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Original Research

Spatial and Temporal Analysis of China's Environmental Regulatory Framework: A Multidimensional Assessment

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Abstract

The environmental regulatory framework is crucial for sustainable development. In China, the framework has evolved into a complex, multidimensional system. However, due to the uneven regional development in China, the environmental regulatory framework exhibits significant spatial variations. Previous studies have overlooked the multidimensionality of China's environmental regulatory framework and the temporal and spatial development differences among provinces. This gap poses challenges to comprehensively analyzing and evaluating China's environmental regulatory framework. This study addresses this oversight by introducing a multidimensional composite indicator to assess the environmental regulatory framework's spatial and temporal dynamics. By incorporating command-and-control, market-based, and public participation dimensions, we analyze data from 31 Chinese provinces over the period 2011 to 2021 using dynamic factor analysis. Our findings reveal that command-and-control and public participation dimensions play a dominant role in China's environmental regulatory framework, while the market-based dimension requires further enhancement. We observe a general weakening in the intensity of the environmental regulatory framework from east to west, with provinces like Jiangsu, Shandong, and Hubei showing improvements over the decade, contrary to the decline in less developed, resource-rich western and northeastern regions. The study suggests that these latter regions could significantly benefit from leveraging local wind and solar energy resources to boost their renewable energy potential and fortify the market-based dimension of the environmental regulatory framework.

Keywords: environmental regulatory framework, China, multidimensional, spatial and temporal analysis

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Introduction

Environmental regulation has emerged as a pivotal response to global environmental challenges, including climate change, pollution, and resource scarcity. The global commitment to environmental protection and sustainable development was historically marked by the "Declaration of the United Nations Conference on the Human Environment" in 1972, inspiring nations, including China, to develop comprehensive environmental regulations.

The environmental regulatory framework is an important system of environmental governance, which refers to a combination of administrative instruments, economic incentives tools, and policies implemented by the government to solve environmental problems [1]. As the largest developing country, China's environmental regulatory framework is characterized by significant variability and complexity [2]. It has evolved through three main stages, transitioning from initial legislation efforts to the implementation of local environmental regulations and, most recently, to the development of a multidimensional framework that integrates command-and-control, market-based, and public participation dimensions [3, 4].

Despite these advancements, the literature reveals critical gaps in our understanding of the environmental regulatory framework. Past studies have explored various measurement methods of environmental regulation, often relying on singular indicators like environmental protection investment or environmental taxes [5-8]. However, these approaches seldom capture the multidimensional nature and regional disparities within China's environmental regulatory framework. Recent research has begun employing multi-indicators to assess regulation strength, yet these too primarily focus on emission reduction outcomes, neglecting the framework's comprehensive dimensions and tool characteristics [9-11].

Furthermore, an often overlooked issue is the regional imbalance in the development of China's environmental regulatory framework. Significant variation exists across provinces in natural resources, economic development, and pollution levels, resulting in substantial spatial differences in regulation development and implementation [12, 13]. Past empirical studies have analyzed the consequences of these disparities [14-16], yet rarely do they capture the specific characteristics of these spatial differences and their evolutionary features over time.

This study aims to bridge these identified gaps by providing a comprehensive, multidimensional assessment of China's environmental regulatory framework. To achieve this, we propose two research questions: What are the spatial and temporal dynamics of China's environmental regulatory framework? How do command-and-control, market-based, and public participation dimensions influence the effectiveness of China's environmental regulatory framework? To address these questions, we propose a composite indicator that combines multidimensional aspects and tool characteristics of the framework, employing dynamic factor analysis to examine the temporal and spatial trends of the framework's development.

Our contributions are threefold: First, we introduce a multidimensional composite indicator, capturing the actual development of China's environmental regulatory framework. Second, we identify key factors within the environmental regulatory framework, comparing provincial strengths and weaknesses to suggest targeted policy recommendations. Third, using dynamic factor analysis, we illustrate the spatial and temporal dynamics of the environmental regulatory framework, a methodology that could extend to similar index constructions in other contexts. Our findings offer valuable insights for refining China's environmental regulatory framework and enhancing provincial environmental governance.

Review of Literature

The environmental challenges China confronts are vast and multifaceted, extending beyond traditional pollution issues. Rapid industrialization and urban expansion have escalated environmental issues such as carbon emissions [17, 18], urban thermal environment [19, 20], and land use changes [21, 22], presenting new challenges to environmental regulation. As one of the world's largest carbon emitters, China faces the urgent task of effectively reducing greenhouse gas emissions to achieve its carbon neutrality goals [18].

Thus, the scope of China's environmental regulation is broad, encompassing pollution control and governance [23], ecological environment quality enhancement [24], climate change mitigation [8, 25], and sustainable land use planning [26]. To address these challenges, it is imperative for the Chinese government not only to develop and implement comprehensive environmental regulatory policies but also to leverage economic incentives and incorporate mechanisms for public participation, all aimed at achieving a harmonious integration of environmental protection and economic development [1].

The complexity of China's environmental regulation framework cannot be captured by simplified or single-dimensional assessments. There is a pressing need for a comprehensive evaluation. However, existing studies predominantly rely on single indicators, focusing on the efficacy of isolated policies or tools. For instance, Liu et al. [5] utilized the revised Chinese environmental protection law of 2015 as a quasi-natural experiment to evaluate the effectiveness of environmental regulation in China. Tang et al. [27] assessed the Environmental Targets of China's 11th Five-Year Plan, revealing a negative impact on eco-innovation efficiency. Stef and Ben Jabeur [25] utilized the number of environmental legislations (regulations, laws) as a variable of the environmental regulatory framework to investigate its impact on carbon emissions. Neves et al. [8] used environmental tax revenue as a proxy for environmental regulation, exploring its effect on carbon emissions. Wang et al. [28] measured the strength of environmental regulation by environmental investments per GDP unit, studying its impact on ecological environmental efficiency. Wu et al. [29] applied the Baidu Environmental Index as a proxy measure for environmental regulation, while Guo and Bai [30] used public environmental complaints and proposals to assess the intensity of environmental regulation, examining the effect of public participation-based regulatory tools in China on industrial pollution. Fan et al. [26] utilized the frequency and weighting of environment-related words in municipal government reports as proxy variables for environmental regulation, analyzing the impact of the regulatory framework on urban land use efficiency.

To meticulously examine the distinct roles of various types of environmental regulatory tools, scholars typically categorize China's environmental regulatory framework into command-and-control, market-based, and public participation approaches [31]. For instance, Xie et al. [32] utilized two proxies to study environmental regulation: "Environmental Investments in New Construction Projects" for command-and-control and "Pollutant discharge fees" for market-based regulation. They concluded that market-based tools are more effective than their command-and-control counterparts. Zhang et al. [4] used similar indicators and found that in China, both command-and-control tools and market-based tools exhibit a "U"-shaped relationship with clean production, while public participation tools have a significantly positive impact. Conversely, Luo et al. [33] found that command-and-control and public participation in environmental regulations in China are more effective than market-based approaches. However, most past studies have only compared the effectiveness of market-based, command-and-control, and public participation-based environmental regulation, without a comprehensive assessment of the overall effectiveness of the regulatory framework.

To understand the overall situation of a country or region's environmental regulatory framework, researchers often use a composite indicator, which combines various single indicators, to assess the environmental regulatory framework. Past studies have combined different pollution indicators into a composite indicator to profile the overall level of environmental regulation to allow for comparisons between industries and countries [11, 31, 34]. However, this method, primarily when based on pollution emissions, mainly reflects how regulations control emissions without addressing the environmental regulatory framework's broader dimensions, legal underpinnings, and tool-specific characteristics. This limitation makes it difficult to fully evaluate the impact and relevance of different regulatory tools and restricts detailed investigation into specific areas of the environmental regulatory framework. Additionally, some scholars argue that composite indicators built on pollution emissions are endogenous to the processes of environmental governance and economic development. This often leads to endogeneity issues in empirical analyses, resulting in biased estimates. More sophisticated econometric techniques are needed to address these endogeneity issues [26].

China's regional development is markedly uneven, leading to significant interest in the regional heterogeneity of environmental regulation's effects. Zhang et al. [35] found an inverted U-shaped relationship between environmental regulation and carbon emissions. Their research shows that stronger environmental regulation more effectively reduces carbon emissions in the eastern and central regions than in the western regions, indicating substantial regional variability in regulatory effectiveness across China. Similarly, Feng et al. [36] reported a gradient in environmental regulatory intensity from east to west across 30 provinces. Yu and Shen [37] further confirmed these findings, demonstrating notable differences in environmental regulatory intensity and its impact on industrial capacity utilization across Chinese provinces. These studies collectively underscore the importance of considering regional variations when assessing the effectiveness of China's environmental regulatory policies. While these studies offer valuable insights into regional differences in environmental regulation, they overlook how these differences evolve and fail to delve into the specific performances of different regions across various dimensions of the environmental regulatory framework. This limitation restricts a deeper understanding of the reasons behind the varied effectiveness of environmental regulation across different regions.

Regarding the measurement of composite indicators, past studies have predominantly employed principal component analysis [38, 39], factor analysis [40], and the entropy method [11, 31, 34]. These techniques, while effective for cross-sectional data analysis, fall short of capturing the time-based evolution and dynamics of the environmental regulatory framework. Consequently, they overlook the nuanced changes and challenges that emerge over time within this framework.

Overall, previous studies frequently utilize single indicators to evaluate the environmental regulatory framework, often leading to inconsistent findings because of varied metrics. These indicators highlight the effects of specific regulatory tools and facilitate comparisons across environmental regulation aspects. However, they do not fully capture the impact of a comprehensive, multidimensional framework. This oversight leads to biased empirical results. Therefore, the need for a composite indicator becomes evident to more accurately gauge the effectiveness of the environmental regulatory framework. Existing composite measures, like total pollution emissions and treatment rates, fail to capture the multidimensionality of the environmental regulatory framework, as well as its legal foundation and tool characteristics. Previous methods for developing composite indicators have also neglected the evolving nature of the environmental regulatory framework, missing crucial temporal and spatial analyses. In response, this study develops a multidimensional composite indicator reflecting the legal bases and characteristics of environmental regulatory tools. We then apply dynamic factor analysis to explore the evolution and advancement of China's environmental regulatory framework over time and space. The subsequent section will elaborate on the construction of the composite indicator and the methodology of dynamic factor analysis.

Research Methodology

This study takes into account that the environmental regulatory framework encompasses many different types of policy tools. From the actuality of China's environmental regulatory framework, a composite indicator is constructed from three dimensions, command-and-control, market-based, and public participation dimension, to measure China's environmental regulatory framework comprehensively. In terms of measurement, this study refers to Lukoianove et al. [41] based on principal component analysis and factor analysis. It adopts dynamic factor analysis to measure the overall situation and dimensions of China's environmental regulatory framework from 2011 to 2021. Since the situation varies from province to province in China, the data used in this study are obtained from the provincial level to compare the development of the environmental regulatory framework in time and space.

Construction of Composite Indicator

This study, drawing from the actual development of China's environmental regulatory framework and integrating research on the classification of environmental regulatory tools, has developed a composite indicator that reflects both multidimensional characteristics of the tools. China's current environmental regulatory framework contains three main dimensions: command-and-control, market-based, and public participation. Based on the principle of availability of indicator data, within each dimension, this study selected representative tools and identified indicator variables that best capture the characteristics of these tools.

The command-and-control dimension is a traditional approach that the government directly prescribes, through administrative command-style tools, the environmental standards or restrictions that enterprises or individuals must follow [7]. Within the command-control dimension, the government mainly targets pollution control and management [1, 42]. Previous studies have used the number of regulations enacted by the government as an indicator of the extent of government pollution control [43]. Pollution management can be gauged by the human, facilities, and financial resources invested by the government, reflecting their effort and capability in enforcing environmental regulations [27].

This study draws on ideas from past literature and selects the number of current effective environmental regulations and rules of the year as an indicator of the extent of government pollution control. Drawing from past research, the human resource input in environmental management is represented by the number of personnel in the environmental administration of each province [27]. Facility resource input is indicated by the number of pollution treatment facilities invested in by the provincial government, while financial resource input is denoted by the provincial government's environmental management investment rate, which is the total investment per unit of GDP for environmental pollution management [1].

The market-based dimension refers to the market-based tools governments employ to reduce environmental pollution and incentivize green innovation through price adjustments, price incentives, taxes, and fees [27]. China's market-based tools include emission fees, environmental protection taxes, carbon emissions trading systems, and renewable energy price incentive programs. China's carbon emissions trading system has been in place nationwide for less than three years, and limited continuous data is available, so this system is not included. This study refers to the common indicators used in previous studies [44-46] and selects indicators from three aspects: emission fee, environmental protection tax, and renewable energy incentive. Considering that China has changed the collection of emission fees to the form of environmental protection tax starting from 2018, the emission fees are replaced by environmental protection tax payment data after 2018. In terms of renewable energy incentives, this study follows the approach of Xiong et al. [47], measuring the incentive level for renewable energy electricity relative to coal electricity. This is done by computing the ratios of wind power feed-in tariffs to coal-fired electricity prices and solar power feed-in tariffs to coal-fired electricity prices.

The public participation dimension is a form of environmental regulation in which citizens obtain environmental information to express their environmental demands and their concerns and discussions about environmental issues through various channels, thereby exerting pressure on government regulators [30, 48, 49]. In China, the government has established various official channels, both online and offline, to facilitate public reporting and complaints concerning illegal pollution activities. Online channels encompass social media platforms, official government websites, and service portals. Meanwhile, offline channels include letters and visits to authorities, proposals and motions made by the National People's Congress (NPC) and the Chinese

People's Political Consultative Conference (CPPCC). Given the availability of data, this study has selected three representative channels of public participation to capture this dimension: The number of proposals of NPC, the number of motions of CPPCC, and the level of public environmental concern expressed through online platforms.

In assessing public concern for environmental issues, a commonly employed method is the analysis of discourse intensity on online social media platforms [29]. Such analyses typically rely on search engines and online community platforms that host extensive user data [50]. Buntaine et al. [51] found that public complaints made via online platforms and social media led to a reduction of over 60% in corporate non-compliance with pollution standards, highlighting the efficiency of this low-cost regulatory approach. In China, sources like the Baidu search engine, Baidu Tieba, and Weibo are frequently utilized for this type of analysis [52, 53]. Similarly, at the international level, discussions on Google, Facebook, and Twitter serve as important data sources [50, 54]. The public discourse on these platforms has been widely recognized as a valid indicator of public attitudes towards environmental protection. Therefore, this study adopts the approach used by Yu and Jin [53], selecting a set of "Baidu Index" data related to environmental keywords as a proxy for measuring public environmental concerns in China. Baidu, China's largest search engine, offers vast user search data reflecting public interest and discussion intensity on environmental issues. The Baidu Index for specific keywords is calculated based on the volume and frequency of user searches, with a higher index indicating greater public interest in those keywords [55].

The composite indicator system of environmental regulatory framework and data measurement are shown in Table 1.

Data and Sources of Data Collection

This study collected data from 31 provinces (autonomous regions and municipalities) in mainland China for the period 2011-2021. The starting point, 2011, was chosen because China's multidimensional environmental regulatory framework was essentially established around 2010 [56]. This choice was made to maximize information collection on various indicators within the environmental regulatory framework. This study utilizes various reliable data sources, including internal and online government documents, websites of governmental agencies, statistical yearbooks, statistical bulletins, and the Baidu Index database.

Table 1. Composite indicator system of China's environmental regulatory framework

Dimension	Indicator	Calculation method	Var
Command and Control	Environmental Management Investment Rate	Total investment in environmental pollution management / Gross Domestic Product	var1
	Number of Pollution Treatment Facilities	Number of exhaust gas treatment facilities + Number of wastewater treatment facilities	var2
	Number of Personnel in Environmental Administration	Number of people working in the Environmental Protection Agency / Provincial population	var3
	Number of Current Effective Environmental Regulations and Rules	Total number	var4
Market-Based	Number of Emission Fees Collected	Emission Fees (Environmental Protection Tax)/ Gross Domestic Product	var5
	Feed-in tariff for wind	Feed-in tariff for wind/Electricity tariffs for coal-fired power generation	var6
	Feed-in tariff for solar	Feed-in tariff for solar/Electricity tariffs for coal-fired power generation	var7
Public Participation-Based	Number of proposals of The National People's Congress (NPC)	Total number	var8
	Number of motions of the Chinese People's Political Consultative Conference (CPPCC)	Total number	var9
	Public Environmental Concern	Environmental Baidu Index (keywords: low carbon, Sulphur dioxide, carbon dioxide, environmental protection, environmental pollution, emission reduction, water conservation, sustainable, air quality, green space, greening, green, emissions, clean energy, decontamination, global warming, ecology, acid rain, greenhouse effect, pollution, emission, haze, recycling, PM2.5)	var10

Dynamic Factor Analysis

Including the environmental regulatory framework in the dynamic structure can reflect the changes in time and space of the environmental regulatory framework, compensating for the shortcomings of Factor Analysis, Principal Component Analysis (PCA), and Entropy Method, which can only do static analysis. At the same time, using the Dynamic Factor Analysis (DFA) to measure environmental regulatory framework can also reflect the complexity and the effectiveness or importance of the dimensions, guaranteeing the rationality and scientific validity of the subsequent empirical research in future studies.

The DFA was initially proposed by Geweke [57] as an extension of the factor model. A significant early study by Sargent and Sims [58] demonstrated that a core set of quarterly macroeconomic variables in the US, such as output, wages, employment, and prices, could be effectively explained by a mere two dynamic common factors. In recent studies, DFA has clear advantages in calculating composite indicators. For example, Zhou et al. [59] employed the DFA with four dimensions to assess a composite index of green growth in China spanning from 2011 to 2018. Raouf [39] has developed a dynamic PCA method based on the DFA and utilized it to assess the composite index of financial inclusion for 45 countries in Europe, the Middle East, and Africa from 2008 to 2019. Lukoianove et al. [41] proposed a new methodological framework based on the DFA and demonstrated how DFA could be employed to evaluate the political environment of nations.

Due to the existence of common factors among the various factors in the dimensions of the environmental regulatory framework, the DFA can be used to extract these common factors from the group of variables and investigate their contribution to the environmental regulatory framework. By computing factor scores, the importance indices of each factor can be obtained, enabling the calculation of a composite score for the multidimensional indicators in the time series. In contrast to traditional factor analysis methods, the DFA aims to perform a cross-sectional analysis of panel data through the PCA and combines the data's time series and cross-sectional dimensions using a linear regression model [60]. In essence, the DFA calculates the average of panel data in the time dimension, extracts common factors from the correlation matrix or covariance matrix to achieve dimensionality reduction, and ultimately obtains common factors and composite scores.

Based on the above principle, this study calculated the correlation matrix of the panel data for each year and then calculated the average of the correlation matrix in the time dimension. Finally, the common factors were extracted from the average correlation matrix using the principal component method. Due to space constraints, this study does not show specific computational principles.

Results and Discussion

Measurement Process

This study employed Stata statistical software to conduct DFA to comprehensively measure China's environmental regulatory framework from 2011 to 2021. Before using DFA to solve the composite indicator weight, this study first standardized the data set of the environmental regulatory framework indicator system from 2011 to 2021. Secondly, to ensure the selected variables are suitable for DFA, the variables need to undergo a KMO test and Bartlett sphericity test before analysis. The result of the KMO test was 0.754, and the p-value for the Bartlett sphericity test was less than 0.05, indicating strong reliability of the variables used in the DFA.

Thirdly, this study calculated the variance-covariance matrix of the samples through Stata and further calculated the eigenvalue, explained variability, and cumulative variability of the variance-covariance matrix. The results are shown in Table 2.

Three common factors were extracted with the criterion of eigenvalue greater than 1. Table 2 shows that the eigenvalues of the first three factors are greater than 1, and the explained variability is 0.4186, 0.1823, and 0.1146, respectively. The larger the explained variability, the stronger the explanatory power of the factor. The cumulative variability of the first three factors is 0.7155, indicating that these three factors have explained 71.55% of the overall information in the data. Therefore, factor 1, factor 2, and factor 3 were selected as the common factors to measure the environmental regulatory framework.

Table 3 shows the common factor loading matrix. It can be seen that var2, var4, var8, var9 and var10 have higher loadings on the common factor 1, and it can be considered that the common factor 1 is mainly

Table 2. Variance covariance matrix eigenvalues, explained variability and cumulative variability

Factor	Eigenvalue	Explained Variability	Cumulative Variability
Factor1	4.18649	0.4186	0.4186
Factor2	1.82258	0.1823	0.6009
Factor3	1.14562	0.1146	0.7155
Factor4	0.84608	0.0846	0.8001
Factor5	0.59188	0.0592	0.8593
Factor6	0.47476	0.0475	0.9067
Factor7	0.38863	0.0389	0.9456
Factor8	0.26243	0.0262	0.9718
Factor9	0.22195	0.0222	0.994
Factor10	0.05958	0.006	1

Table 3. Common factor loadings

Variable	Factor1	Factor2	Factor3
var1	-0.334	0.478	-0.2223
var2	0.8769	0.1047	-0.1155
var3	0.3843	0.1731	0.7919
var4	0.8507	0.1995	-0.2331
var5	0.5816	0.2851	-0.0048
var6	-0.2097	0.8684	-0.1228
var7	-0.208	0.8223	0.1913
var8	0.8926	-0.0017	-0.2206
var9	0.8766	0.0346	-0.2552
var10	0.7312	-0.0268	0.4856

determined by the number of pollution treatment facilities (var2), the number of current effective environmental regulations and rules (var4), the number of proposals of the NPC (var8), the number of motions of the CPPCC (var9), and the degree of public environmental concern (var10). These results indicate that the command-and-control dimension and the public participation dimension play a major role in factor 1.

Var6 and var7 load higher on the common factor 2, which recognizes that wind and solar feed-in tariffs play a major role in the common factor 2. Var3 loads high on the common factor 3, and it can be assumed that the number of personnel in the environmental administration plays a major role in the common factor 3. In addition, var1 and var5 are weak in all three common factors, indicating that environmental management investment rate and emission fees (environmental protection taxes) play an insufficient role in China's environmental regulatory framework. The above steps achieve the effect of multidimensional data downscaling and further identify the more potent factors in the system.

Spatial Patterns of China's Environmental Regulatory Framework

Analysis of Common Factors Scores

Using the explained variability of common factors as weights, we computed the static score of each common factor across the provinces from 2011 to 2021. The results are shown in Table 4.

Table 4 indicates that provinces such as Jiangsu, Guangdong, Zhejiang, Shandong, and Hubei lead in Factor 1 static scores, demonstrating their superior performance in command-and-control and public participation dimensions. This observation aligns with previous research findings, revealing that economically developed provinces, like Jiangsu and Guangdong, tend to allocate more economic resources to environmental governance and enhance public environmental awareness through higher education levels, thereby improving the efficacy of the environmental regulatory framework. For example, Yu and Wang [61] emphasized that economically prosperous areas often implement more effective environmental regulation policies, likely due to better allocation of resources for environmental management. In contrast, regions like Gansu, Ningxia, Hainan, Qinghai, and Tibet, characterized by lower levels of economic development and reliance on extensive growth models based on traditional energy sources, show weaker performances in both command-and-control and public participation dimensions. This finding resonates with the observations of Wei et al. [62], who note that the performance of these areas closely relates to their economic and social characteristics.

Factor 2 scores are significantly influenced by market dimensions, particularly the wind and solar feed-in tariffs. The top five provinces in this regard are Beijing, Shaanxi, Shanghai, Xinjiang, and Tianjin. These scores closely align with the geographical distribution of renewable energy resources in China [63], which is characterized by uneven distribution. Different types of renewable resources vary significantly across regions. Specifically, northern China is a major hub for wind energy, while high levels of solar radiation are received in western Tibet, northwestern, northern, northeastern, and certain southwestern regions [38]. The top five provinces not only exhibit a high degree of marketization but also boast substantial wind and solar resources, making them more responsive to renewable energy pricing incentives [64]. Despite high rankings, provinces such as Xinjiang, Ningxia, Guizhou, and Inner Mongolia have relatively undeveloped economies and markets. Their advantageous positioning is primarily attributed to their extensive wind and solar energy resources.

Factor 3 is mainly determined by the number of personnel in environmental administration. Provinces such as Inner Mongolia, Shanxi, Guizhou, Ningxia, and Jiangsu, which rank highly, likely place special emphasis on environmental administrative supervision due to their heavy reliance on resources and energy, as well as a concentration of heavy industries. This finding aligns with existing literature that explores the relationship between resource-dependent economies and the intensity of environmental protection policies. For instance, Yang and Song [65] suggest that the resource curse in China's central and western regions can be mitigated by strengthening environmental administrative efforts. In contrast, provinces like Hunan, Shanghai, Henan, Beijing, and Sichuan, which rank lower, tend to focus on developing low-pollution or pollution-free technologies and services. This reflects the diverse impacts of different economic structures on the demand for environmental administration.

Table 4. Static score of common factors.

Rank	Province	Factor1	Province	Factor2	Province	Factor3
1	Jiangsu	-0.040068	Beijing	-0.007676	Inner Mongolia	0.005794
2	Guangdong	-0.069547	Shaanxi	-0.015624	Shanxi	0.004550
3	Zhejiang	-0.079001	Shanghai	-0.018939	Guizhou	0.004022
4	Shandong	-0.100799	Xinjiang	-0.023741	Ningxia	0.002124
5	Hubei	-0.128102	Tianjin	-0.024928	Jiangsu	0.001747
6	Hebei	-0.132216	Chongqing	-0.024929	Heilongjiang	-0.000265
7	Henan	-0.153523	Hebei	-0.026413	Hainan	-0.000525
8	Sichuan	-0.182123	Ningxia	-0.027518	Guangdong	-0.000533
9	Shanxi	-0.184090	Guizhou	-0.027920	Yunnan	-0.000538
10	Liaoning	-0.190132	Shanxi	-0.028514	Xinjiang	-0.000673
11	Anhui	-0.191436	Jiangsu	-0.029044	Gansu	-0.001031
12	Hunan	-0.195650	Inner Mongolia	-0.031312	Liaoning	-0.001072
13	Yunnan	-0.199671	Yunnan	-0.033210	Jilin	-0.001271
14	Fujian	-0.206255	Jiangxi	-0.035472	Qinghai	-0.002021
15	Shaanxi	-0.214993	Henan	-0.035744	Shaanxi	-0.002167
16	Inner Mongolia	-0.217886	Guangdong	-0.036058	Tibet	-0.002844
17	Chongqing	-0.219096	Fujian	-0.038599	Shandong	-0.003502
18	Jiangxi	-0.224930	Anhui	-0.039638	Anhui	-0.003840
19	Guizhou	-0.232692	Heilongjiang	-0.040581	Hubei	-0.004548
20	Beijing	-0.238137	Liaoning	-0.042233	Hebei	-0.004620
21	Shanghai	-0.248394	Shandong	-0.042737	Tianjin	-0.005104
22	Heilongjiang	-0.253435	Gansu	-0.043425	Fujian	-0.005141
23	Xinjiang	-0.254320	Qinghai	-0.044589	Chongqing	-0.006570
24	Guangxi	-0.255016	Sichuan	-0.044979	Jiangxi	-0.006701
25	Tianjin	-0.265769	Hubei	-0.047249	Zhejiang	-0.007089
26	Jilin	-0.270504	Zhejiang	-0.047377	Guangxi	-0.007253
27	Gansu	-0.271280	Guangxi	-0.047404	Hunan	-0.007264
28	Ningxia	-0.281819	Hainan	-0.048141	Shanghai	-0.009234
29	Hainan	-0.297816	Jilin	-0.050362	Henan	-0.011090
30	Qinghai	-0.304551	Hunan	-0.051569	Beijing	-0.012749
31	Tibet	-0.306528	Tibet	-0.051571	Sichuan	-0.012803

Analysis of Composite Indicator Scores

The static composite indicator score of the environmental regulatory framework in 2011-2021 for each province was calculated by summing up the scores of the three common factors, and the specific formula is as follows:

$$ER = Factor1\times0.4186 + Factor2\times0.1823 + Factor3\times0.1146$$

ER represents the environmental regulatory framework composite indicator score, and the coefficient for each common factor corresponds to its explained variability.

Combining the results of factor loading analysis, common factor analysis, and composite indicator scores, we found that the command-and-control and public participation dimensions play a dominant role in China's environmental regulatory framework. Specifically, common factor 1 occupies a significant proportion in the composite indicator score of the environmental regulatory framework. In comparison, the market-based dimension has a smaller coefficient in the composite indicator score of the environmental regulatory framework, indicating its relatively weaker influence within the overall framework. However, this does not diminish its importance. Western and northeastern regions, characterized by underdeveloped economies and excessive reliance on the input of energy resources, possess the potential for renewable energy development. Thus, enhancing the market-based dimension is crucial to shifting these provinces from extensive to green growth, promoting effective market mechanisms and sustainable development.

The results of the ER calculations were mapped to visually observe the differences between the provinces, as shown in Fig. 1.

From the spatial distribution in Fig. 1, the development of the environmental regulatory framework in China gradually decreases from east to west. The first tier of provinces with the strongest intensity of environmental regulatory framework is Jiangsu, Zhejiang, and Guangdong provinces. The second tier is Liaoning, Hebei, Shanxi, Shaanxi, Henan, Shandong, Anhui, Hubei, and Yunnan provinces. The third tier is Inner Mongolia, Sichuan, Chongqing, Guizhou, Hunan, and Fujian provinces. The fourth tier is Xinjiang, Tibet, Qinghai, Gansu, Ningxia, Guangxi, Jiangxi, Heilongjiang and Jilin. From the perspective of industrial migration, stringent environmental regulations have led to the exit of pollution-intensive production activities and altered the locational choices of businesses, aligning with the findings of Zhang et al. (2021) [66]. This spatial distribution coincides with the actual situation of China's heavily polluting industries moving from the East to the West [67]. Importantly, the distribution of the fourth tier overlaps with the distribution of renewable energy resources [38], suggesting that provinces with a less stringent environmental regulatory framework possess significant development potential in terms of renewable energy resource advantages.

Temporal Patterns of China's Environmental Regulatory Framework

This study calculated the dynamic composite indicator scores for the development of the environmental regulatory framework from 2011-2021 using the dynamic eigenvector scores of the common factors, and the temporal trend was graphed as shown in Fig. 2.

Fig. 2 shows the temporal trend of the environmental regulatory framework in 31 provinces in China from 2011 to 2021. Most provinces in China have experienced varying degrees of decline in the intensity of the environmental regulatory framework. The trend of decline is stronger in the western and northeastern regions like Xinjiang, Tibet, Qinghai, Gansu, Ningxia, Guangxi, Jiangxi, Heilongjiang, and Jilin. Conversely, provinces like Jiangsu and Shandong experienced noticeable increases in regulatory intensity. These trends are reflected in our findings of high and low rankings in Factor 1, emphasizing the impact of command-and-control and public participation dimensions. The alignment of our observations with Feng et al. [36], who noted a decrease in environmental regulation

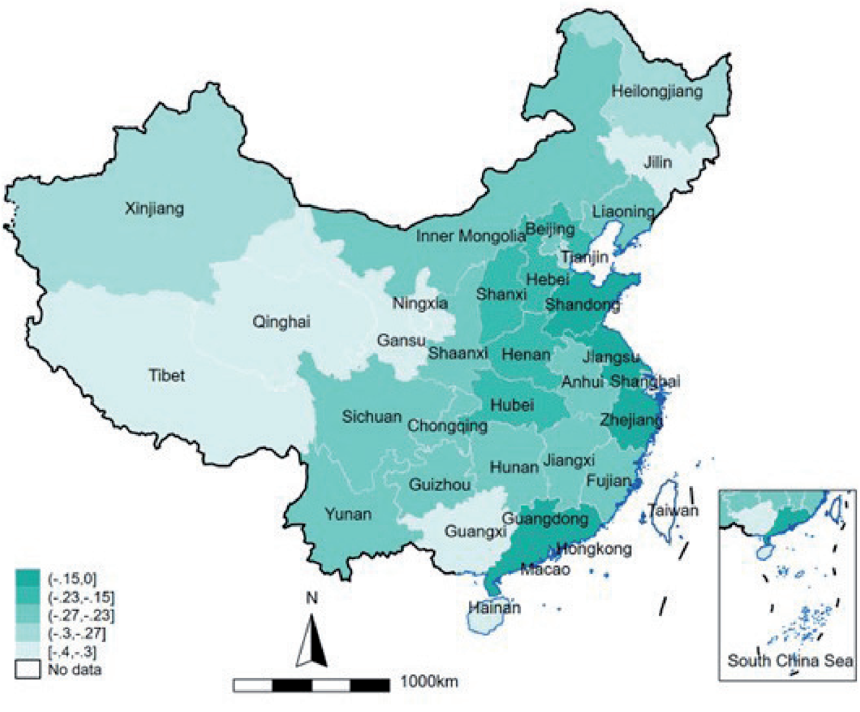

Fig. 1. Static composite indicator score

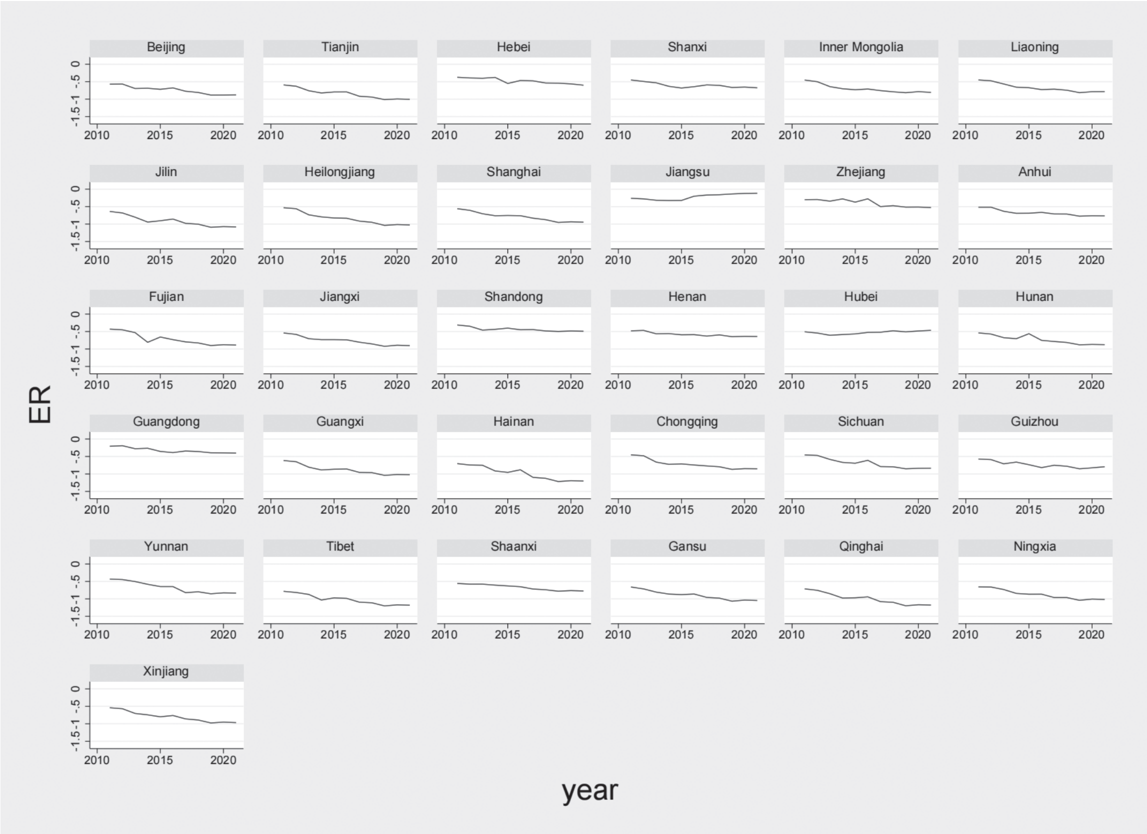

Fig. 2. Dynamic composite indicator score.

intensity due to improved environmental quality and reduced pollution emissions, suggests a broad national trend. However, this decline also signals a potential reduction in environmental management investment by local governments, raising questions about the long-term sustainability of these environmental quality improvements. This study contributes to the discourse by providing a nuanced understanding of the temporal and spatial dynamics of China's environmental regulatory framework, urging a reevaluation of policy approaches to sustain environmental governance efforts amidst evolving economic and environmental landscapes.

Conclusions

This research developed a multidimensional composite indicator to analyze the spatial and temporal dynamics of China's environmental regulatory framework from 2011 to 2021. By incorporating command-and-control, market-based, and public participation dimensions into our analysis, we provide a comprehensive view of China's approach to environmental regulation. Our findings highlight the predominant role of command-and-control and public participation measures, in contrast to the less impactful market-based regulations. This pattern aligns with observations by Luo et al. [33]. In the command-and-control dimension, both the quantity of pollution treatment facilities and the enforcement of current environmental regulations and rules are crucial. These factors significantly influence the effectiveness of environmental regulation. However, the investment in environmental management, although vital, has not been fully leveraged. Increasing this investment can potentially enhance the efficiency and impact of command-and-control measures.

From both a spatial and temporal perspective, our analysis reveals a general weakening of the regulatory framework's intensity from east to west. This finding aligns with the study by Feng et al. [36] and correlates with the industrial migration patterns observed across the country, as discussed by Fu et al. [67]. It is noteworthy that the provinces in Western and Northeastern China exhibit a greater decline, reflecting the challenges to the environmental regulatory framework posed by underdeveloped economies and dependency on resources.

Our study suggests that adopting a uniform regulatory approach across provinces with varying economic statuses may not be effective. Instead, it emphasizes the need for region-specific strategies that leverage local resources, such as wind and solar energy, to bolster the market-based dimension. Furthermore, enhancing public environmental awareness and participation is crucial for a more holistic environmental governance model.

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Conflict of Interest

The authors declare no conflict of interest.

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