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Impact of environmental regulation policy on ecological efficiency in four major urban agglomerations in eastern China

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A R T I C L E I N F O

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A B S T R A C T

Rapid economic development of any country will usually lead to negative environmental impacts. A free market economy cannot fundamentally solve this issue, which requires the guidance and control of the government. The environmental policies of governments can effectively improve the ecological conditions in a region. This study quantifies environmental regulation policies and takes four urban agglomerations in eastern China as the research object to explore the influence of environmental regulation on regional ecological efficiency. First, policies can be divided into policy control, pollution control, ecological protection, and social adjustment by building a Latent Dirichlet Allocation (LDA) model of a policy text library to measure differences in urban policy bias. Next, a slack-based measure (SBM) model was used to measure urban ecological efficiency. Finally, using the qualitative comparison analysis method, the time effect was considered and the ecological efficiency configuration of the entire region was obtained. In addition, contrast analysis was conducted for different path configurations and the reasons of the statuses of the four urban agglomerations were obtained. The results show that policy control, pollution control, ecological protection, and other mandatory policies can significantly reduce the negative environmental effects, especially when the policy controls involve an explicit form of punishment, which is a necessary condition for achieving a high level of ecological efficiency. However, social adjustment means having higher requirements for regional total factor development, which requires improving the environmental awareness of residents and improving corporate social responsibility. Regional differences will mean that areas with a lower level of economic development have a higher intensity of policy control, and the means of policy control should be matched with the level of economic development. In addition, this study proposes some policy suggestions, such as strengthening policy control and pollution prevention, strengthening social regulation, and promulgating environmental laws and regulations according to local conditions.

1. Introduction

Academicians have reached a consensus that rapid economic development in many countries will normally lead to a series of environmental issues and problems (Xing et al., 2017; Shang et al., 2018; Adedoyin et al., 2020; Kuriqi et al., 2020). However, the free market mechanism cannot solve problems related to the environmental pollution and other issues, which requires the guidance and control of the government (Bei, 2009). The Chinese government has always attached great importance to maintaining a balance between the maximization of economic benefits and the minimization of ecological impacts. It has issued a series of environmental regulation policies based on local conditions to develop environmental protection measures that are consistent with sustainable economic development goals (Xie et al., 2017). This has greatly improved the overall ecological situation in China (Zhu et al., 2020), although an imbalance is also gradually emerging between the needs for economic development and environmental protection in some regions (Zhang et al., 2019. From a national perspective, owing to the differences in the availability of natural resources, geographical location, ability to innovate, attraction of talented personnel, and other aspects, the ecological conditions of cities in eastern China are obviously better than those of other regions (Qin et al., 2018; Li et al., 2020). In the eastern region, the four urban agglomerations also present different levels of development and ecological impact

Abbreviations: LDA, Latent Dirichlet Allocation; QCA, Qualitative comparative analysis; SBM-DEA, Slack-based Measure Data envelopment analysis.

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Table 1
Geographical space and division basis of urban agglomeration in eastern coastal area of China.

The Four Major Urban Agglomerations	Cities Covered	Policy Basised
Beijing-Tianjin-Hebei	Beijing, Tianjin, Shijiazhuang, Tangshan, Qinhuangdao, Baoding, Zhangjiakou, Chengde, Cangzhou, Langfang	*Outline of the Plan for Coordinated Development for the Beijing-Tianjin- Hebei Region*
The Shandong Peninsula	Jinan, Qingdao, Zibo, Dongying, Yantai, Weifang, Weihai, Rizhao	*Shandong Peninsula Blue Economic Zone Development Plan*
The Yangtze River Delta	Shanghai, Nanjing, Wuxi, Changzhou, Suzhou, Nantong, Yangzhou, Zhenjiang, Hangzhou	*Development plan for the Yangtze River Delta City Cluster*
The Pearl River Delta	Shenzhen, Guangzhou, Dongguan, Zhuhai, Foshan, Zhongshan, Huizhou, Jiangmen, Zhaoqing	*Outline of the Reform and Development Plan for the Pearl River Delta Region (2008–2020)*

(Table 1). Based on the above phenomena, the following questions are posed. To what degree does the influence of policy factors affect urban ecological efficiency among the many factors that can be considered? Do different types of policies have the same effect on ecological efficiency? What types of environmental policies create the differences in ecological efficiency among the four urban agglomerations?

In order to discuss the impact mechanism of environmental policies on regional eco-efficiency and the specific action path of different types of policies on ecological efficiency in the eastern urban agglomeration of Eastern China, this study proceeds as follows. Section 1 proposes the research question. Section 2 provides a detailed literature review of issues related to environmental regulations and eco-efficiency along with the concepts and measurements involved. The data sources and research methods, including latent Dirichlet allocation (LDA), slack-based measure (SBM), and qualitative comparative analysis (QCA), are then described in Sections 3 and 4, respectively. Section 5 describes the empirical results, includes the construction of a test base of environmental policy for each city within the last 10 years and the evaluation of the eco-efficiency of eastern cities in the last 10 years, and analyzes the effects of the characteristics of combinations of policies on eco-efficiency. Section 6 concludes with a summary of the main findings and policy implications.

2. Literature review

2.1. Environmental regulations

Environmental regulation policies refer to the relevant codes of conduct issued by government authorities that are designed to protect the environment, rationally develop and use resources, and promote the harmonious and stable development of human beings and the social environment (Vollebergh, 2007). Existing studies have divided environmental regulation policies into three categories based on the degree of environmental control involved: (1) Command-control policy tools, which achieve the goal of environmental protection by imposing economic or administrative penalties on polluters (Oosterhuis et al., 2007); (2) Economic incentive policy tools, which influence the price or production cost of products by regulating ecological taxation and subsidies, and then change the investment and income of market subjects; and (3) Voluntary policy tools, which are self-regulating policies that mainly rely on polluters, allowing governments and polluters to adopt non-mandatory and cooperative policies (Jordan et al., 2003).

Early studies on environmental regulation policies have focused on the effects of policies on regional economic development and have mainly focused on the negative effects. For example, Jorgensonet al. (1990) believed that under the constraint of environmental regulations, enterprises should bear the additional cost of pollutant emissions, which would lead to an increase in production costs resulting in a reduction of output and profits, and hinder regional economic development. The pollution haven hypothesis also holds that within a short period, strict environmental regulations will increase production costs for enterprises and force enterprises to relocate into less tightly regulated areas (Conrad and Wastl, 1995), ultimately affecting the economic development of the original regions. But then Porter's hypothesis caused scholars to pay more attention to the positive effects of environmental regulations. Porter pointed out that strict environmental regulations can promote the technological innovation of enterprises to offset the cost of environmental protection, and create net income. This not only gives enterprises a competitive edge in the market, but also achieves a win–win situation when balancing environmental protection and economic growth (Porter and Van der Linde, 1991, 1995). The scholars have also proved that environmental regulations have positive effects on industrial technological innovation and industrial institutions (Lanjouw and Mody, 1996; Domazlicky and Weber, 2004). They believe that appropriate environmental regulations can stimulate innovation while improving market performance and efficiency (Yuan et al.,2017), while multi-dimensional environmental regulations can more significantly promote regional development (Zefeng et al., 2018). With the deepening of the research, the single theory suggesting environmental regulations will either "suppress" or "promote" the economy remains controversial; scholars have started to comprehensively consider other factors to study the environment, and uncertainty in the relationship has been proposed. In other words, the relationship between environmental regulation and regional economy, technological innovation, ecological efficiency, and other factors is not simply a "promoting or inhibiting" type of relationship, but may be non-linear.

Determining the quality of environmental regulation policies has always been at the core of policy factor research; scholars have also proposed a variety of related research methods. The first method used to determine the quality of such policies is based on qualitative indicators and mainly relies on expert or weighted rating (Walter and Ugelow, 1979). The second method employs existing quantitative indicators to find indirect proxy variables; the resulting indicators mostly use the amounts of pollutant discharged based on published data from the industrial sector (Xing and Kolstad, 2002), the cost of pollutant treatment (Gollop and Roberts, 1983) and so on, or take multiple indicators into comprehensive consideration. Although this can reflect the effectiveness of environmental policies to some extent, this method is not good at comprehensively quantifying environmental policies because proxy variables are vulnerable to change based on other factors. The third method involves combining several individual indicators into a comprehensive index through using statistical methods such as factor analysis and standardization; this method can better consider the multidimensional nature of environmental policies. The indicators considered in the third method include pollutant discharge indicators and enterprise input costs (Botta, Enrico and Tomasz Koźluk., 2014). The fourth method involves directly measuring the effects of the environmental policy itself, which avoids measurement inaccuracies caused by looking for proxy variables; in this fourth method the effects of regional environmental policies are generally measured by the number of environmental regulation policies issued by regional governments (Levinson, 1996). Some scholars also quantify environmental regulation policies by measuring the changes in the degree of enforcement before and after the release of environmental policies (McConnell and Schwab, 1990).

Because environmental policies are complex, no single quantitative method is widely accepted for analyzing their effects. The existing methods have the following defects: consulting with subject matter experts is too subjective and cannot accurately reflect the effects of environmental policies. A proxy variable is one-sided and cannot fully measure the effects of the environmental policy itself. At the same time, the selection of quantitative indicators is not accurate and provides incomplete data making it difficult to measure the investment involved and income generated by environmental regulation. Because a wide variety of methods are employed, the results of the same type of research in different areas are not comparable, because the results are often unreasonable and inconsistent. Hence, by starting from an analysis of each environmental regulation policy itself, the present study involved the collection of a large number of environmental regulation policy documents and constructed a topic analysis model through Python, which can directly and objectively reflect the effects of environmental regulation; this allows for conducting a quantitative comparison of environmental policy documents from different regions. Applying a topic analysis model can solve some problems involved in existing research and provide a new method for policy quantification.

2.2. Ecological efficiency

In the face of resource shortage and environmental deterioration, scholars at home and abroad have carried out research on ecological environment in many fields (Kuriqi et al., 2021; Suwal et al., 2020). Ecological efficiency refers to the ratio between the value of economic growth and environmental load in a certain period. A high level of ecological efficiency usually reflects the ability of a region to produce additional goods and services while consuming fewer natural resources and having less impact on the environment as proposed by Schaltegger and Sturm (1990) Methods of ecological efficiency measurement include the single-index ratio method, factor analysis, and data envelopment analysis; different methods are selected based on different types of research. The simplest method used to measure ecological efficiency is the single-index ratio method (Nieminen et al., 2007), which is applicable to independent objects. However, under complex conditions, it is generally necessary to construct an index system to measure ecological efficiency (Van Caneghem et al., 2010), which is inevitably affected by subjective factors (Martinez-Alier et al., 1998). In recent years, data envelopment analysis (DEA) has been widely used in the evaluation of ecological efficiency (Dyckhoff and Allen, 2001; Quariguasi Frota Neto et al., 2009; Lauwers, 2009; Yang and Zhang, 2018). However, a traditional DEA model only considers economic output and does not include any negative environmental externalities (Xu et al.,2017), so the measurement results are not reasonable. Hence, some scholars have proposed the super-efficiency DEA model(Tone, 2001) Although this model solves the problem related to the fact that many decision-making units (DMUs) are in the frontier and cannot be compared, the radial measurement method cannot measure the degree of inefficiency by improving the equal ratio of input and output, and cannot measure the lack of efficiency of the relaxation variable. Based on this, Tone and Kaoru (2004) proposed the non-radial and non-angular SBM model, and divided the output into desirable and undesirable types of output. This makes the measurement of regional ecological efficiency more reasonable. After that, scholars continue to build on these basic models and add more constraints to consider the problem (Li and Shi, 2014). Super-SBM model is proposed, which combines the super efficiency with the SBM model. This model takes into account both the slack variables and the undesired outputs and overcomes the deficiency of the traditional DEA model that could not determine the level of efficiency when there were multiple effective DMUs (Cooper et al., 2001). Thus, this study employed the supper efficiency SBM model with a fixed scale effect and undesirable output to evaluate the level of urban ecological efficiency.

At present, most research studies related to ecological efficiency have concentrated on the regional industry field (Chen and Lin, 2020; Shao et al., 2019). Industrial enterprises are not only the main contributors to a regional economy, but also serve as the main objects of pollutant emission and control. In contrast, regional industrial ecological efficiency is closely related to the overall development of a region, and the data on industrial enterprises are often more readily accessible than data from non-point source pollutants. In terms of factors that influence ecological efficiency, some researchers believe that suitable environmental policies can stimulate technological innovation within industrial enterprises and improve the greening of total factor productivity (Porter and Linde, 1995). Some scholars have also provided contrasting research perspectives, believing that in addition to environmental policy regulation, other factors such as the degree of decentralization of the government and the degree of openness to the outside world would have an impact on the ecological efficiency of a region (Matuszczak et al., 2020). In the current study, the effects of environmental regulation on regional ecological efficiency are mainly cause by influencing regional economic development and environmental pollution prevention and control; in addition, environmental regulation can be studied as one of the various factors affecting ecological efficiency.

In the present study, the effects of environmental regulation on regional ecological efficiency mainly occurred through the two aspects of affecting regional economic development and environmental pollution prevention and control. However, environmental regulation is considered as one of the various factors affecting ecological efficiency (Dasgupta et al., 2002; Bjorn and Stigson, 2000), and such regulations mostly use spatial econometric analysis (Liu et al., 2020; Ren et al., 2018). The relationship between environmental regulation and eco-efficiency can be divided into the following three kinds. (1) Negative effects: Represented by early studies, strict environmental regulations will not only increase costs and reduce profits, but also affect regional production efficiency(Jorgenson and Wilcoxen, 1990; Conrad and Wastl, 1995). (2) Positive effects: Represented by Porter Hypothesis, environmental regulation can bring about a win–win result of economic growth and environmental protection(Porter and Van der Linde, 1991; Porter and Linde, 1995). Further studies have shown that there is a positive interaction effect between the two types of formal and informal regulations in improving industrial ecological efficiency (Xueguo and Junjie, 2019). Environmental laws and regulations made by policy makers can provide guidance for the sustainable development of the environment (Yasmeen et al., 2020b). (3) Uncertainty effects: The relationship between the two is not simply positive or negative. For example, Close J. (Isern et al., 2001) proposed that the relationship between environmental regulation and regional eco-efficiency is nonlinear and presents an “inverted U-shaped” curve. Some scholars also pointed out that the relationship between them changes over time due to the spillover effect of neighboring regions (Becker, 2011). In the study of sub-regional ecological efficiency, Chinese scholars have found that environmental regulations have a positive impact on the ecological efficiency in central and eastern China, while there is a lack of correlation in western China (Yasmeen et al., 2020a). The relationship between the two is in a U-shaped curve, and the eastern part of China is on the right, while the central and western parts are usually on the left (Yuling and Ye, 2018).

Therefore, this study begins from the quantification of environmental regulation policies and takes the four urban agglomerations in eastern China as the research object to discuss the mechanism involved in influencing environmental regulation on regional ecological efficiency. The innovation of this paper is that, it innovatively uses the natural language processing method to encode and quantify the environmental regulation policies by constructing a topicanalysis model, and objectively describes the environmental policies. This is different from the past research methods, which usually adopt expert consultation method or scoring method, and have strong subjectivity. This textual analysis provides a new method for the study of environmental regulation. After that the SBM model is adopted to calculate urban ecological efficiency, and QCA is finally used to discuss the combinational influence relationship of the configuration of environmental policy conditions on ecological efficiency, which can provide a new perspective improving environmental conditions.

3. Methodology

The eastern region of China is the center of gravity of China's economic and social development. In the process of development, four urban agglomerations have gradually formed, centered on the Beijing-Tianjin-Hebei region, Shandong Peninsula, Yangtze River Delta and Pearl River Delta, with high ecological level and complex ecological pattern. It is of great significance to study the level of ecological development and analyze the composition of influencing factors for the improvement of social ecological efficiency in China. The four major urban agglomerations cover cities and their classification basis are shown in the following table.

This section introduces the research methods and models used in the research process successively. Then takes the four major urban agglomerations as the research space scope and introduces the sources of research data. As for the design of study is multilevel and quite complicated, we provide Fig. 1 to present the procedure.

3.1. Environmental regulations —Latent Dirichlet Allocation (LDA)

The main steps of LDA topic model are as follows:data cleaning, word segmentation, model building and model evaluation. Because the policy text was standardized, this study selected the commonly used Chinese stopwords to clean the data since the policy documents that were analyzed here were written in Chinese. Stopwords are commonly used words that were not used for further text analysis; for example, in English stopwords might include the following words: the, is, and. Jieba word segmentation, which is the most widely used word segmentation method in Chinese, was applied to the policy documents. Then we build the LDA model to train the text database.

First, in order to ensure the subject extraction results, it is necessary to calculate perplexity, and the number of topics is selected according to the perplexity, which is generally the inflection point of the line graph. Finally, the text is classified and quantified to obtain the quantitative data of the policy text.

LDA topic model (Latent Dirichlet Allocation) is a three-layer Bayesian theme model based on text mining unsupervised learning. It can give the topic of each document in the form of probability distribution so as to carry out subject cluster analysis or text classification (Blei et al., 2003). It has been widely used in various research fields, such as news subject extraction (Liu et al., 2018a), emotion analysis (Liu et al., 2018b), etc. However, because the text content is complex, LDA topic model usually analyzes titles and contents of abstracts (Agrawal et al., 2018), which is also applicable to the normative policy regulations themselves. This study firstly analyzes the whole corpus of all the policies in the environmental regulation policy database.

Assume that each document D in a corpus consists of multiple topics, the document d can be generated by the following progress (Blei et al., 2003).

1. Choose document length N from Dirichlet distribution $N\ Dir(\beta)$.
2. Choose θ from Dirichlet distribution $\theta\ Dir(\alpha)$.
3. Choose z_n $Multinomial(\theta)$ for each word in the document, choose $w_n$from a multinomial distribution $p(w_n|z_n,\beta)$conditioned on the topic z_n.

α and β are the hyper-parameter of the Dirichlet prior determined based on the topic distribution and word distribution, respectively. The K-dimensional Dirichlet random variable θ is the probabilistic distribution of document-topic matrix. w_n denotes the nth word and z_n indicates the latent topic assigned to w_n.

After the LDA topic model is designed, the training results need to be evaluated to determine the optimal number of topics. Perplexity is a good index to evaluate topic model, which can determine the number of topics and evaluate the performance of the topic categorization. Theoretically, the lower the perplexity value, the better the model results, indicating that the topic classification can better represent all the text (Blei et al., 2003). In general, the more topics there are, the lower the perplexity value will be, which leads to topic redundancy and makes subsequent analysis more difficult. Therefore, in practical application, the number of topics is determined by the inflexion of the line chart. The perplexity is calculated as:

$$\text{perplexity} = e^{\frac{-\sum \log(p(w))}{N}}$$

p(w) refers to the probability of each word appearing in all texts, which is specific to the LDA topic model is as $p(w) = \sum zp(z|d)^{*}p(w|z)p(w)$, in which z and d represent the subject in the text and each document in the policy database. N is all the words that appear in the text database, including duplicate values (Wallach et al., 2009).

3.2. Measurement of ecological efficiency

3.2.1. Index system

Based on literature review and previous research results, it is believed that capital, labor force and resources are the most important input factors, and economic output and the volume of pollutant discharge are considered to be the most widely used output factors. Considering the availability of data and the rationality of the index system, this paper constructs the eco-efficiency evaluation index system, as shown in Table 2. On the input side, the variable "total fixed asset investment of the entire society" represents the input factors of capital; the number of employees at the end of the period represents the input factors of labor; the urban built-up area represents the total electricity consumption of the entire society; and the total urban water supply represents the input of the three natural factors of land, energy, and water resources (Yang and Zhang, 2018; Huang et al., 2014). On the output side, it is divided into desirable and undesirable output. The

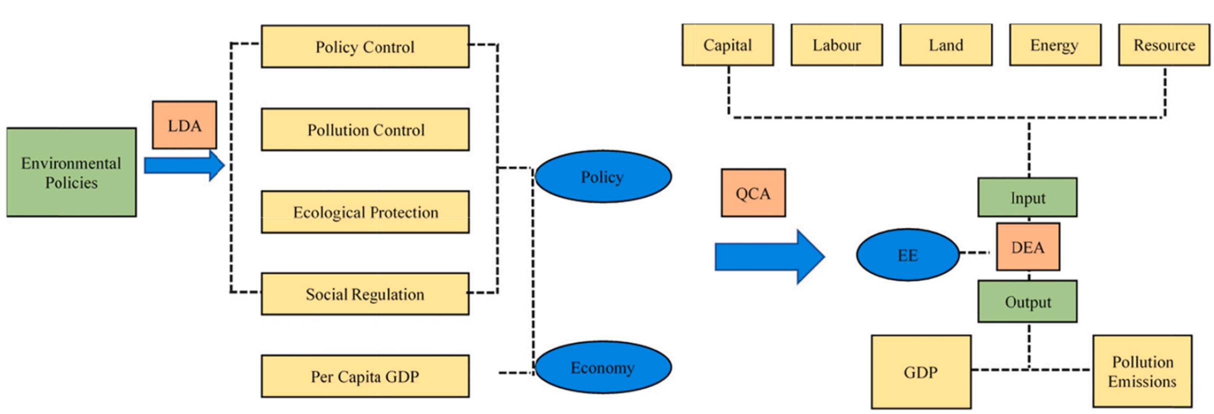

Fig. 1. Research process of the study.

Table 2
Descriptions of the evaluation index system.

Indicators	Variables	Descriptions
Input	Total fixed asset investment(I_1)	The capital stock is estimated using the perpetual inventory method with 2010 prices unchanged.
	Employees (I_2)	The number of employees at the end of the year measures labor input.
	Land area (I_3)	In previous studies, the land input was less considered, but the land area changed greatly over several years, and the land input was measured by the urban built-up area.
	Total power consumption(I_4)	The total amount of electricity in the whole society measures the energy consumption.
	Total urban water supply(I_5)	Water resources are increasingly becoming an important factor restricting urban development, which is measured by the total urban water supply.
Desirable output	GDP (DO_1)	Gross domestic product is the most intuitive variable of expected output.
Undesirable output	Industrial wastewater (UO_1) Industrial sulfur dioxide emissions (UO_2) Industrial smoke (powder) dust emissions (UO_3)	Most studies have chosen environmental pollutants as undesirable outputs. In this study, three different types of pollutant emissions were selected as measurement criteria.

Gross Domestic Product (GDP) of the city was selected as the desirable output to represent the level of urban economic development, and the emissions of industrial waste water, industrial sulfur dioxide, and industrial soot were selected as the undesirable outputs to measure desirable output comprehensively.

3.2.2. Slack based measure-data envelopment analysis (SBM-DEA) model

Slack based measure-data envelopment analysis (SBM-DEA) model is the ecological efficiency measurement model of non-radial and non-angled SBM model proposed by Tone (2001) for the first time, and it can well solve the problem of deviation of the slack variables in previous model, so as to improve the accuracy of evaluation. The fractional programming problem of the constant returns to SBM model is expressed as follows:

$$\begin{cases} \min\left[\theta - \varepsilon\left(\sum_{i=1}^{m} S_{i-} + \sum_{r=1}^{s} S_r^{+}\right)\right] \\ s.t.\sum_{n}\lambda_j x_{ij} + S_i^{-} = \theta x_0, i = 1, 2, \cdots, m \\ \sum_{n}\lambda_j y_{ij} - S_r^{+} = y_0, r = 1, 2, \cdots, s \\ \lambda_j \geq 0, j = 1, 2, \cdots, n, S_r^{+} \geq 0, S_i^{-} \geq 0 \end{cases}$$

where, θ stands for theefficiency value of the DMU, which represents the relative ecological efficiency of the region. m、s、n represents the dimension of input variables, the dimension of output variables and the number of regions, respectively. Si^{-}, Si^{+} represents slack variables. x_{ij}、y_{ij}为represents inputs and outputs. λ represents the weight coefficient. If θ is less than 1, the DMU is inefficient, or the DMU achieves optimal efficiency, and the higher the value is, the higher the ecological efficiency is.

3.3. Configuration Analysis—Qualitative comparative analysis

Qualitative comparative analysis (QCA) involves building upon causal interpretation, visualization, and analysis of causal complexity as well as principles of logical minimization, which is suitable to an intermediate number of cases. This type of analysis combines qualitative analysis with quantitative analysis and has many advantages. Qualitative comparative analysis assumes the conditional variables have interdependent relationships, conducts the overall configuration analysis of conditions, expands the single symmetric relationships, reveals more complex causal relationships, and is more in line with social phenomena (Ragin, 2009a; Ragin, 2009b). In addition, it allows the same result to be obtained through different paths (Ragin and Rihoux, 2009; Rihoux, 2009), which attempts to establish a logical relationship between the combination of conditions and the result. Thirdly, in the selection of samples, no strict requirement exists related to the number of samples, only that the selection of cases should be differentiated and cover all types as far as possible, which is also applicable to the analysis of small samples (Cooper et al., 2001).

In practical application, QCA includes Crisp-set QCA (csQCA), multi-value QCA (mvQCA), and fuzzy-set QCA (fsQCA). According to the characteristics of the data and cases in this paper, fsQCA based on Boolean algebra and set analysis is more accurate than the other two QCAs (Ragin, 2009b; Schneider et al., 2010; Ragin, 2008; Schneider, 2012). In addition, the fuzzy-set QCA, as a sustainable development method, has been documented to take the effects of time into account and provides a common measure to evaluate panel data, making this method applicable to longitudinal studies (Garcia-Castro and Ariño, 2016). The authors propose calculations of three consistent methods designed to assess the stability of different cases over time: pooled consistency (POCONS), between consistency (BECONS), and within consistency (WICONS), as well as pooled coverage (POCOV), between coverage (BECOV) and within coverage (WICOV). In Section 5, this paper draws on this research, takes the effect of time into consideration, and evaluates the effects of environmental regulation policies on ecological efficiency in each of the four urban areas evaluated here within a decade, so as to provide a new perspective for regional environmental regulation research (Fig. 2).

3.4. Data sources

The data are divided into two categories, policy data and research data, based on the methods and types of data collection involved.

The policy text database includes laws and regulations related to the changes in environmental conditions in 36 cities from 2009 to 2019. It was collected mainly through Python code, GooSeeker software, and manual supplementary methods. The text data source of environmental policies comes from the official website of the Chinese municipal departments of environmental protection and the Legal database of BeidaBaisan (https://www.pkulaw.com/). The website for this data source is provided in the appendix. The text database contains a total of 1158 normative documents. The numbers and examples of relevant documents in each city are shown in Table 3.

Research data, such as data related to total fixed asset investment, urbanized area, the number of employees at the end of the year, total power consumption, total urban water supply, and pollutant discharge, were collected from China Statistical Yearbooks, China Statistical Yearbooks on the Environment, and the respective official municipal websites of various cities, which were mainly used to evaluate the ecological efficiency of each city. Since some 2019 data were not available, the statistical yearbook data from 2009 to 2018 was used for exponential smoothing to supplement the missing data.

4. Results

4.1. Quantification of environmental regulations

The text database was trained through running an LDA algorithm, and a Perplexity value was calculated under a number of different topics to evaluate the model.

Figure 3 shows the Perplexity values for different topics, with the

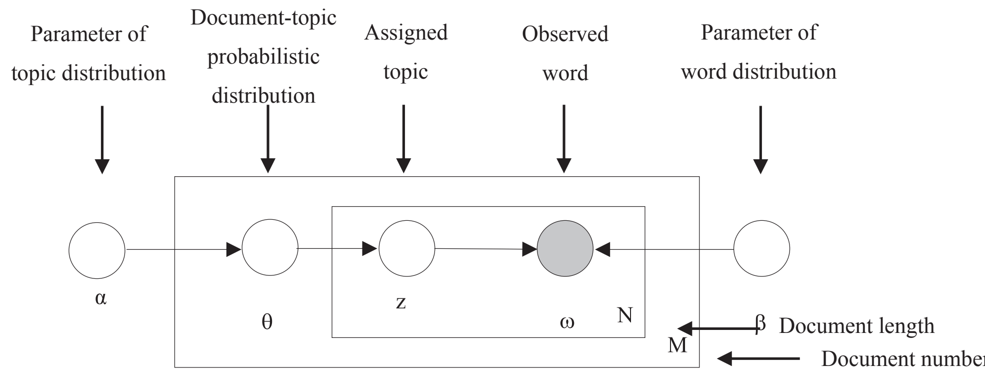

Fig. 2. Probabilistic graphics of Latent Dirichlet Allocation topic model.

Table 3
Description of environmental policies of some cities in the eastern coastal area of China.

City	Number of Regulations	Total Words/ byte	Examples
Beijing	56	626,084	*Beijing Municipal Environmental Protection Bureau Administrative Penalty Discretionary Benchmark (2018), The Implementation Plan of Beijing's Pollutant Emission Control Permit System*
Guangzhou	23	395,180	*Measures For Reporting Environmental Violations with Rewards in Guangzhou, Guangzhou Greening Ordinance*
Qingdao	68	385,616	*The Implementation Plan Focuses on Strengthening Environmental Supervision of Key Enterprises Provisions on the Discretion Standard of Administrative Penalty For Environmental Protection in Qingdao*
Suzhou	27	327,362	*Regulations of Suzhou on The Prevention and Control of Environmental Pollution by Hazardous Waste* (2018)*, Regulations of Suzhou On Wetland Protection*
Nanjing	33	394,130	*Measures of Nanjing For Ecological Protection Compensation, Nanjing Municipality Implements The Implementation Measures For Third-party Treatment of Environmental Pollution*

number of topics ranging from 1 to 19. With an increase in the number of topics, the Perplexity value was lower with a better degree of fitting; however, when the number of topics become too large, overfitting will occur, resulting in topic redundancy. An inflection point of topics = 4 was selected to ensure that the Perplexity value was greater than 500 and the number of topics was not redundant, so that an LDA algorithm could be produced for all policies.

The database contained 1,158 policy documents, including government policy documents on ecological protection and environmental regulations for each city from 2009 to 2018. Through the LDA topic model, different topics were classified and summarized according to the characteristics of keywords and protection objects. A lag effect exists between the timing of the release of policies and the time when their impacts are felt; this lag period of such policies for the environment is generally about one year (Du et al., 2019). Table 4 provides the keywords related to the four topics, and selects some words that are significantly representative of the topic category.

Topic 1 is policy control, which mainly focuses on control and command; Topic 1 involves the use of coercive means such as fines to control behaviors that negatively affect the environment. Topic 2 is related to pollution control, which aims to reduce and control the release of pollutants into the environment and helps enterprises or cities to better control the discharge of harmful substances in water and gas. Topic 3 is ecological protection; this includes proposals or policy plans that are proposed to protect the environment from the aspects of energy conservation and afforestation. Topic 4 is about social regulation, which is mostly used to persuade enterprises or the public to avoid causing pollution; this is done by means of publicity or education to arouse the public's awareness of the need for environmental protection. Although such policies require a major financial investment and the effects are generated slowly, these policies typically have long-term effects (Fig. 4. Fig. 5).

The number of environmental policies released by government

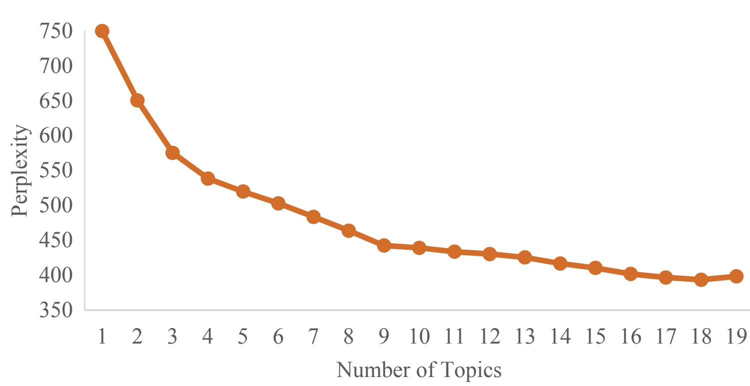

Fig. 3. Perplexity with different topic number.

Table 4
Top keywords for four different topics analyzed here.

Topic	Topic1	Topic2	Topic3	Topic4
Number	282	263	345	268
Keywords and probability distribution	competent department (0.093)	warning(0.073)	emission reduction(0.071)	emergency(0.146)
	protection(0.048)	Atmospheric pollution (0.054)	sewage(0.067)	incident(0.111)
	penalty(0.040)	issue(0.052)	industry(0.064)	sudden(0.085)
	regulations(0.039)	govern(0.046)	governance(0.062)	environmental protection administration (0.050)
	violate(0.039)	dust(0.042)	energy conservation (0.054)	organization(0.041)
	charge(0.034)	Air quality(0.041)	green(0.051)	evaluation(0.039)
	approve(0.031)	repair(0.037)	industrial(0.049)	examine and approve(0.035)
	this city(0.029)	Soil pollution(0.037)	system(0.047)	scene(0.031)
category	Policy control	Pollution control	Ecological Protection	Social regulation

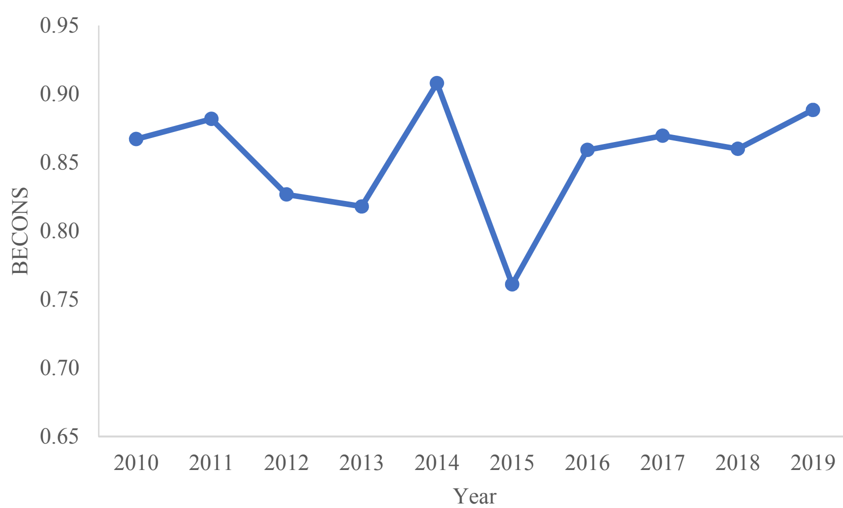

Fig. 4. BECONS (between consistency) values during 2010 to 2019.

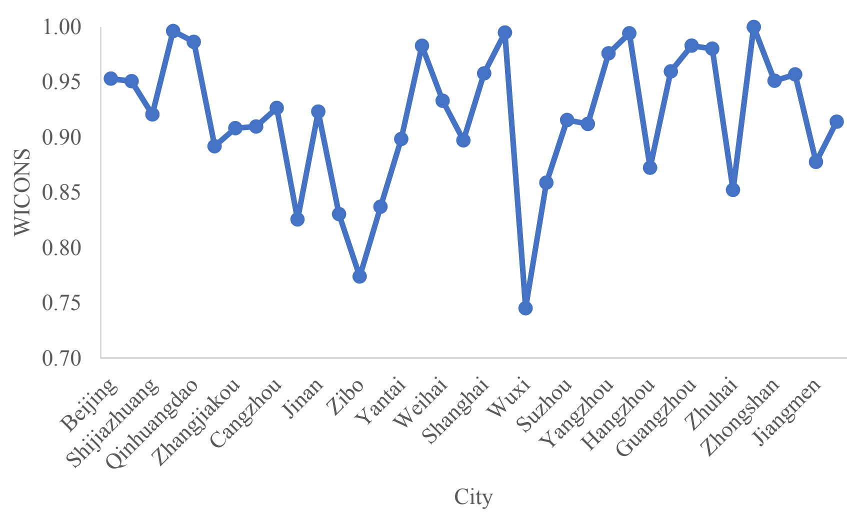

Fig. 5. WICONS (within consistency) values for all cities.

agencies on Topics 1, 2, 3, and 4 over the ten-year study was 282, 263, 345, and 268, respectively (Table 4). The key words under each topic can well reflect the main idea of each classified theme. Therefore, the LDA topic model better captured some potential characteristics of environmental policies and can effectively quantify the policy documents of 36 cities. The model outputs a probability distribution for each type of document in the subject category. It takes Qingdao in 2018, one of the 36 cities analyzed here, as an example; Table 5 shows the quantitative results related to policies.

Obviously, the distribution of each policy manuscript on the four topics adds up to 1. The four topics categorized policy factors into control, governance, prevention, and education factors. According to the

Table 5
An example: Political factors of Qingdao in 2018.

Probability of policy on topic	Topic1	Topic2	Topic3	Topic4	Total
Text1	0.013	0.547	0.197	0.243	1.000
Text2	0.005	0.674	0.189	0.132	1.000
Text3	0.011	0.967	0.011	0.011	1.000
Text4	0.000	0.028	0.000	0.971	1.000
Sum of policy factors	0.029	2.216	0.398	1.357	4.000

probability distribution of the policy manuscripts on the four topics, the sum of all quantitative policy factors of each city was obtained for each year.

Qingdao issued four environmental regulations in 2018, among which two address Topic 2, with the quantitative scores of 0.029, 2.216, 0.398, and 1.357 in governing the political factors 1, 2, 3, and 4, respectively.

4.2. Results of regional ecological efficiency analysis

The descriptive statistics of each indicator are shown in Table 6.

Using DEAPro5.0 software and measuring by non-radial and non-angular SBM-DEA, the ecological efficiency results of each city from 2009 to 2018 were found as follows. Some of the missing data are supplemented by the exponential smoothing method, and all the results are shown in Table 7.

On the whole, the ecological efficiency of some 36 cities mentioned above fell below 1,which means the city is not performing very well, while that of some other cities exceeded 1, indicating that there is great room for improvement of the ecological efficiency for some cities in China. On the whole, the ecological efficiency of the Yangtze River Delta is relatively good. The ecological efficiency of each region also showed an increasing trend year by year.

4.3. Qualitative comparative Analysis-Based on panel data

This section discusses the initial calibration of the data, analyzes the configuration effect of five conditions (four policy conditions and per capita GDP) on the outcome variable (ecological efficiency) through fsQCA2.5 software (http://www.fsqca.com), and finally analyzes the stability degree of the conditional configuration in time and space. Four policy factors in the five independent variables are extracted from Section 4.1. After the text is quantified from the policy document and the model is classified, the quantitative results of the four policy types are obtained. Per capita GDP is the economic factor added to the study after consulting a large number of literatures. The result variable is obtained through 4.2, which is evaluated by the DEA model.

4.3.1. Calibration

Of the five conditions listed above, the first four are determined according to the four topics drawn from the LDA topic model above, namely policy control, pollution control, ecological protection, and social regulation. Since the economic role is rarely reflected in manuscript classification in this study, and previous studies have shown that economic development has a relatively large impact on regional environmental efficiency (Taylor et al., 2016; Huang et al., 2018), per capita GDP to measure regional economic development was chosen in the present study.

The data calibration process was used to convert raw data; the selection of anchors in the process refers to previous studies (Ryan and Berbegal-Mirabent, 2016) as follows: full non-membership point (5%), the crossover point (50%), and full membership point (95%), which has been widely used in subsequent studies (Fiss, 2011).

4.3.2. Necessary conditions and results

First, test to see whether any of the conditions are necessary for the existence or non-existence of positive ecological efficiency results. The necessary condition requires the consistency of the calibrated variables to exceed 90% (Ragin, 2009b). In the overall analysis of 36 cities, none of the variables meets the requirements to be classified as a necessary condition.

The fsQCA2.5 software provides an output consisting of complex, parsimonious, and intermediate solutions, with a threshold for determining sufficient conditions of 87% (Ragin, 2009b). The present study mainly discusses the intermediate solution containing logical terms, supplemented by the parsimonious solution. Specifically, black circles (●) represent the presence of the condition and circles (○) indicate its absence, while represents the condition where the factor has no impact. In addition, large circles represent core conditions while small circles indicate peripheral conditions.

The consistency and coverage of all data and data for the four urban agglomerations were greater than 0.8 and 0.1, respectively (Ragin and Rihoux, 2009), indicating that the results are satisfactory.

The comprehensive data provides three configurations, all of which indicate a high level of economic development, in line with the current status of urban development in eastern China. Configuration 1 (T1) shows that strict policy control and pollution control will result in high ecological efficiency in economically developed areas. This configuration reflects the state of environmental regulation in most regions; that is, environmental protection policies and social regulation are not required, and high ecological efficiency can be achieved only through strict policy control along with pollution prevention and control. Configuration 2 (T2) indicates that strict policy control and environmental protection will constitute a sufficient condition configuration for high ecological efficiency when residents have poor awareness of the need for environmental protection and low social regulatory effects. This configuration reflects the policy configuration before environmental pollution occurs. In areas with low social regulation effects, punitive policy control and forward-looking environmental protection measures can better protect the environment. Configuration 3 (T3) indicates that strict pollution prevention and social regulation can achieve high ecological efficiency in the case of weak ecological protection policies. This configuration is often appeared in the late stage of urban development, attached importance to the cultivation of consciousness of residents and enterprises of the need for environmental protection and

Table 6
Descriptive statistics of input and output.

Indicators	Variables	Unit	Mean	Std.	Min	Max
Input	Total fixed asset investment(I_1)	10^4yuan	29,934,103	2.13E + 07	137,374	1.30E + 08
	Employees (I_2)	10^4persons	214	230	21	943
	Land area (I_3)	km^2	348	332	41	1446
	Total power consumption(I_4)	10^8kwh	411	327	36.2	1527
	Total urban water supply(I_5)	10^4t	54,690	72,762	3509	354,546
Desirable output	GDP (DO_1)	10^4yuan	63,267,157	6.70E + 07	4,045,897	6.28E + 08
Undesirable output	Industrial wastewater (UO_1)	10^4t	19,967	24,728	1363	211,951
	Industrial sulfur dioxide emissions (UO_2)	t	68,779	58,471	1329	331,863
	Industrial smoke (powder) dust emissions (UO_3)	t	45,512	69,437	700	536,092

Table 7
Eco-efficiency for various cities.

Area	City	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Jingjinji	Beijing	1.077	1.054	1.135	1.124	1.115	1.137	1.043	1.108	1.027	1.138	1.084
	Tianjin	0.506	0.156	0.653	0.731	1.005	1.027	0.196	0.691	1.039	1.029	0.457
	Shijiazhuang	0.369	0.132	0.409	0.411	1.122	0.462	0.150	0.321	1.074	0.778	0.583
	Tangshan	0.423	0.163	1.011	1.002	1.020	1.004	0.202	0.409	0.371	0.541	1.112
	Qinhuangdao	0.327	0.103	0.333	0.325	0.320	0.335	0.111	0.245	0.350	1.003	0.465
	Baoding	0.396	0.163	1.006	1.021	1.013	0.636	0.175	0.488	0.276	0.444	0.345
	Zhangjiakou	0.250	0.100	0.279	0.314	0.307	0.319	0.134	0.215	0.220	0.378	0.379
	Chengde	0.299	0.129	1.003	1.025	1.007	1.015	0.187	0.470	0.121	0.414	0.331
	Cangzhou	1.140	0.347	1.139	1.143	1.124	1.127	1.104	1.146	0.276	1.115	1.089
	Langfang	0.488	0.209	0.723	0.754	0.777	1.038	0.557	1.033	0.277	1.081	1.027
Shandong	Jinan	1.001	0.137	0.668	0.670	1.215	0.762	0.174	0.565	1.067	1.070	1.039
	Qingdao	1.021	0.192	1.060	1.053	1.035	1.054	0.212	1.110	1.045	1.075	1.032
	Zibo	0.363	0.134	0.504	0.514	0.511	0.511	0.149	0.290	0.414	0.488	0.449
	Dongying	1.023	0.217	1.094	1.094	1.109	1.125	0.279	1.037	1.033	1.076	0.318
	Yantai	1.009	0.203	1.030	1.012	1.015	1.022	0.248	0.652	0.332	1.068	0.703
	Weifang	1.078	0.182	0.576	0.579	0.576	0.583	0.250	0.388	0.223	1.031	1.027
	Weihai	1.081	0.223	1.086	1.102	1.086	1.062	0.226	1.027	0.397	1.028	1.004
	Rizhao	0.353	0.153	0.436	0.485	0.416	0.440	0.176	0.302	0.403	0.512	0.358
The Yangtze River Delta	Shanghai	1.011	0.162	1.063	1.050	1.061	1.051	0.148	1.061	1.085	1.021	1.064
	Nanjing	0.307	0.121	0.458	0.510	1.016	0.509	0.132	0.543	1.111	0.747	1.018
	Wuxi	0.777	0.580	1.040	1.041	1.059	1.026	0.217	1.015	0.451	1.035	1.038
	Changzhou	0.435	1.029	1.017	1.039	1.041	1.035	0.206	1.016	1.040	1.017	1.032
	Suzhou	1.079	1.092	1.057	1.039	1.032	1.039	0.192	1.002	0.371	1.039	1.068
	Nantong	1.035	0.190	0.841	1.015	1.044	0.916	0.181	1.004	0.353	1.039	1.043
	Yangzhou	1.019	0.200	1.010	1.006	1.013	1.006	0.188	1.011	1.032	1.035	1.052
	Zhenjiang	0.701	0.167	0.609	0.688	0.820	0.811	0.214	1.005	0.528	1.020	1.050
	Hangzhou	0.476	0.115	0.644	0.658	0.653	0.648	0.152	0.618	1.074	0.718	0.740
The Pearl River Delta	Shenzhen	1.239	1.195	1.297	1.304	1.304	1.301	1.254	1.219	1.297	1.210	1.253
	Guangzhou	1.006	0.023	1.007	1.001	1.010	1.055	0.136	0.576	0.574	0.482	0.524
	Dongguan	1.084	0.051	0.306	0.288	0.284	1.008	1.281	0.337	0.327	0.294	1.020
	Zhuhai	0.367	0.056	0.401	0.254	0.393	0.640	0.094	0.374	0.413	0.357	0.411
	Foshan	1.049	0.119	1.038	1.018	1.092	1.092	0.156	1.068	1.137	1.119	1.131
	Zhongshan	1.048	0.133	1.098	1.087	1.018	1.092	0.138	0.467	0.355	0.560	0.482
	Huizhou	0.461	0.060	0.397	0.390	0.399	0.644	0.090	0.324	0.213	0.313	0.282
	Jiangmen	0.410	1.277	0.433	0.388	0.371	0.472	0.078	0.246	0.155	0.293	0.335
	Zhaoqing	0.386	0.064	0.367	0.371	0.408	0.509	0.105	0.240	0.185	0.292	0.290

the need to improve social regulation of environmental management and at the same time, reduce the policy control, because having less punitive policy control is useful; in the later stage of development, cities often need to deal with the pollution situation urgently, so strict pollution prevention and control can improve the ecological efficiency of a region.

The different condition configurations of the four urban agglomerations also reflect some regional differences.

The Beijing-Tianjin-Hebei urban agglomeration has only two reasonable paths, both of which require a high level of economic development and pay more attention to policy control. Configuration 4 (J1) requires strict policy control, pollution prevention and careful management of the environment, as well as weak ecological protection and social regulation. This configuration is consistent with T1. Configuration 5 (J2) is a configuration with high coverage and consistency in Jingjinji, which requires strict policy control and social regulation, but has no requirements on pollution prevention and environmental protection. It is represented by Beijing and Tianjin. This reflects the regional characteristics of Jingjinji; the policy focuses on cultivating the environmental awareness of residents and enterprises in the region, advocating social adjustment and punitive policy control, which can achieve the goal of improving ecological efficiency.

The Shandong agglomeration provides four configurations, and reflects the difference of economic development level between regions. The first two paths covered 72.09% of the cases, and the second path was similar to T3 for full data. Configuration 6 (S1) indicates that in economically developed areas, strict pollution prevention and control along with loose environmental protection policies are required, with an emphasis on the treatment of polluted areas. In view of the unbalanced economic development in Shandong Province, Configuration 8 (S3) for the low level of economic development is proposed; this requires strict pollution control and loose policy control, environmental protection, and social regulation. The representative cases of S3 are the cities of Weifang and Yantai. In relatively underdeveloped areas, the implementation of policies related to pollutant emissions can improve ecological efficiency more rapidly.

The Yangtze River Delta urban agglomeration provides four configurations where more attention should be paid to policy control. However, Configuration 10 (C1) does not require policy control, while requiring loose pollution control, environmental protection, and social regulation. This may be related to the characteristics of cities, where Hangzhou, Suzhou, and other cities should pay attention to the development of tourism and internet-based enterprises, which have little impact on the environment. Therefore, environmental regulation policy of C1 is relatively loose and only requires a higher level of economic development. Configuration 12 (C3), similar to T2, requires strict policy control and ecological protection when the social regulation is loose. The representative cities of Configuration 13 (C4) are Zhenjiang, Nantong, and so on. This configuration also reflects the unbalanced economic development in the Yangtze River Delta region, and provides solutions for cities with relatively backward economic development; strict environmental policy regulation is required, and comprehensive management and control in four aspects should be emphasized.

The Pearl River Delta region has five configurations, and the coverage rate is above 20%; the case distribution is balanced. Here, more attention should be paid to policy control. Configuration 15 (Z2) is consistent with T1, and Configuration 18 (Z5) is basically consistent with T3. Configuration 14 (Z1) requires strict policy control, a high level of economic development, and low level of social regulation, and the case coverage is the largest, indicating that clear policy control is more likely to produce higher ecological efficiency when the public and enterprises lack awareness of the need for environmental protection. The representative cases include Dongguan and Guangzhou.

Overall, the means of policy regulation cover several stages of prevention in advance, control of the event and governance after the event. However, managers of the four major urban agglomeration areas pay more attention to policy control; that is, policies should have punitive and clear restrictions, and less attention should be paid to the role of social regulation. That is, the education and cultivation of environmental awareness of the masses and enterprises should be given attention. This can also reflect the drawbacks in China's environmental governance system. Although publicity and education on environmental protection are advocated, this concept is seldom reflected in the formulation and implementation of government policies, which may be related to the level of social development and the lag time observed in the effects of the implementation of new policies.

4.3.3. *Analysis of consistency and coverage distances*

This section reports on two types of consistencies: the BECONS measures the cross-sectional consistency for each year in the panel and the WICONS measures how consistent the relationships are across time for each particular case (Guedes et al., 2016), where the analysis contains 10 BECONS and 36 WICONS. In addition, the BECOV and WICOV measure the cross-sectional coverage for each year and cross-time coverage for each particular case, respectively, while the POCOV and POCONS measure the whole data. The two consistent methods, borrowed from Roberto's research (Roberto et al., 2016), can better reflect the stability of the panel data in different cities and years (Table 8 and Table 9).

The results show that BECONS and WICONS values are relatively stable, above 0.8 except in some cases. The value of BECONS showed that during the study period, the influence of policy factors on ecological efficiency evolved steadily over time. The results did not show a strong time effect lower than the base value, which may have occurred because China's environmental regulation policies did not change significantly which changes in policy direction and control methods during the study period. The stability of WICONS indicates that no polarization exists between the four major urban agglomerations in Eastern China analyzed here. The overall methods of environmental regulation, levels of economic development, and ecological efficiency tended to be consistent, and policy spillover effects may exist.

In order to clarify the difference between different years and cities, Roberto et al. (2016) suggested calculating the Euclidean distance of BECONS and WICONS to confirm that the time effect and cross-sectional effect were relatively dominant. The results show that the BECONS distance (0.015) was higher than WINCONS distance (0.011), which implies that time effects dominate over the cross-sectional effects. However, the BECONS Distance was lower than the benchmark threshold (|A| = 50,0.028), so there is no obvious time effect; that is,

Table 8
Analysis of the conditions necessaryfor the existence or non-existence of positive ecological efficiency results.

Item	Consistency	Coverage
poli	0.560	0.665
~poli	0.614	0.575
poll	0.514	0.632
~poll	0.662	0.604
ep	0.545	0.636
~ep	0.634	0.602
sp	0.532	0.642
~sp	0.641	0.593
pgdp	0.627	0.721
~pgdp	0.567	0.545

Table 9
Main configurations for 36 cities in the four major urban agglomerations.

All Areas				Jingjinji		Shandong				The Yangtze River Delta				The Pearl River Delta				
Parsimonious solution	T1	T2	T3	J1	J2	S1	S2	S3	S4	C1	C2	C3	C4	Z1	Z2	Z3	Z4	Z5
Configuration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
poli	●	●		●	●			○	○		•	●	●	●	●	●	●	
poll	●		●	●		●	●	•		○	○		●		●	●	○	●
ep		●	○			○		○	●	○	●	•	•			○	●	○
sp		○	●		●		●	○	●	○	○	○	●	○		○	○	•
pgdp	●	●	●	●	●	•	●		•	●		●	○	●	●			●
Consistency	0.822	0.836	0.841	0.883	0.906	0.856	0.853	0.859	0.868	0.850	0.877	0.866	0.872	0.825	0.850	0.882	0.895	0.868
Raw coverage	0.281	0.237	0.216	0.299	0.320	0.351	0.370	0.245	0.263	0.303	0.239	0.247	0.219	0.265	0.290	0.211	0.208	0.215
Unique coverage	0.052	0.046	0.043	0.047	0.068	0.030	0.024	0.041	0.031	0.129	0.029	0.019	0.053	0.037	0.046	0.035	0.021	0.046
Solution coverage	0.370			0.367		0.507				0.466				0.467				
Solution consistency	0.802			0.876		0.829				0.820				0.814				

environmental regulation does not reflect a strong periodicity.

We also report the BECOV and POCOV results (Table 10). Overall, POCOV coverage is low, indicating that environmental regulation and economic variables cannot fully explain high level of ecological efficiency; that is, other variables still exist that can be explained, such as technological progress and foreign investment. Moreover, the BECOV value fluctuates over time, indicating that the effects of environmental regulation and economy on ecological efficiency is also constantly changing. China's environmental policies have not entered a stage of stable development, but are constantly seeking a balance between the economy, politics, and ecology.

5. Discussion

The results of DEA show that there are huge differences in the ecological efficiency of the four urban agglomerations: horizontal and vertical differences. Horizontal differences are reflected in the huge differences in the eco-efficiency of various cities among regions. This is also fully reflected in the existing studies (Jian-Kai S U, 2018). For example, Shenzhen and Beijing have the highest eco-efficiency in their respective city clusters. In recent years, Beijing has issued 56 documents related to environmental regulations, a total of 626,084 bytes, and Shenzhen has issued 51 documents, both of which rank first in the number of environmental regulations issued by cities. It can be seen that the restriction of environmental policies has a promoting effect on the improvement of ecological efficiency. At the same time, the proportion of traditional industrial enterprises in the GDP of these two cities is very small, and the high-tech industrial institutions are expanding year by year. In 2020, the proportion of high-tech industries in the GDP of Beijing is 25.6%, providing an efficient and environmentally friendly industrial structure for the sustainable development of the society. The difference between cities in Shandong Peninsula shows obvious polarization. The relatively developed cities represented by Qingdao and Yantai show high eco-efficiency, while the less developed areas such as Zibo, Weifang and Rizhao show low eco-efficiency. This is due to the development of industrial enterprises in the region, the number of environmental regulations is less than 50, and the government supervision is not in place, resulting in a low eco-efficiency. The vertical difference is reflected in that the eco-efficiency change trend of the four urban agglomerations is different over time. Among them, the development trend of cities in the Yangtze River Delta tends to be the same, which are in a steady state of improvement. This is because the cities in the Yangtze River Delta urban agglomeration, such as Hangzhou and Shanghai, started their development later than the northern cities such as Beijing, and have a sound urban planning and policy-making system. In the process of development, documents such as *the Development Plan of the Yangtze River Delta Urban Agglomeration* were issued to support the development synergy among cities and finally make the development trend of urban ecological efficiency consistent.

In order to explore the reasons of eco-efficiency differences in urban agglomerations, QCA analysis was conducted to obtain the configurations of the overall board data and the four major urban agglomerations respectively. The three paths provided by the comprehensive data represent the configurations of urban development in the early stage (T2), the middle stage (T1) and the late stage (T3), respectively. Most cities in eastern China are in the middle stage, with insufficient awareness of social regulation, which requires punitive policy control and forward-looking environmental protection measures. The difference between cities is reflected in the configuration of the four major urban agglomerations. The configurations of the Beijing-Tianjin-Hebei region provide suggestions for the developed regions: pay attention to cultivating the environmental awareness of enterprises and residents in the policy making process, and advocate social adjustment, so as to improve ecological efficiency. The other three urban agglomerations all provide the configurations of the less developed areas: strict control of pollutant emission and more punitive measures can effectively improve the ecological efficiency. Through the discussion, we can get the following results:

Mandatory policies such as environmental policy controls, pollution prevention and control, and environmental protection can significantly reduce negative environmental externalities and promote the improvement of ecological efficiency. In particular, policy control with clear penalties is a necessary condition for achieving a high level of ecological efficiency. This kind of policy control method is also a control method that the government currently applies broadly. Command-type policy control can effectively limit the production and operation activities of enterprises that produce large amounts of pollutants, promote the optimization of the structure of energy consumption, and realize the sustainable development of environmental economy.

Social regulation has higher requirements on the development of all regional factors. At present, the four coastal regions use relatively few social adjustment methods, which may be a result of the low skills of the residents or poor corporate social responsibility; the serious lag effect related to such policies and regulations means that these will require a long period of time from implementation to the production of positive results.

Areas with a low level of economic development have higher intensity of policy control. Specific punishment measures in underdeveloped areas can more effectively promote environmental protection. The means of policy control should be matched with the level of economic development and adapted to local conditions. Many methods can be used to realize efficient environment protection, and different types of policies should be formulated based on the characteristics of different regions.

6. Conclusions and implications

Prior to conducting an empirical analysis, a manuscript database of environmental policies from four urban agglomerations in eastern China covering the past ten years was constructed in this study, and then these documents were processed quantitatively. Through an LDA topic model, the policy documents were divided into four thematic categories: policy control, pollution control, ecological protection, and social regulation, which were then used to measure the policy tendencies of different cities and serve as the basis for subsequent quantitative analysis. The empirical study herein combined the SBM and fsQCA methods, considered the ecological efficiency of 36 cities as the result variable, analyzed the conditional configuration that can produce high ecological efficiency, and made a comparative analysis of the difference paths of the four urban agglomerations. The results show that in the current

Table 10
Between and within consistency.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Between consistency (BECONS)	0.867	0.882	0.827	0.818	0.908	0.761	0.859	0.870	0.860	0.888
Between coverage (BECOV)	0.618	0.298	0.341	0.415	0.499	0.746	0.510	0.616	0.352	0.597
BECONS distance	0.015									
WINCONS distance	0.011									
POCONS	0.802									
POCOV	0.370									

implementation path of high ecological efficiency, less attention was paid to social regulation with more emphasis placed on policy control along with pollution prevention and control; command-based policies tended to be preferred.

Based on the above research results, this paper proposes the following policy recommendations for reference.

Strengthen policy control methods along with pollution prevention and control techniques, and strictly enforce relevant laws and regulations. In some regions, the thematic factors of policy control along with pollution prevention and control are not prominent, which may be related to the strict implementation of government policies which need to be strengthened;

Strengthen the role of social regulation and highlight the role of residents' quality of life and corporate social responsibility in improving the environment. In the long run, social regulation can better play the role of promoting sustainable economic and social development by cultivating residents' environmental awareness and corporate social responsibility.

The promulgation of environmental laws and regulations should be adapted to local conditions. Economically developed cities should play a role in social regulation and give local residents, enterprises, and society a leading role in environmental protection. Relatively underdeveloped regions should strengthen government control, clarify strict laws and regulations, and give attention to the leading role of the government.

The results of this study provide an important reference and advice for cities related to making efficient ecological protection policies, and mainly provides different implementation paths for the coastal cities of eastern China. At the same time, the analysis method using a panel QCA provides a new perspective for ecological efficiency assessment. The method still has some deficiencies that will been to be supplemented in the future. First, the cases involved in this paper involve the eastern coastal city clusters in China, and the extension of its conclusions to other regions remains to be investigated. Secondly, the conditional setting of this study involves a single field, which is mainly inclined to policy making and the economic development level. If other factors are added, there may be different path results. Finally, in terms of research methods, as a method that has not been used in the field of environmental regulation and ecological efficiency, this paper makes a new attempt, and the expansion of the research results needs to be further studied.

CRediT authorship contribution statement

Man Qin: Conceptualization, Methodology, Software. **Mingxue Sun:** Data curation, Writing - original draft. **Jun Li:** Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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