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Original Research

How Do Different Types of Environmental Regulations Affect Green Energy Efficiency? – A Study Based on fsQCA

Liang Liu[1#], Shu Liu [1#], Yirui Yang[1], Xiujuan Gong[1] , Yuting Zhao[1], Ruifeng Jin[1], Donglin Ren[1], Pan Jiang [1, 2*]

[1]School of Economics and Management, Southwest University of Science and Technology, Mianyang 621010, Sichuan, China
[2]School of Environment and Resources, Southwest University of Science and Technology, Mianyang Sichuan 621010, Sichuan, China

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Abstract

Faced with both economic and environmental pressures, how to improve energy efficiency in a green way is gradually attracting attention. Reasonable environmental regulations can promote the green transformation of energy and improve green energy efficiency, which is of great practical significance for achieving global sustainable development. This paper measures the green energy efficiency of 30 Chinese provinces in 2019 based on the Super-SBM model, selects five representative antecedent conditions of three environmental regulation dimensions: command-and-control, market-incentive, and voluntary public, and uses fsQCA to explore the group effects and enhancement paths of different types of environmental regulations on green energy efficiency. The results found that (1) there are four green energy efficiency enhancement paths: government pressure type, market mobilization type, government-led public association type, and multiple subject type; (2) command-and-control type environmental regulations play an important role in enhancing green energy efficiency in most provinces; and (3) multiple subject type enhancement paths can achieve higher green energy efficiency. This study investigates the impact of environmental regulation on green energy efficiency in order to provide reference and reference for the improvement of green energy efficiency in China's provinces.

Keywords: environmental regulation, super slack based measure, green energy efficiency, fuzzy-set qualitative comparative analysis

# These authors contributed equally to this work and should be considered co-first authors.
*e-mail: jp510722@163.com

Introduction

The global warming trend continues, with glacier melting, sea level rise, heat wave invasion, drought and other hazards persisting, and human society and nature are facing an increasingly severe ecological and environmental situation. Energy consumption is an important condition for economic growth, but also an important reason for the destruction of the ecological environment. In the face of increasing pollution and ecological degradation, how to improve energy efficiency in a green way has gradually become a concern [1]. Based on the development concept of "green water and the green mountain is the silver mountain of gold", the study of environmental regulation can effectively improve green energy efficiency and help achieve sustainable development [2].

With the increasing awareness of environmental protection, international attention is being paid to the issue of green energy efficiency more and more. The 7th Annual Global Energy Efficiency Conference shows that adhering to the concept of green development and improving energy efficiency is the top priority in addressing climate change and solving international energy problems [3]. As a major energy-consuming country, it is China's due responsibility to follow international green energy concepts, participate in global environmental governance and safeguard the common interests of all mankind. Since the reform and opening up, China's economy has grown by leaps and bounds, with a GDP of $1,120,207 billion by 2022, up 3.0% from the previous year. Meanwhile, since the reform and opening up to 2022, China's National Bureau of Statistics shows that China's total energy consumption has increased from 630 million tons of standard to 5.41 billion standard coal year by year [4]. However, China's current economic development is still characterized by high dependence on energy consumption and low energy use efficiency, which has caused serious environmental pollution, and how to transform the energy system with high energy consumption and high pollution into a green energy efficiency system is an urgent problem for China. Xi Jinping mentioned at the 20th National Congress of the Communist Party of China that to achieve China's "double carbon" goal "based on energy endowment, promote the clean, low-carbon and efficient use of energy." Environmental regulation, as an important grasp to improve energy use efficiency, addresses the negative externalities caused by environmental pollution by restraining polluting behavior [5-6]. In recent years, China has actively implemented different types of environmental regulations for green and low-carbon energy transformation, such as the Regulations for Central Ecological and Environmental Protection Inspectors, the Reform Plan for the Ecological and Environmental Damage Compensation System, and the Opinions on Improving Institutional Mechanisms and Policy Measures for Green and Low-Carbon Energy Transformation. With the promotion of environmental regulation, according to the Statistical Bulletin of the National Economic and Social Development of the People's Republic of China 2022, China's energy consumption of 10,000 yuan of GDP decreased by 0.1% compared with last year, the proportion of clean energy consumption reached 25.9%, CO_2 emissions of 10,000 yuan of GDP decreased by 0.8%, and the average concentration of PM2.5 decreased by 3.3 % compared with the previous year. Environmental regulations have driven the green and low-carbon transformation of energy with remarkable results, and the efficiency of energy resource utilization has increased significantly [4]. However, China still faces prominent energy constraint problems, and continuous improvement of environmental policies is needed to reach higher targets.

In the face of economic and environmental dilemmas, environmental regulation has become an important measure to improve green energy efficiency. Different environmental regulations and their combinations have different impacts on green energy efficiency, and how to properly formulate and select environmental regulations has become a hot topic of research nowadays. Therefore, this paper is dedicated to investigate the impact mechanisms and improvement paths of different types of environmental regulations on green energy efficiency. Firstly, the Super Slack Based Measure (Super-SBM) model is used to calculate the green energy efficiency values of each province. Second, based on the data of different types of environmental regulations in 30 Chinese provinces in 2019, the Fuzzy-set Qualitative Comparative Analysis (fsQCA) method is applied to explore the combined effects of command-and-control, market-incentive and public voluntary environmental regulations on green energy efficiency and obtain the green energy efficiency improvement paths. Finally, based on the results of the study, we hope to propose realistic policy recommendations for realizing China's green and low-carbon energy transition and improving green energy efficiency in each province and city.

Material and Methods

Literature Review

Improving green energy efficiency is an effective way to accelerate the green energy transition in China. How to properly measure energy efficiency is a prerequisite for the study of green energy efficiency. The current literature on energy measurement contains methods such as single factor efficiency measurement [7], total factor efficiency measurement [8,9], stochastic frontier analysis (SFA) [10-12], data envelopment analysis (DEA) [13, 14], etc. Each measurement method has differences and unique applicability. Scholars have studied different perspectives and found that green technology [15, 16], economy [17, 18], industrial agglomeration [19], and environmental regulation [20, 21] all have an impact on green energy efficiency. In this paper, we focus on the mechanism of environmental regulation on green energy efficiency grouping.

Environmental regulation is a binding force aimed at protecting the environment and exists in the form of tangible institutions and intangible awareness. With the development of environmental regulation, the classification of environmental regulation by scholars is not uniform. According to different governmental actions, environmental regulations are divided into coercive and incentive-based environmental regulations [22, 23], which are specifically subdivided into command-and-control, market-incentive, and voluntary public [24-26] environmental regulations; cost-based and investment-based environmental regulations [27, 28] according to different financial investment methods; and formal and informal environmental regulations according to different actors [29, 30]. Among the existing studies, command-and-control, market-incentive, and public-voluntary regulations are widely respected and used by scholars because of their comprehensive classification perspectives and outstanding characteristics. The command-and-control type of environmental regulation restricts the behavior that endangers the environment through laws and regulations, and the main tools include: environmental administrative penalties [31], environmental treatment investment [32], environmental administrative inspectors [33], etc., which are characterized by rapid and objective improvement of the environment and have certain compulsory and mechanical nature; the market incentive type of environmental regulation guides enterprises to protect the environment with the help of the market, and the main tools include: emission fees [34, 35], taxes and fees [36], subsidies [37], etc., which are characterized by the freedom of choice of economic agents and have a certain time lag and freedom; voluntary public environmental regulation exists within the individual and is an invisible ideological attitude, the extent of which is judged by the environmental awareness of the masses and has an implicit and voluntary nature [38].

By sorting out the existing studies, this paper selects command-and-control, market-incentive and public-voluntary environmental regulations as the classification criteria of the antecedent variables in this paper. The command-and-control environmental regulation has a binding effect on the heavily polluting enterprises, and the legislation and standards are used to impose serious penalties on violations and cover all aspects of treatment. In this paper, we choose emission fees and environmental protection expenditure as the indicators of market incentive environmental regulation; voluntary public environmental regulation is the embodiment of public awareness of environmental protection and plays a supervisory role in environmental protection.

However, regardless of the type of environmental regulation, its main purpose is to improve China's environment, expect green development of energy efficiency, and thus promote China's energy green transformation. Scholars have studied how different types of environmental regulations affect green energy efficiency, and there are three main views. The first one supports the "Porter hypopaper", which argues that reasonable environmental regulation gives firms a competitive advantage and enhances green energy efficiency by stimulating their technological innovation [39]. Hongbin Tian found that environmental regulation stimulates green technology innovation, promotes green patent inventions, and enhances green innovation efficiency [40]. Qiaoxin Xie used a sample of listed companies in the manufacturing industry to confirm the positive moderating effect of environmental regulations on firms' technological innovation [41]. Hua Zhang used the green energy efficiency estimation method to verify the existence of "Porter's hypopaper" in the energy sector within a certain range [42]. Some scholars oppose Porter's hypopaper and support the second viewpoint, the cost hypopaper, which suggests that environmental regulations put additional cost pressure on enterprises to invest more money in environmental management, which reduces their competitiveness [43] and inhibits the improvement of green energy efficiency. Using a double difference approach, Yankun Xu found that environmental regulations inhibit firms' innovation and increase costs constraining firms' green production efficiency [44]. Fuxin Jiang studied panel data of 28 manufacturing firms and found that environmental regulation reduces firm technological innovation by inhibiting technology spillover and firm large-scale effects [45], which negatively affects green energy efficiency. The third group of scholars takes a "heterogeneous" approach to the relationship between environmental regulation and green energy efficiency, arguing that the relationship between environmental regulation and green energy efficiency is not just a single trend of "promoting" or "inhibiting", but has a differential effects. Lin combined the "Porter hypopaper" and "cost hypopaper" to detect the heterogeneous effect of environmental regulation on industrial energy efficiency in China, indicating that environmental regulation is not relevant for energy efficiency in low-resource areas, but significantly promotes it in high-resource areas [46]. Lin used a Tobit regression model to conclude that environmental regulation promotes green energy efficiency in eastern China, but hurts the central and western regions due to the green paradox [47].

The three perspectives validate the relationship between environmental regulations and green energy efficiency from different aspects. From the established literature studying green energy efficiency, this paper differs from previous studies in the following ways. First, fewer studies are exploring the impact of green energy efficiency from the perspective of different types of environmental regulations. There have been studies that treat environmental regulation as a single element and do not explore the impact of different types of environmental regulation on green energy efficiency in depth. However, different types of environmental regulations can produce different impacts on green energy efficiency, which cannot be represented by a single indicator. Second, most of the existing studies are based on quantitative empirical analysis methods, and few of them combine qualitative methods to analyze. In contrast, this paper adopts the fsQCA method that combines quantitative and qualitative approaches to better explore the necessity and sufficient causal relationships among variables. Based on this, this paper selects 30 Chinese provinces and cities as research samples and adopts the fsQCA method to study the influence mechanism of inter-group effects of different types of environmental regulations on green energy efficiency, to find out the optimal path to improve green energy efficiency and make scientific suggestions for the realization of China's green and low-carbon energy transition.

Theoretical Foundation

The theory of sustainable development is a theory that seeks to meet the needs of the present without jeopardizing the development needs of future generations [48]. It treats human development, energy use, and environmental protection as an organic whole and emphasizes the principles of equity, sustainability, and commonality. According to the theory, economic and social activities should be carried out globally with sustainable goals to develop energy efficiency in a greener way [49, 50]. In this paper, we uphold the principle of sustainable development and select green energy efficiency as the outcome variable of this paper to explore the path of improving green energy efficiency in China, in the hope that the environment of Chinese provinces will be green, sustainable, and coordinated.

The environmental regulation theory is developed based on the theory of regulatory economics, which believes that the government needs to develop a policy system to eliminate negative externalities from the market. Through government intervention, the negative externalities brought by the market can be reduced to meet the needs of the public and bring well-being to the whole society. Environmental regulation has become an indispensable tool for environmental governance in China, and with the development of society and economy, environmental regulation has been gradually subdivided into different types. The role of different types of environmental regulations on environmental protection and energy use varies. In this paper, drawing on Yulong Zhao [38], we classify environmental regulations into command-and-control, market-incentive, and public-voluntary types to study the effects of different types of environmental regulations on green energy efficiency grouping.

Energy economic theory aims to seek a reasonable way of energy development and utilization to meet the process of social and economic development. As the research progresses, energy economic theory is no longer limited to the relationship between energy and economy, but also emphasizes the coordinated development of energy-economy-environment. Energy use is an important input and driver of economic growth, but there are negative externalities in energy use, which can pollute and damage the environment in the process of energy use. Faced with the contradiction between exhaustible and indispensable energy, we should not only consider economic development but also pay attention to environmental issues and eliminate the negative externalities of energy use. The elimination of negative energy externalities requires thinking about how to formulate reasonable environmental regulations according to the characteristics of different regions to protect the regional environment and enhance regional green energy efficiency. From the perspective of different types of environmental regulations, command-and-control environmental regulations can quickly and effectively improve the regional environment by imposing government administrative penalties and government governance investments to curb negative energy externalities; market-incentivized environmental regulations can be used to curb enterprises' bias toward costly inputs with high negative externalities by collecting sewage charges and environmental fiscal expenditures and incentivizing enterprises to green their technology and innovation according to their development needs. The government and the market alone can hardly solve the problem of negative energy externalities, so public voluntary environmental regulation, such as proposals, is needed to achieve a multifaceted environmental governance mechanism of government control, market regulation, and public restraint to achieve high efficiency of green energy.

This paper explores the different effects of three types of environmental regulations on green energy efficiency, namely, command-and-control environmental regulation, market-inspired environmental regulation, and public voluntary environmental regulation, from the perspectives of government, market, and public, respectively. According to sustainable development theory, environmental regulation theory, and energy economy theory, this paper takes five indicators of three types of environmental regulations as the antecedent variables and green energy efficiency as the outcome variable, explores the group effect of three types of environmental regulations on green energy efficiency through fsQCA method, and explores the path to improve green energy efficiency. The research framework is shown in Fig. 1.

Research Methodology

In this paper, we choose the Super-SBM model to measure green energy efficiency, and on this basis,

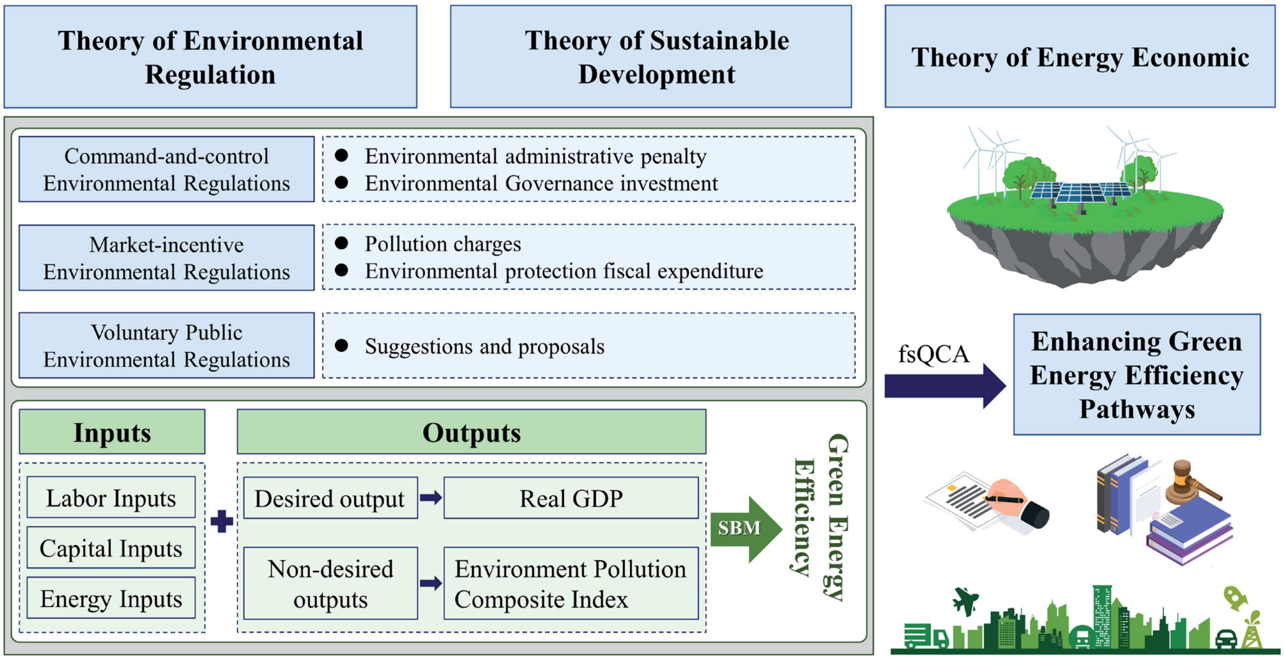

Fig. 1. Research Framework.

we adopt the fsQCA method to explore the improvement path of green energy efficiency in the context of different types of environmental regulations.

Super-SBM Model

The mainstream methods for measuring efficiency are currently divided into two types, data envelopment analysis (DEA) and stochastic frontier analysis (SFA). This paper adopts the DEA method to measure green energy efficiency because of the characteristics of "multiple inputs and multiple outputs" and the fact that the DEA method does not require pre-calculated weights. DEA methods do not require the construction of production functions or evaluation systems, and the data can be objectively evaluated from the perspective of multiple inputs and multiple outputs. DEA methods are widely used to measure efficiency, but traditional DEA also has the drawback that it cannot distinguish between desired and undesired outputs. The SBM model is an essential innovation of the DEA method, but it has some limitations, i.e., it cannot be used to rank DMUs with an efficiency greater than 1. The Super-SBM model can effectively overcome the shortcomings of traditional DEA [51]. The Super-SBM model effectively overcomes these shortcomings and can distinguish differences in efficiency values more precisely [52]. In recent years, more and more scholars have adopted the Super-SBM model to measure efficiency values, and it is widely used to measure efficiency values in sustainable development [53], low-carbon economy [54], ecological environment [55], and energy [56, 57]. The reasons for choosing the Super-SBM model in this paper are as follows: the Super-SBM model comprehensively considers input, desired output, and non-desired output indicators, which is consistent with the characteristics of green energy efficiency of the research object. Secondly, the Super-SBM model can calculate the Super-1 efficiency and can compare the differences in efficiency values among various regions in China in detailThe Super-SBM model (with variable payoffs to scale) used to calculate green energy efficiency in 30 Chinese provinces, with reference to the Tone super-efficiency formula [58], is expressed as follows.

In this paper, we assume that there exist n DMUs, each with m inputs, q desired outputs, and r non-desired outputs, where the inputs, desired outputs, and non-desired outputs are denoted as x, y, and b, respectively, and $x \in R^m$, $y \in R^q$, $b \in R^r$.

$$\gamma^* = min \frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^x}{x_{i0}}}{1+\frac{1}{q+r}\left(\sum_{p=1}^{q}\frac{s_p^y}{y_{p0}}+\sum_{k=1}^{r}\frac{s_k^b}{b_{k0}}\right)} \quad (1)$$

$$\begin{cases} \sum_{j=1,j\neq 0}^{n} x_{ij}\lambda_j \le x_{i0} + s_i^x (i = 1,2,3,\dots,m) \\ \sum_{j=1,j\neq 0}^{n} y_{pj}\lambda_j \ge y_{p0} - s_p^y (p = 1,2,3,\dots,q) \\ \sum_{j=1,j\neq 0}^{n} b_{kj}\lambda_j \le b_{k0} + s_k^b (k = 1,2,3,\dots,r) \\ \sum_{j=1}^{n}\lambda_j = 1(VRS) \\ \lambda_j \ge 0, s_i^X \ge 0, s_p^y \ge 0, s_k^b \ge 0 \end{cases} \quad (2)$$

where s_i^x denotes input slack variables, s_p^y denotes desired output slack variables, and s_k^b is non-desired output slack variables, i.e., quantities for which inputs and outputs can be further optimized and improved; λ denotes the weight vector; VRS denotes variable payoffs to scale, and y^* is the green energy efficiency value. The DMU reaches efficiency when and only when $y^* \geq 1$. Otherwise, the DMU is inefficient, and the inputs and outputs need further improvement.

Qualitative Comparative Analysis of Fuzzy Sets

Social science analytical research methods can be divided into two main categories, namely qualitative and quantitative research methods. Each of the two methods has its unique advantages in different aspects but also has its shortcomings. To compensate for the shortcomings of both methods, Charles C. Ragin attempted to combine qualitative and quantitative methods in 1987, giving birth to Qualitative Comparative Analysis (QCA) [59]. The QCA method is suitable for small and medium-sized sample studies and can be divided into the clear-set qualitative comparative analysis (csQCA), multi-valued qualitative comparative analysis (mvQCA), and fuzzy-set qualitative comparative analysis (fsQCA) based on the characteristics of the antecedent variables. Among them, csQCA can only deal with data where the antecedent condition is calibrated to 0 or 1 with the outcome. mvQCA makes up for the deficiency of data processing of csQCA, but mvQCA and csQCA are only applicable to analyze category problems. In contrast to the first two QCA methods, fsQCA possesses greater advantages and can handle three types of problems: category, degree change, and partial affiliation [60].

The reasons for choosing fsQCA in this paper are as follows: 30 provinces in China are used as case samples, which meets the requirement that fsQCA is suitable for small and medium-sized samples. Each province in China has a different resource endowment and geographic location, and the factors affecting green energy efficiency are complex, so we cannot simply analyze the "one-to-one" cause-effect relationship, but need to compare the impact of the group relationship between variables on green energy efficiency. Therefore, based on the scope of application of fsQCA, the purpose of this study, and the characteristics of the analyzed objects and data, fsQCA is chosen as the research method of this paper.

Sample Description

In this paper, 30 provincial-level regions in China are selected as the study cases (samples from Tibet, Hong Kong, Macao, and Taiwan are excluded due to the unavailability of relevant data), which meet the requirement that fsQCA applies to a small and medium-sized number of samples. And through the fsQCA method, we explore the improvement paths of different types of environmental regulation antecedent variable grouping on green energy efficiency in the 30 provincial samples in China.

Measurement and Data Sources

Result Variables

In this paper, the Super-SBM model is used to measure the green energy efficiency values of 30 Chinese provinces in 2019, and the resulting values are used as the outcome variables in this study. Based on the existing literature and drawing on the studies of Ming Meng [61], Zhao [62], and Liu [63], the Super-SBM model is constructed by using labor, capital, and energy consumption as input variables, the real GDP of each province as the desired output, and the comprehensive index of environmental pollution obtained by the entropy weight method as the non-desired output.

(1) Labor inputs. Labor resources contain both quantitative and qualitative dimensions, but the calculation of labor quality has not been unified, and data on the average years of education in each province are not available, the number of employed population can measure the degree of labor contribution to energy efficiency to some extent. Therefore, this paper selects the number of the employed population in each province of China at the end of 2019 as the labor input in this study in million.

(2) Capital inputs. Most scholars use the indicator of capital stock, which responds to the total amount of various types of capital input at a certain point and more objectively responds to the comprehensive indexes of production technology level and business scale. Referring to the study by Jun Zhang [64] and Haoge Shan [65], the capital stock of each province in 2019 was calculated using the perpetual inventory method. The formula is:

$$K_{it} = K_{i,t-1}(1 - \delta_{it}) + I_{it} \tag{3}$$

In the above equation, Kit denotes the capital stock of province i in year t; δ_{it} denotes the depreciation rate of fixed assets; and I_{it} denotes the amount of fixed investment in province i in constant prices in that year. Considering the depreciation of the fixed capital stock, the depreciation rate is 10.96%.

(3) Energy inputs. The total energy consumption of each Chinese province at the end of 2019 is chosen as the energy input for this study, in million tons of standard coal.

(4) Desired output. The GDP of each province in China is selected and converted into real GDP in 2011 as the desired output in billion yuan.

(5) Non-desired outputs. It mainly refers to the pollution emitted during the production process, mainly wastewater, waste gas, and solid waste, etc. Considering the integrity and availability of data, the entropy weight method is used to process the sulfur dioxide emissions (tons), wastewater emissions (tons), and general industrial solid waste (tons) generation of each province in China at the end of 2019, and the data of these three indicators are dimensionless,

Table 1. Input-output related variables.

	Variable Name	Variable Definition	Measure units	Resources
Inputs	Labor inputs	Total number of employed persons at the end of the year	Per ten thousand person	CSMAR
	Capital inputs	$K_{it} = K_{i,t-1}(1 - \delta_{it}) + I_{it}$ (3)	Hundred million RMB	CHINA STATISTICAL YEARBOOK
	Energy inputs	Total energy consumption expressed in standard coal	Ten thousand tons	CSMAR
Desired output	Regional GDP	Adjusted real GDP calculated using 2011 as the base period	Hundred million RMB	CSMAR
Non-desired outputs	Environmental pollution composite index	The sum of sulfur dioxide emissions (tons), wastewater emissions (tons), and general industrial solid waste (10,000 tons) treated by the entropy method of empowerment area	-	CHINA STATISTICAL YEARBOOK ON ENVIRONMENT

and the positive standard treatment is selected, referring to the algorithm of Ma, Haitao [66] to the comprehensive index of environmental pollution as the non-desired output.

Details of the input-output variables are shown in Table 1.

Antecedent Variables

There are various factors influencing green energy efficiency, and in this paper, five antecedent variables are selected from three different types of environmental regulation dimensions: environmental administrative penalties, investment in environmental management, emission fees, environmental fiscal expenditures, and proposals.

(1) Command-and-control environmental regulation dimension. Environmental administrative punishment aims to maintain the sustainable development of the ecological environment, including three regulatory functions: legal deterrence, risk prevention, and ecological restoration [67], which prompt enterprises to choose green production methods, thus affecting green energy efficiency; environmental management investment includes investment in industrial pollution source management, investment in "three simultaneous" environmental protection of construction projects, and investment in urban Environmental governance investment include industrial pollution source treatment investment, construction project "three simultaneous" environmental protection investment, and urban environmental infrastructure construction investment [68], which changes the governance ideology from "after pollution" to source treatment, prompting enterprises to choose green and clean energy, thus affecting green energy efficiency. The number of environmental administrative punishment cases in each province in China in 2019 and the share of investment in environmental governance in regional GDP are chosen to represent the antecedent variables of environmental administrative punishment (EAP) and investment in environmental governance (EGI).

(2) Market-incentivized environmental regulation dimension. Pollution charges are one of the manifestations of the "Pigou tax", which aims to curb negative externalities of enterprises [69] and drive green technology innovation [70], thus affecting green energy efficiency; environmental fiscal expenditure is a "breakthrough" for industrial technology upgrading in China, which drives environmental fiscal spending is a "breakthrough" for industrial technology upgrading in China, which leads to technical efficiency and technological progress of enterprises [71], thus affecting green energy efficiency. The share of emission fee revenue in regional GDP and the share of fiscal expenditure on environmental protection in regional GDP are chosen to represent the two antecedent variables of emission fee (PC) and fiscal expenditure on environmental protection (EPFE) for each province in China in 2019.

(3) Public voluntary environmental regulation dimension. Environmental protection-related suggestions and proposals can express public environmental protection demands, promote environmental protection legislation [72], and supervise corporate environmental protection operations, thus enhancing green energy efficiency. The sum of the number of proposals from the National People's Congress and the number of proposals from the Chinese People's Political Consultative Conference (CPPCC) in each province of China in 2019 was chosen to represent the antecedent variable of suggestions and proposals (SP).

See Table 2 for specific definitions and sources.

Results and Discussion

Green Energy Efficiency Measurement Results

According to the theory of sustainable development and energy economics, green energy efficiency was selected as the outcome variable in this paper, and the green energy efficiency of 30 Chinese provinces in 2019

Table 2. Definitions and sources of antecedent variables.

Names of variables		Definitions of variables	Measure units	Resources
Conditional variables	Environmental Administrative Penalty (EAP)	Number of environmental administrative penalty cases in 2019	Piece	CHINA STATISTICAL YEARBOOK ON ENVIRONMENT
	Environmental Governance Investment (EGI)	Investment in environmental pollution control as a share of regional GDP in 2019	%	CSMAR
	Pollution Charges (PC)	2019 Emission fee revenue as a share of regional GDP	%	CHINA STATISTICAL YEARBOOK ON ENVIRONMENT
	Environmental Protection Fiscal Expenditure(EPFE)	Fiscal spending on environmental protection as a share of regional GDP in 2019	%	CSMAR
	Suggestions and Proposals (SP)	The sum of the number of NPC recommendations and CPPCC proposals on environmental protection in 2019	Piece	CHINA STATISTICAL YEARBOOK ON ENVIRONMENT

was measured using the Super-SBM model (variable payoffs to scale) that takes into account the non-desired output, and the results were recorded as green energy efficiency. The green energy efficiency values for each province are shown in Table 3. From the table, it is clear that the average value of green energy efficiency of Chinese provinces and cities is 0.742113342, the maximum value is 3.150698, the minimum value is 0.297800, and the difference is 2.852889. It indicates that the general green energy efficiency value in China is not high, there is a large gap between provinces and cities, and there is a lot of room for improvement. The remaining provinces and cities have green energy efficiency values of less than 0.75, with Gansu, Inner Mongolia, Heilongjiang, Hebei, Anhui, Shaanxi, Guangxi, Shanxi, Guizhou, Xinjiang, and Yunnan in low green energy efficiency state, with green energy efficiency values less than 0.45 (Table 3).

To analyze green energy efficiency more intuitively, ArcGIS software was used to draw a green energy efficiency distribution map for each province and city in China in 2019. As shown in Fig. 2, the

Table 3. Green energy efficiency values by province.

Province	Green Energy Efficiency	Province	Green Energy Efficiency
Beijing	2.081577	Henan	0.513060
Tianjing	1.033690	Hubei	0.514953
Hebei	0.426209	Hunan	0.541970
Shanxi	0.367540	Guangdong	1.016733
Inner Mongoria	0.444956	Guangxi	0.367736
Liaoning	0.468687	Hainan	3.150698
Jilin	0.474173	Chongqing	0.550364
Heilongjiang	0.430325	Sichuan	0.491705
Shanghai	1.050229	Guizhou	0.332175
Jiangsu	1.110325	Yunnan	0.297800
Zhejiang	1.044664	Shaanxi	0.412177
Anhui	0.421875	Gansu	0.446815
Fujian	0.551886	Qinghai	1.136498
Jiangxi	0.485136	Ningxia	1.043647
Shandong	0.727529	Xinjiang	0.328268

color of the color block in the figure from light to dark represents the increase in green energy efficiency values. According to the Statistical Bulletin on National Economic and Social Development of the People's Republic of China 2020, which divides China into four major regions, the average green energy efficiency in the eastern region (Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan) is about 1.2, in the central region (Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan) is about 0.47, and in the western region (Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang) is about 0.53, and the northeast region (Liaoning, Jilin, and Heilongjiang) is about 0.46. The average green energy efficiency values of the four major regions in China are ranked from highest to lowest: Eastern region>Western region>Central region>Northeast region. Among them, the efficiency value of the eastern region is much higher than the other regions, and the difference between the efficiency value of the central region and the northeastern region is not large (Fig. 2.).

Efficiency Improvement Path

Variable Calibration

Before using fsQCA analysis, the variables need to be calibrated to a value between 0 and 1. First, this paper uses the PERCENTILE function of Excel to calculate the 95%, 50%, and 5% quartiles of the antecedent variables EAP, EGI, PC, EPFE, and SP with the outcome variable green energy efficiency values as fully affiliated, crossover, and fully unaffiliated points. Second, the five antecedent variables were calibrated with one outcome variable using fsQCA software and transformed into variables of pooled dimensions. The anchor points of each variable are shown in Table 4.

Necessary Conditions Analysis

At the end of calibration, a necessity analysis is performed for each antecedent variable to determine whether the variable is necessary for the results. The necessity analysis of the variables using fsQCA will result in the Consistency and Coverage results of the variables. If the Consistency result of a variable is greater than 0.9, it is considered necessary for the result and needs to be excluded from the subsequent analysis. After the necessity analysis in this paper, it was found that the Consistency (Consistency) of all variables was less than 0.9, as shown in Table 5, and there were no necessary conditions affecting green energy efficiency. It indicates that the effects of different types of environmental regulations on green energy efficiency are diversified and not the result of the action of a single variable, which provides room for the following research to explore the combined effects

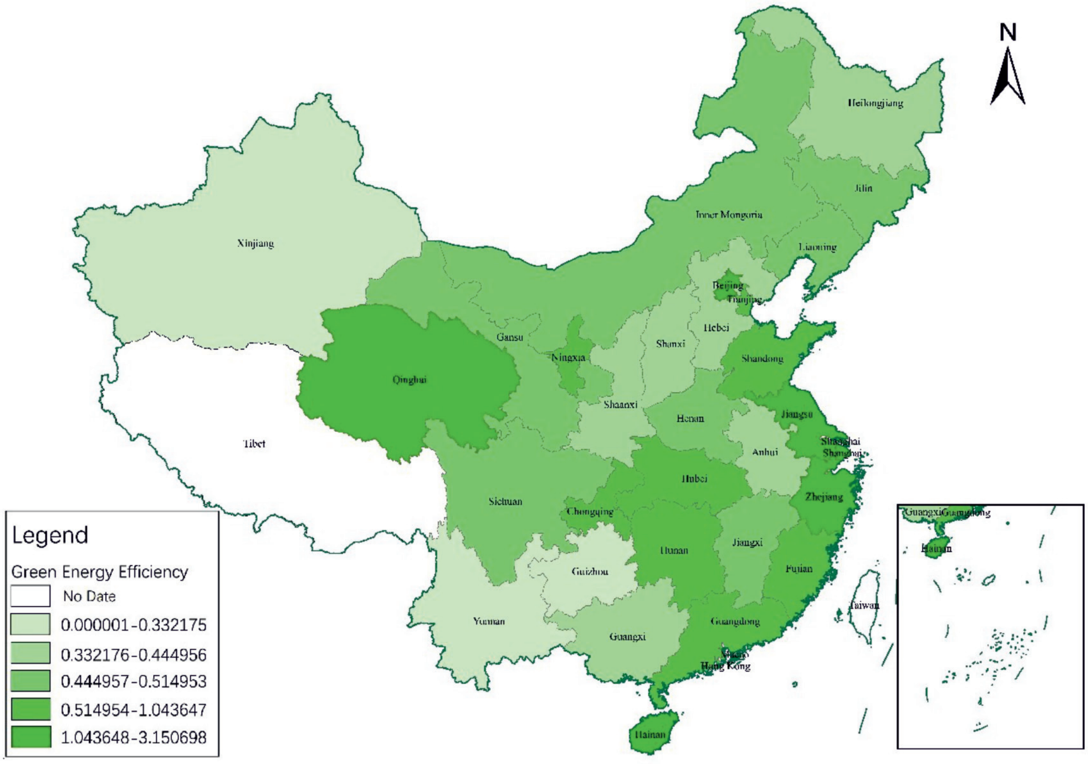

Fig. 2. Distribution of green energy efficiency situation
(Source: China Standard Map-Review Number GS (2020) 4619).

Table 4. Calibration anchor points for each variable.

Variable		Full membership	Cross-over point	Full non-membership
Consequences	Green energy efficiency	0.723486	0.090150	0.005521
Conditional Variables	EAP	0.092949	0.015106	0.001977
	EGI	0.002449	0.000436	0.000098
	PC	0.023311	0.010472	0.005645
	EPFE	0.794625	0.205565	0.020654
	SP	1.656292	0.502382	0.330026

of different types of environmental regulations antecedent variables to enhance green energy efficiency (Table 5).

Conditional Configuration Analysis

Due to the small sample size in this paper, the consistency threshold is set to 0.8 and the case threshold is set to 1 following the results of the study by Yun-Chou Du. fsQCA is used to analyze the data and obtain simple, intermediate, and complex solutions. The most explanatory strength among the three solutions is the intermediate solution, which considers the logical residual term in the analysis process that is consistent with the theoretical direction, and its analysis results are better than the simple and complex solutions, so it is the main criterion for judging the analysis results. The antecedent conditions of both simple and intermediate solutions are core conditions, and the antecedent conditions of only intermediate solutions are marginal.

In this paper, we analyzed the antecedent conditions based on the impact of different environmental regulations on green energy efficiency, and the results are shown in Table 6.

Table 5. Results of analysis of necessary conditions for each variable.

Variable	Consistency	Coverage
EAP	0.570522	0.643596
~EAP	0.698166	0.567986
EGI	0.563470	0.581937
~EGI	0.710860	0.619545
PC	0.500705	0.518248
~PC	0.748237	0.650920
EPFE	0.599436	0.610194
~EPFE	0.758110	0.668948
SP	0.516220	0.563510
~SP	0.729901	0.608466

The results of the fsQCA analysis of 30 Chinese provinces and cities are shown in the table above. The consistency of the overall solution is 0.810256, which is higher than the consistency acceptable threshold of 0.8, indicating that the 4 combined paths are sufficient conditions for the effects of different types of environmental regulations on green energy efficiency. The coverage of the overall solution is 0.445698, which indicates that the 4 combined paths have some explanatory strength for improving green energy efficiency.

By comparing and analyzing the four grouping condition variables, four paths can be summarized to improve green energy efficiency.

First, the government pressure type. Path 1 (EAP95*~EGI95*~PC95*~EPFE95*~SP95) has high environmental administrative penalties (core condition) and lacks environmental governance investment (marginal condition), sewage charges (core condition), environmental fiscal spending (marginal condition), and proposal proposals (marginal condition). This path suggests that only the existence of government-led command-and-control environmental regulation can enhance green energy efficiency. In the state of lack of market and public awareness of environmental green development, the government becomes the only subject to ensure environmental green development. First, by relying on mandatory government regulation, we can effectively remedy companies' polluting practices and adopt technologies and resources that meet green standards. Second, anyone who does not follow environmental regulations will be penalized. Pressured by command-and-control environmental regulations, the original corporate pollution violations are transformed into greener production and living practices, thus promoting green energy efficiency. The corresponding case is Beijing, which is the capital and political center of China, with faster social and economic development than other provinces and cities, high population density, and high pressure on the natural environment, and needs a high-intensity environmental policy to promote

Table 6. Analysis of combinations of antecedent conditions.

Configuration	Path 1	Path 2	Path 3	Path 4
EAP	●	□		■
EGI	□	□	●	□
PC	○	□	○	○
EPFE	□	●	□	■
SP	□	○	■	●
Raw coverage	0.287024	0.320875	0.231312	0.202398
Unique coverage	0.051481	0.062764	0.031030	0.009168
Consistency	0.916667	0.828780	0.815920	0.829480
Solution coverage	0.445698			
Solution consistency	0.810256			

Note: ● means the core condition exists; ○ means the core condition is missing; ■ means the edge condition exists; □ means the edge condition is missing; blank means the condition can exist or be missing

green energy efficiency. Therefore, order-controlled environmental regulation can enable such provinces and cities to improve green energy efficiency.

The second is the market mobilization type. Path 2 (~EAP95*~EGI95*~PC95*EPFE95*~SP95) has high environmental fiscal expenditures (core condition) and lacks environmental administrative penalties (marginal condition), environmental governance investments (marginal condition), emission fees (marginal condition), and proposal proposals (core condition). Market incentive-based environmental regulation is a market-based environmental governance instrument, where the important subject of the market is enterprises. The government encourages companies to choose low-pollution production methods, use clean energy, and innovate production technologies to promote green energy efficiency through market-incentivized environmental regulation. Under this condition, market-incentivized environmental regulations stimulate enterprises to protect the environment, but the lack of mandatory regulatory efforts makes them much less effective in improving green energy efficiency than in provinces under command-and-control environmental regulations. Typical cases are Liaoning and Heilongjiang provinces, which have rich resource endowments, fast industrial economic growth, and a large share of the role of the market in the economic development process. Under these conditions, incentivizing the market can motivate enterprises to enhance environmental awareness and transform energy-intensive operations into sustainable green and low-carbon operations, thus improving green energy efficiency.

Third, government-led public association type. Path 3 (EGI95*~PC95*~EPFE95*SP95) has high environmental governance investment (core condition) with high proposal proposals (marginal condition) and lack of sewage charges (core condition) with environmental protection financial expenditure (marginal condition). The environmental proposals at the people's congresses reflect citizens' awareness of environmental protection, and path 3 suggests that public awareness of environmental protection plays an important role in green energy efficiency improvement under command-and-control environmental regulation as the main means of governance. Command-and-control environmental regulation relies on government coercion to make heavy polluters choose green practices and green energy. However, with the development of regional green energy systems, government coercion alone cannot achieve the desired goals, and the establishment of a green development system with joint public participation is a necessary measure to promote green energy efficiency improvement. For example, two important provinces in the Yangtze River Delta, Zhejiang Province, and Anhui Province, which face systemic, regional, and transboundary environmental problems, have issued the "Yangtze River Delta Regional Ecological and Environmental Protection Plan", which follows the principle of "shared governance" and builds a system of government guidance, social participation and public supervision for shared governance. The Yangtze River Delta Regional Ecological and Environmental Protection Plan, which is based on the principle of "shared governance", is a government-led, socially participatory and publicly supervised system. Among them, mandatory policies are the endogenous driving force of environmental management, and public attention is the external driving force of environmental management, thus combining internal and external to enhance green energy efficiency.

Fourth, multiple subject types. Path 4 (EAP95*~EGI95*~PC95*EPFE95*SP95) has a high environmental administrative penalty (marginal condition), high environmental protection financial expenditure (marginal condition) with the high proposal (core condition), and lack of emission fee (core condition) with environmental treatment investment (marginal condition). This path fully reflects the necessity of the joint role of multiple actors to improve green energy efficiency. The command-and-control environmental regulation restrains enterprises from polluting the environment, the market-incentive environmental regulation stimulates enterprises to protect the environment from the market perspective on a large scale, and the public voluntary environmental regulation promotes the green development of the general environment. Among them, the implementation of public voluntary environmental regulation can raise people's awareness of environmental protection, fundamentally establish the concept of green environmental protection, and enable the sustainable development of a green energy system. A typical case in this path is Hainan Province. As a clean energy demonstration zone, Hainan Province has implemented environmental penalties in policy, promoted clean energy in the market and achieved success, and educated enterprises and society on ecological protection in public awareness. It can be seen that building a "government-market-public" green energy system can improve green energy efficiency.

Conclusion

Conclusions and Recommendations

This paper differs from most of the previous literature studying green energy efficiency by using a fsQCA approach that combines qualitative and quantitative methods to explore pathways for improving green energy efficiency from the perspective of different environmental regulation group effects. This paper selects 30 provinces in China in 2019 as the research object, measures the green energy efficiency value using the Super-SBM model and uses it as the outcome variable, selects five antecedent variables from three types of environmental regulations, environmental administrative penalties, environmental treatment investment, emission fees, environmental protection financial expenditure, and proposal proposals as the paper, and finally uses the fsQCA method to analyze the influence mechanism and improvement path of different types of environmental regulations on the green energy efficiency of Chinese regions, and obtains the following conclusions.

(1) The average value of green energy efficiency of each province in China is 0.742113342, and the overall green energy efficiency value is low, and there are large regional differences among provinces. The average value of green energy efficiency is ranked from high to low: Eastern region > Western region > Central region > Northeast region, where the efficiency value of the Eastern region is much higher than the other three regions.

(2) There are four paths to improve green energy efficiency in China's provinces, namely, government pressure, market mobilization, government-led public association, and multiple subjects. four groups show the improvement paths of different regions based on their policy conditions and resource endowments, in which no single variable is necessary to improve green energy efficiency. However, command-and-control environmental regulation is present in three paths, indicating that it has a key role in enhancing green energy efficiency in most regions.

(3) Combining the antecedent conditions of path 4 with the case, the sustainable development of green energy system should transform the command-and-control dominant type of environmental regulation system into a pluralistic subject type of environmental regulation system, and manage environmental problems from three levels, giving full play to the role of strict government control, market regulation, and public supervision, to achieve a better level of green energy efficiency.

Based on the above research findings, the following 3 recommendations are made.

(1) Strengthen command-and-control environmental regulation and play the role of strict government control and supervision. For provinces and cities with relatively backward green energy efficiency, command-and-control environmental regulation can rapidly improve their green energy efficiency. The government needs to improve scientific and strict supervision and review mechanisms, build green development mechanisms with strict pollution control, eliminate corporate pollution, and promote regional energy green transformation.

(2) Improve the environmental information disclosure system and promote the formation of a joint public governance system. The public plays an important role as a participant and supervisor in the field of environmental governance. The government should strengthen the cultivation of public awareness of environmental protection, improve the legal regulations for public participation, ensure a fair and open public participation platform, achieve timely and accurate environmental information disclosure, and enable social citizens to properly exercise their right of supervision and supervise the development of China's green cause.

(3) Establish a system of shared governance of multiple subjects to make the green environment develop in the long run. To build a "government-market-public" multi-governance system, it is necessary to scientifically arrange the configuration structure of environmental governance rights, improve the information sharing system between governance subjects, and strengthen the orderliness and effectiveness of enterprise and public participation.

Outlook

This paper explores the environmental regulation grouping that affects green energy efficiency, with the following shortcomings: first, due to data availability, there are other forms of environmental regulation tools that are not included in the grouping analysis; second, this paper only examines the impact of environmental regulation grouping on green energy efficiency at the provincial level, but there are also differences in resource endowments within provinces. The impact of other forms of environmental regulation tools on green energy efficiency and the specific analysis of intra-provincial energy efficiency needs to be further examined in future studies.

Conflict of Interest

The authors declare no conflict of interest.

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