and China Energy Statistical Yearbook. The data of environmental regulation, urbanization rate, marketization level, consumer consumption index, and government environmental protection expenditure are from China Statistical Yearbook (2019), China Energy Statistical Yearbook (2019), IPCC2006, and CNRDS databases. The descriptive statistical results of each variable are shown in Table 2.

Table 2. The descriptive statistical results of all the variables.

Index	Units	Mean	Std.dev.	Min	Max
Input of labor	10,000 person	570.5633	412.4381	67	2064.6
Input of capital	10.000 Yuan	61350.33	38870.59	10470	158346
Input of energy	10,000 tons	16310.9	9631.61	2264	41390
Regional GDP		11.06721	0.3925273	10.45469	11.99397
Carbon dioxide	10,000 tons	44514.76	31837.17	3250.39	132622.7
Environmental regulation		0.0018557	0.0013106	0.0001289	0.0057061
Urbanization level		0.6232467	0.1084541	0.4615	0.9414
Marketization level		7.532667	2.163618	3.61	11.4
Consumer price index	%	102.7688	0.4101231	101.944	103.716
Government environmental protection expenditure	10,000 yuan	230.9368	140.5756	54.0388	747.439

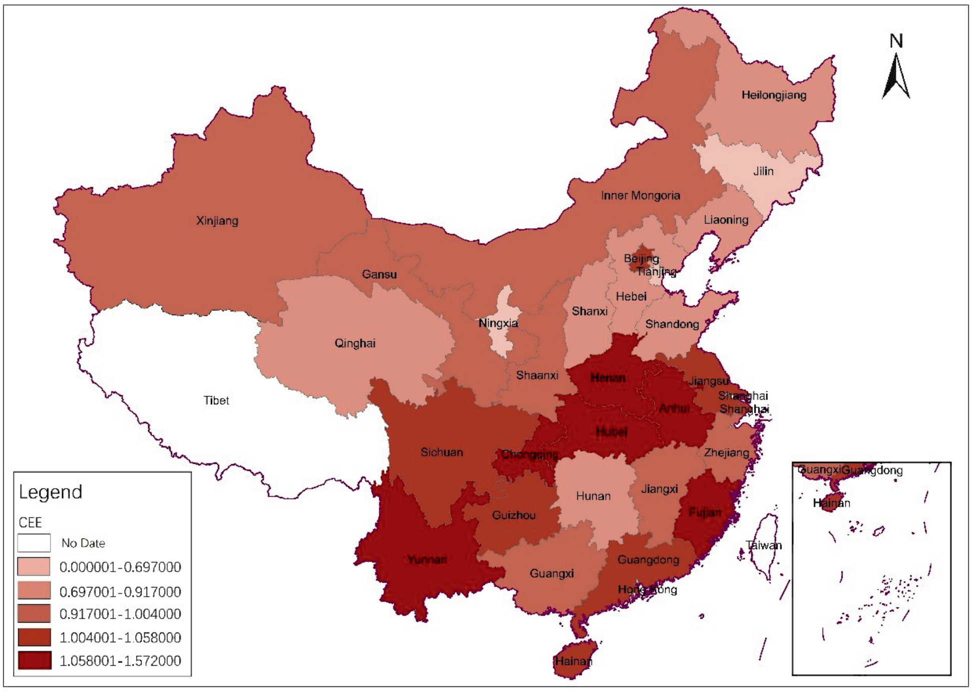

Fig. 2. Carbon Emission Efficiency Distribution Map
(Source: China Standard Map-Review Number GS (2020) 4619).

Data Analysis

Measurement Results of Carbon Emission Efficiency

According to formula (1)-(4), the carbon emission efficiency of the 30 Chinese provinces (excluding Tibet, Hong Kong, and Macao) in 2019 are obtained (as shown in Fig. 2 Paint it by ArcGIS). Through the comparison of the data of each province and municipality, it is found that, in the top ten regions, most are coastal regions, such as Beijing, Fujian, Hainan, Jiangsu, Shanghai, and Guangdong. These areas obtained a better output with relatively less input. The economy of these provinces and municipalities is more developed and the use of energy is more reasonable. The provinces and municipalities that rank in the middle are mostly located in central China, western and northeast China, such as Hebei, Henan, Anhui, Hunan, Shanxi, Jilin, Liaoning, Inner Mongolia, Qinghai, Guangxi, etc. In the progress of their local economic development, the energy utilization ratio is lower than that of the eastern coastal cities. At the same time, to boost their local economy, these areas take over these heavy polluting industries in the eastern region. The provinces and municipalities at the bottom of the carbon emission efficiency list include Gansu, Heilongjiang, Guizhou, Shanxi, etc. These provinces have abundant natural resources like coal and gasoline, but the consumption intensity in these provinces is also high, which leads to low carbon emission efficiency.

Efficiency Improvement Path

Variables Calibration

According to the type of variables, QCA can generally be divided into the clear set qualitative comparative analysis (csQCA), multi-valued qualitative comparative analysis (mvQCA), and fuzzy set qualitative comparative analysis (fsQCA) [44]. csQCA is generally used for variables with clear definitions and distinctions, while the outcome and condition variables selected in this paper can obtain better analysis results by using fsQCA, through Stata and QCA software converts the raw data into pooled data and determines the degree of affiliation, which gives the advantages of both qualitative and quantitative analyses. The current choices for anchor points are 95% and 75%, and the specific steps are as follows: (1) determine the 95% quantile, 50% quantile, and 5% quantile of the different variables through Stata software to determine the full affiliation, crossover point, and full non-affiliation [45]; (2) then use the compute function of QCA software to calibrate the outcome variable and the conditional variable that was converted to collection variables between 0 and 1. The final anchor points for each variable are shown in Table 3.

Analysis of Necessary Conditions

Before conducting the truth table analysis, it is necessary to analyze the necessity of the condition variable. If a condition variable always appears

Table 3. Results and condition variables to calibrate the anchor points.

Variables		Fully affiliation	Cross point	Fully non-affiliation
Result Variables	CEE	1.2735	1.00175	0.6752
Conditional Variables	ER	0.003852904	0.001569516	0.000375137
	UL	0.85853	0.6031	0.50617
	MI	10.942	7.62	4.511
	CPI	103.404915	102.77055	102.16492
	GEPE	444.12113	208.1083	66.962655
Note: Carbon emission efficiency (CEE), Environmental regulation (ER), Urbanization level (UL), Marketization index (MI), Consumer price index (CPI), Government environmental protection expenditure (GEPE).				

when the result occurs, it means that this condition is a necessary condition, and the histogram analysis generally determines whether it is a necessary condition by the consistency, and if the consistency is greater than 0.9 after the software analysis, the condition can be considered necessary, and the condition needs to be removed in the next step of the truth table analysis. In this paper, QCA software was used to analyze the five condition variables in 2019 to obtain sufficient-essential results (as in Table 4) [46].

It can be seen from Table 3 that the consistency levels of the condition variables do not reach 0.9, indicating that none of the five condition variables is necessary for the outcome variable, and the influence of a single variable on carbon emission efficiency is weak and different variables need to cooperate to affect carbon emission efficiency in each province. In detail, the consistency level of four indicators, namely, urbanization level, marketization rate, resident consumption index, and government environmental protection expenditure, is above 0.6, among which government environmental protection expenditure and marketization rate have a greater impact on carbon emission efficiency. Based on the analysis of the necessary conditions, it is necessary to further explore the influence of different combinations of condition variables on carbon emission efficiency.

Table 4. Conditional analysis of the conditional variables.

Conditional Variables	Consistency	Coverage
ER	0.551773	0.536552
~ER	0.756028	0.687742
UL	0.617021	0.633649
~UL	0.751064	0.650891
MI	0.703546	0.694678
~MI	0.626241	0.561705
CPI	0.648227	0.617568
~CPI	0.65461	0.607237
GEPE	0.706383	0.689273
~GEPE	0.650355	0.589711

Analysis of Conditional Configuration

In the histogram analysis, the number of cases and the familiarity of the researchers with the cases affect the setting of the threshold value, and there are generally two kinds of one-time thresholds of 0.75 and 0.8 in the existing studies. In this paper, a one-time threshold of 0.8 is set according to the sample situation analysis, a frequency threshold of 1 is set considering the small number of samples, a PRI consistency threshold of 0.5 is set, and the complex, intermediate and simple solutions are obtained after running. The complex solution includes all the groups of the actual observed cases, the simple solution incorporates the "easy" and "difficult" "logical remainders" based on the actual cases, and the intermediate solution includes the "easy" and "difficult" "logical remainders" based on the actual cases, and the intermediate solution includes the grouping of the actual observed cases and the "easy logical remainders". The intermediate solution is between the two solutions and is more reasonable for path and case interpretation, so this paper mainly uses the intermediate solution combined with the simple solution for analysis [47].

The combined analysis results were obtained according to the intermediate and simple solutions (as shown in Table 3). Among them, the conditional variables that appear in both intermediate and simple solutions are core conditions, and the variables that appear only in intermediate solutions are marginal conditions. As can be seen from the table, there are four combination paths, and the total consistency level is 0.822277, which is higher than the consistency theoretical threshold of 0.8, indicating that the four combination paths are sufficient conditions to influence carbon emission efficiency, and the total coverage rate is 0.712057, indicating that the four paths can explain the influence of antecedent conditions on carbon emission efficiency up to more than 70%, and the

Table 5. Analysis of the combination of high carbon emission efficiency antecedents.

Conditional Variables	Path 1	Path 2	Path 3	Path 4
ER	○	■	○	○
UL	■	○		○
MI	●	●	●	□
CPI	□		■	○
GEPE		●	■	□
Raw coverage	0.374468	0.321986	0.461702	0.310638
Unique coverage	0.0822695	0.0588654	0.124823	0.0971631
Consistency	0.852989	0.86148	0.832481	0.895705
Solution coverage	0.712057			
Solution consistency	0.822277			

Note: ● means the core condition exists, ■ means the marginal condition exists, ○ means the core condition is missing, □ means the marginal condition is missing, and blank means the variable does not exist. Same as below.

selected antecedent conditions have strong explanatory strength.

Through a comparative analysis of the condition combinations of the four paths and the provinces under the paths, a total of four paths exist that can achieve high carbon emission efficiency. (1) Path 1 (~ER*UL*MI*~CPI): the core variable under this path is the marketization rate, the marginal condition is the level of urbanization, the values of environmental regulation and residents' consumption index are low, and the government environmental protection expenditure does not exist, indicating that the carbon emission efficiency of the provinces under this path is mainly dominated by the market. An important measure of a region's economic development level is the marketization rate and urbanization level. The higher the marketization rate the higher the degree of productive services, where high-end services have a significant positive contribution, and the urbanization level has an impact on R&D investment, technology introduction, information technology infrastructure construction and industrial structure, which affects urban carbon emission efficiency. From the government's perspective, with higher marketization and urbanization, the market has a strong regulatory capacity and does not require excessive government intervention, so there is no need to introduce strong environmental regulation policies under such regions, and the market will take the initiative to eliminate enterprises that seriously hinder the improvement of carbon emission efficiency. The typical provinces under path 1 are Beijing, Fujian and Chongqing, among which Beijing, as the capital, has a high level of market index and urbanization, a high level of development of high-end service industries, and a high level of urbanization that puts science and technology innovation, infrastructure and industrial structure at a high level, both of which have obvious positive promotion effects on Beijing's carbon emission efficiency. (2) Path 2 (ER*~UL*MI*GEPE): This path is characterized by the strong support from the government for the improvement of carbon emission efficiency, with government environmental spending and market-oriented index as the core conditions, environmental regulation as the marginal condition, and the non-existence of the resident consumption index, indicating that the government's fiscal spending on the environment and environmental regulation policies have an important impact on the improvement of carbon emission efficiency. Therefore, to improve carbon emission efficiency, the government needs to enhance government environmental expenditure through fiscal transfer payments and introduce environmental regulation policies to ensure the improvement of carbon emission efficiency. The government's environmental expenditure can provide a financial guarantee for the upgrading and transformation of enterprises, and the environmental regulation policies can improve the level of urban technological innovation and adjust the energy structure of cities and finally achieve the improvement of carbon emission efficiency. The typical provinces under this path are Shaanxi, Anhui, and Henan, among which Henan Province has gradually optimized the ratio of primary, secondary, and tertiary industries after a long period of development, but the primary industry still dominates at present, and enterprises are under greater pressure to face environmental protection and carbon emission efficiency improvement for their development, so they need to help enterprises to upgrade and improve carbon emission efficiency through government funding and environmental regulatory policies. (3) Path 3 (~ER*MI*CPI*GEPE): This path is characterized by the fact that the improvement of carbon emission efficiency is influenced by both the market and the government. The three variables of marketization rate, consumer consumption index, and government environmental protection expenditure play an important role in the improvement of carbon emission efficiency of the provinces under this path. To create a better working and living environment, the government will also increase its investment in environmental protection to form positive feedback and effectively improve carbon emission efficiency to build a green and healthy environment. The typical provinces under this path are Guangdong, Hubei, Zhejiang, Jiangsu, Hunan, and Sichuan. The environmental investment will also increase to improve the natural environment, business environment, and consumption environment, which has a significant role in promoting the efficiency of carbon emissions. (4) Path 4 (~ER*~UL*~MI*~CPI*~GEPE): this path is characterized by the weak influence of both market and government on improving carbon emission efficiency, as can be seen from the conditions, environmental regulation, urbanization level, market index, resident consumption index and government environmental protection expenditure all exist, where environmental regulation, urbanization level, and consumption index are missing in the core condition, and marketization rate and government environmental protection expenditure are missing in the marginal condition, indicating that the five antecedent variables have less influence on the provinces under this pathway, and high carbon emission efficiency can be achieved at a lower level. The typical provinces under this pathway, Guizhou and Yunnan, have the first and second highest forest coverage rates in China, with Yunnan Province focusing on building green "three cards" such as green energy, green food, and healthy living destinations, and continuously strengthening the construction of clean energy, mainly hydropower, so that the share of non-fossil energy in primary energy consumption exceeds 40%. Therefore, it can effectively improve carbon emission efficiency.

Through the study of the four paths, it can be found that a single variable cannot have a decisive influence on carbon emission efficiency, and the influence of conditional variables on the outcome variables will be influenced by other condition variables. Therefore, for any province or city to allocate resources, it should focus on comprehensive development instead of developing only one resource element, but it also needs to choose a high carbon emission efficiency path that suits itself according to the objective situation and develop synergistically.

Conclusion and Outlook

Research Conclusions

This paper measures the carbon emission efficiency of 30 Chinese provinces and municipalities based on the CO_2 emissions of each province in China using the SBM-ML index model with non-expected output and then analyzes the effects of five antecedent variables, namely, environmental regulation, urbanization level, marketization rate, resident consumption index, and government environmental protection expenditure, on the carbon emission efficiency of each province based on fuzzy set qualitative comparative analysis (fsQCA), and different combinations to achieve paths of high carbon emission efficiency. The main findings are as follows.

One is to explore the factors affecting the carbon emission efficiency of provinces and cities at the micro level. The total consistency level of the four combined paths was 0.822277, indicating that the influencing factors under the four paths are sufficient conditions for the outcome variable. Specifically, the carbon emission efficiency of each province and city is affected by the synergistic effects of environmental regulation, urbanization level, marketization rate, residential consumption index, and government environmental protection expenditure, with multiple concurrent characteristics. A total of four paths that can achieve high carbon emission efficiency of provinces and cities are identified through group analysis: the core variable of path 1 is the marketization rate, the marginal condition is the urbanization level, and the market plays a major role in the improvement of carbon emission efficiency under this path; under path 2, government environmental expenditure and marketization rate are the core conditions, environmental regulation is the marginal condition, and the resident consumption index is missing, indicating that the government has a strong role in improving carbon emission efficiency Under path 3, the core variable is the marketization rate, the marginal condition is the resident consumption index and the government environmental protection expenditure, the environmental regulation condition does not exist, and the urbanization level condition is missing, indicating that the improvement of carbon emission efficiency is influenced by both the market and the government. The higher the level of marketization, the stronger the consumption power of the residents can effectively promote technological innovation, while the government can better promote the improvement of carbon emission efficiency by providing support. The marginal conditions are missing, indicating that high carbon efficiency can be achieved even when all five conditions are weak. By comparing each path, it can be seen that different precursor conditions can be used as important influence conditions, indicating that each precursor condition is essential, and different precursor conditions play a leading role under different paths.

The second is to combine the influencing factors under different paths and specific cases for the overall analysis. The total coverage rate of the four paths is 0.712057, covering 70% of the cases. Through the cases, an in-depth analysis of the carbon emission efficiency improvement paths can be conducted to explore the specific situation of different factors under the specific cases. For provinces and cities such as Beijing, Fujian, and Chongqing, the marketization rate and urbanization level are at a high level, the high-end service industry is developing at a high level, and the higher urbanization level makes science and technology innovation, infrastructure, and industrial structure at a high level, both of which have obvious positive promotion effect on carbon emission efficiency. For provinces like Shaanxi, Anhui, and Henan, after a long period of development, the ratio of primary, secondary, and tertiary industries is gradually optimized, but the primary industry still dominates, and enterprises may be under greater pressure to protect the environment and improve carbon emission efficiency for their development. Therefore, government funding and environmental regulation policies are needed to help enterprises to upgrade and improve their carbon emission efficiency. For provinces such as Guangdong, Hubei, Zhejiang, Jiangsu, Hunan, and Sichuan, the degree of marketization is at a high level, and the tertiary industry has taken an absolute advantage after years of development, and the high-end service industry brings significant positive drivers for the surrounding areas. The increase in government revenue also positively feeds back to environmental investment, which improves the natural environment, business environment, and consumption environment, and has a significant effect on improving carbon emission efficiency. For provinces with good natural resources, such as Guizhou and Yunnan, environmental regulations, urbanization level, market index, residents' consumption index, and government environmental protection expenditure have weaker effects on carbon emission efficiency, and Guizhou and Yunnan have the first and second highest forest coverage rates in China.

Policy Insights

Based on the above analysis, this paper puts forward the following policy recommendations for provinces and cities to improve their carbon emission efficiency.

(1) Pay attention to the quality of government services and improve the level of marketization. The higher the degree of marketization, the higher the degree of market service segmentation, and the higher the quality of service that can be brought to consumers. Enhance the level of marketization not only relies on full market competition, but also requires efficient government service capabilities, so it is necessary to optimize the process of government services, simplify the relevant procedures, and improve the efficiency of the use of public resources so that operators can improve the level and quality of service, and consumers can feel confident and bold to consume.

(2) Improve the level of scientific and technological innovation and promote the upgrading of industrial structure. The high level of science and technology innovation directly affects the regional high-end production service industry, which has a more obvious role in promoting the carbon emission efficiency of local and neighboring areas, and the high-end production service industry is also a necessary foundation for the industrial optimization and upgrading of the service and manufacturing industries.

Optimize environmental regulation policies and increase environmental expenditure. Effective environmental regulation policies can effectively guide enterprises to make adjustments while avoiding them from making wrong choices due to economic interests, and at the same time, increased government spending on the environment can help enterprises solve financial and technical problems in the process of improving carbon emission efficiency.

Shortcomings and Prospect

This paper only explores the impact on the carbon emission efficiency of each province from the market, environmental and economic perspectives, many other factors have an impact on the carbon emission efficiency of each province, and we can try to select more areas and introduce more influencing factors to explore the impact on the carbon emission efficiency more deeply in the future.

Conflict of Interest

The authors declare no conflict of interest.

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