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Construction and countermeasure discussion on government performance evaluation model of air pollution control: A case study from Beijing-Tianjin-Hebei region

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ABSTRACT

The main purpose of this paper is to build an objective and effective environmental performance evaluation model of air pollution control. Based on the severe air polluted region in China, that is Beijing-Tianjin-Hebei region, this evaluation model consists of four parts, including economic benefits, public service, government management and development potential, and uses the balanced scorecard theory. The weights of the indexes are measured by comprehensive evaluation method, which combined entropy weight method and analytic hierarchy process (AHP). To test the applicability of the evaluation method to different stages, back propagation (BP) neural network is introduced to simulate air pollution control in the future. The results reveal that the environmental performance of air pollution control in Beijing had an upward trend during 2010–2016, and the trend would continue in the next five years. The environmental performance of Tianjin continuously increased, especially from 2014 to 2016. Tianjin has great potential of air pollution control in the future. The environmental performance of air pollution control in Hebei fluctuated from 2010 to 2016 and it dropped to the lowest level in 2015, which mainly due to the large increase in number of days with air quality levelllor above compared with 2014 and the nonsignificant growth in the amount of expenditure on atmospheric prevention and control, the amount of investment in the control of industrial pollution sources and the number of law enforcement personnel. Moreover, the environmental performance of air pollution control closely related with industrial structure, especially with the proportion of the tertiary industry. The upgrading of urban industrial structure and the coordinated development of green industry should be implemented to restructure the environmental transformation in air-polluted region.

1. Introduction

The environmental performance evaluation of air pollution control aims at assessing the ability of air pollution prevention & control, including the formulation of policies and regulations, the monitoring of air quality targets, the expenditure of air pollution control and the improvement of public environmental awareness(Sun, Wang & Shi, 2018). The significance of performance evaluation is to form and measure these systematic and hierarchical indexes. Building a scientific, reasonable and objective index system is the core of environmental performance evaluation (Retief, 2007).

According to the existing performance evaluation system related to environmental pollution control, such as *Pilot Demonstration Area Indicators of National Ecological Civilization*, *Environmental Quality Index System in Sweden*, *Key Indicators of Environmental Beijing Construction,* environmental performance assessment mainly covers the carbon emission(Chen et al., 2018; Zhong et al., 2018), air pollution, water pollution(Verkh et al., 2018), waste management and radiation pollution research fields. Environmental performance evaluation research mainly based on the new ISO standard ISO 14031 (O'Reilly et al., 2000) and the key outline linked to the EU EMAS Regulation (Jasch, 2000). The evaluation subjects contained enterprise (Russo and Fouts, 1997; Yang et al., 2011) and government, and the research perspectives covered public satisfaction, ecology, auditing, budget management, circular economy, tourism development, economic growth, etc (Arbolino et al., 2018; Feng et al., 2018; Thirukrishna et al., 2018).

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Most researchers apply subjective or objective quantitative analysis, including analytic hierarchy process (AHP), data envelopment analysis (DEA), tobit model, factor analysis, pressure-state-response(PSR), drive force-pressure-state-impact-response(DPSIR), game theory, decision tree, clustering and machine learning (Nakashima et al., 2006; Xu et al., 2018) to evaluate the performance of environmental management.

Based on the review of literature on regional air pollution control, China's provincial total-factor air pollution emission efficiency is significantly positive related to the level of economic development, industrial structure optimization, technological innovation and foreign direct investment (FDI), is significantly negative related to the energy consumption structure, and it is also related to environmental regulation(K. Wang et al., 2019). Therefore, this article selects several indexes, like actual GDP, GDP per capita, proportion of the tertiary industry, energy consumption per GDP, investment of industrial pollution management, to assess different stages of air pollution management in Beijing-Tianjin-Hebei.

Researchers construct different indicator systems to evaluate the performance of environmental management. To evaluate the administrative practice of environmental protection performance of Shenzhen, Liu et al. (2016) constructs an evaluation indicator system for district governments, including six parts: ecological and environmental protection, resources conservation, resources conservation, eco-institution implementation, eco-civilization construction working report. Based on the review of literature on environmental performance of airports, Chao et al., (2017) identifies 18 indicators covering four dimensions from the measures currently implemented by airports for environmental management. The four dimensions are green airport design, energy conservation and carbon reduction in airport operations, use of renewable resources, and environmental sustainability management at airports.

However, due to the differences in geography, industrial structure and pollution control mode, it is necessary to evaluate each pollution area separately. This paper mainly focuses on the environmental performance evaluation framework and method of air pollution control. Considering that $PM_{2.5}$ is the primary pollutant of air pollution in most cases, this paper mainly aims at $PM_{2.5}$ emission in the most serious air-polluted area in China, Beijing-Tianjin-Hebei region. Based on the balanced scorecard theory, this paper assesses different stages of air pollution management in Beijing-Tianjin-Hebei by applying multi-level fuzzy comprehensive evaluation, which combines entropy weight method and AHP, and BP neural network(Yaseen et al., 2018).

2. Methodology

2.1. Balanced scorecard theory

The Balanced Scorecard is a performance management system, which is widely used by enterprises. It plays a very important role in the strategic planning and execution management of the group. By decomposing the core index of shareholder return rate into specific indicators of financial dimension, customer perspective, internal business process, learning and growth, the balanced scorecard measures the contribution of each subject to corporate profits and shareholder returns and builds an efficient solution.

The essence of the balanced scorecard is system construction, and it has a wide range of extensional applicability. Therefore, introducing the balanced scorecard into the field of smog treatment is innovative and challenging. Both smog management and enterprise management have core indicators and specific targets at different levels, which brings research value to the implementation of balanced scorecards in smog management.

This paper revises the four dimensions of balanced scorecard into economic benefit, public service, environmental management and development potential, and applies them into the environmental performance evaluation index system of air pollution control.

The economic benefit dimension measures the impact and benefit of air environmental protection on the social and economic development(Lo-Iacono-Ferreira et al., 2018). Therefore, this dimension consists of the economic development and the improvement of air pollution control indexes to properly assess the status quo and the contribution of government environmental protection in social and economic development(Wassenaar et al., 2018).

In order to quantify the public service specifically, the original customer dimension of BSc is switched to the public service dimension(Hsu and Liu, 2010), which measures the quality of government environmental work, and consists of public life satisfaction and the degree of environmental comfort.

Government management dimension measures the performance of government internal management activities and the environmental duty, which reflects the air pollution protection and control ability of the government. Government management dimension is divided into environmental management and environmental monitoring.

The development potential index refers to evaluating the long-term interests of air pollution control work taken by the government. As the first three dimensions based on the status quo of air pollution prevention & control, the development potential indicators aims at predicting the future environmental development of air pollution prevention & control(Wang et al., 2015). Thus, this dimension concludes scientific & technological support and air pollution control potential.

2.2. Multi-level fuzzy comprehensive evaluation

The analytic hierarchy process (AHP) is considered a little subjective by calculating the scores of the experts (Sutherland et al., 2018). While the weights calculated by entropy weight method are based on the statistical data, which is regarded as an objective evaluation method (Sanghamitra et al., 2018). Therefore, this paper applies the multi-layer fuzzy comprehensive evaluation model, which combines subjective AHP and objective entropy evaluation method, and takes into account different influencing factors and objective conditions that affects the weights.

2.2.1. Analytic hierarchy process (AHP)

The analytic hierarchy process (AHP) applied in this study derives from the research of T.l.satty (Saaty, 2003), which combines qualitative and quantitative analysis to allocate the index weight by

Table 1
Scoring matrix of environmental performance evaluation index.

	economic benefit	public service	environmental management	development potential
economic benefit	1	1	3	2
public service	1	1	2	2
environmental management	1/3	1/2	1	1/2
development potential	1/2	1/2	2	1

Table 2
The value of the random consistency index R.I. (G. Wang et al., 2018).

Matrix order	1	2	3	4	5	6	7	8	9
RI	0	0	0.515	0.893	1.119	1.249	1.345	1.420	1.462

mathematical methods. Analytic hierarchy process adopts expert questionnaire(Saaty, 2003; Xie et al., 2018; Zichella et al., 2018), and this paper invited 40 scholars in the related fields to score the performance of air pollution control, and received 25 questionnaires back. There were15 valid questionnaires after checking the consistency of the scoring matrix. These 15 questionnaires were processed by average method, and the relevant judgment matrix are obtained. The scoring matrix is shown in Table 1 as follows:

By normalizing each column of the judgment matrix, the normalized columns [6/17 6/17 2/17 3/17]^{T}、[1/3 1/3 1/6 1/6]^{T}、[3/8 1/4 1/8 1/4] ^{T}、[4/11 4/11 1/11 2/11] ^{T} are obtained. By summing up the above normalized columns in rows, we can get the column vector [1.425 1.300 0.500 0.775] ^{T}. Then we normalize the column vector and get the weight component: $\overline{W_A} = (0.356, 0.325, 0.125, 0.194)$

The maximum characteristic root is calculated as below:

$$\begin{bmatrix} 1 & 1 & 3 & 2 & & & & \\ 1 & 1 & 2 & 2 & \frac{1}{2} & \frac{1}{2} & 2 & 1 \\ \frac{1}{3} & \frac{1}{2} & 1 & \frac{1}{2} & & & & \end{bmatrix} \times \begin{bmatrix} 0.356 \\ 0.325 \\ 0.125 \\ 0.194 \end{bmatrix} = \begin{bmatrix} 1.444 \\ 1.319 \\ 0.503 \\ 0.784 \end{bmatrix} \tag{1}$$

$$\lambda_{\max} = \frac{1}{4}\left(\frac{1.444}{0.356} + \frac{1.319}{0.325} + \frac{0.503}{0.125} + \frac{0.784}{0.194}\right) = 4.046 \tag{2}$$

Then check the results of the consistency.

$$CI = (\lambda_{\max} - k)/_{(k-1)} = (4.046 - 4)/_{4-1} \tag{3}$$

$$CR = CI/RI = 0.015/0.893 = 0.017 \tag{4}$$

where k is the matrix order, $\lambda_{\max}$ is the maximum characteristic root and RI is the random consistency index (Table 2).

Because CR < 0.1, consistency check is passed and it shows that the weight value meets the actual requirements. The weights calculated by AHP are shown in Table 3.

Table 3
Weights calculated by AHP.

Level III	Weight
Actual GDP	0.0199
GDP Per Capita	0.0199
Proportion of the Tertiary Industry	0.0363
Urbanization Rate	0.0167
Energy Consumption	0.0271
Motor Vehicle	0.058
Proportion of Coal	0.0267
NOx Emissions from Motor Vehicles	0.0295
Industrial Gas Emissions	0.0336
Average Annual Concentration of $PM_{2.5}$	0.0294
Average Annual Concentration of NO_X	0.0294
Average Annual Concentration of SO_2	0.0294
Engel Coefficient	0.0057
Disposable Income Per Capita	0.0112
Motor Vehicle Per Capita	0.0679
Public Transport	0.0609
Environmental Petition	0.0168
Air Quality Compliance Rate	0.0957
Public Green Area Per Capita	0.0409
Urban Greening Coverage	0.0259
Industrial Waste Gas Governance Facilities	0.0091
Investment of Industrial Pollution Management	0.0091
Environmental Petition Cases	0.0222
Implementation Rate of EIA	0.0222
Environmental Enforcement	0.0156
Environmental Monitoring Expenditure	0.0469
Elasticity Coefficient of Energy Consumption	0.0103
Energy Consumption Per GDP	0.0252
Proportion of Environmental Investments	0.0615
Emission Intensity of Industrial SO_2	0.032
Emission Intensity of Industrial NO_x	0.033
Emission Intensity of Industrial Smoke	0.032

2.2.2. Entropy weight method

The concept of entropy originated by the German mathematician and physicist, Emanuel Claudius (Paul, 2011), which is used to characterize the uniformity of energy distribution in space. The more uniform the energy distribution is, the greater the entropy is. Entropy weight is an objective weighting method based on the concept of entropy. As thermodynamic entropy is the degree of confusion in the microscopic thermal movement, information entropy is a metric of the degree of importance in the evaluation pattern (Paul, 2011). More concretely, the information entropy represents the amount of information provided by the index. The smaller the information entropy is, the greater the amount of information is, and the higher the weight of the index is.

The basic steps of the entropy weight method are as follows.

Suppose the metric is $n \times m$, which contains n indexes and m evaluated objects as the original input.

$$X_{nm} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix}_{n \times m} \tag{5}$$

Among the above metric, X_{ij} represents the estimated value of the index i for object j.

(1) Dimensionless the metric X_{nm}. The negative indexes are processed by subtraction conformance, and the treatment formula is $y_{ij} = M - x_{ij}$. M is a permissible upper limit of index X_{ij}. Then normalize the converted data according to the following formulas.

$$x^*_{ij} = x_{ij}/x_{i\max}\ ,\ (x > 0) \tag{6}$$

$$x^*_{ij} = x_{i\max}/x_{ij}\ ,\ (x < 0) \tag{7}$$

(2) According to the definition of information entropy,

$$E_i = -\frac{1}{\ln(n)} \sum_{j=1}^{n} X^*_{ij} \ln X^*_{ij}\ . \tag{8}$$

(3) The weight of index i is calculated by

$$W_i = \frac{1 - E_i}{m - \sum_{i=1}^{m} E_i}\ \text{, where } 0 \le W_i \le 1\ ,\ \sum_{i=1}^{m} W_i = 1\ . \tag{9}$$

2.2.3. Combined weight

The combined weight for the multi-layer fuzzy comprehensive evaluation is calculated by

$$C_i = \frac{W_i \times W_i^{'}}{\sum_{i=1}^{n} W_i \times W_i^{'}} , \tag{10}$$

where W_i represents the weight calculated by entropy weight method and $W_i^{'}$ represents the weight calculated by AHP.

Because there are positive and negative indexes in the evaluation system, dimensionless data is used to calculate the evaluation score for making the indicators comparable. (Katal and Fazelpour, 2018). The final score of the comprehensive evaluation is calculated by

$$S = C \times X_{ij}^{*}, 0 < S < 1 . \tag{11}$$

The evaluation results of environmental performance would become better with the increase of the total score.

2.2.4. Air pollution control performance evaluation

(1) Comprehensive evaluation of secondary indicators

According to the air pollution control performance evaluation model, the second-level index is calculated by multiplied the combination weight of the third-level index and the normalized matrix of the third level index data. The function expression is as follows:

$$\mathrm{S}_{(\mathrm{B}_i)} = \mathrm{C}_i \times \mathrm{R}_{\mathrm{C}_i}^{\mathrm{T}} (i = \mathrm{I}, \mathrm{II} \ldots \mathrm{VIII}) \tag{12}$$

Where C_i is the weight value of the third-level indicator relative to the second-level indicator; $R_{C_i}^{T}$ is the normalized matrix of the third level index data;

The formula for calculating the comprehensive weight of the third-level indicator relative to the second-level indicator is:

$$C_I = [\mathrm{C}_1, \mathrm{C}_2, \mathrm{C}_3, \mathrm{C}_4, \mathrm{C}_5, \mathrm{C}_6] = \left[\frac{z_1}{A_1}, \frac{z_2}{\mathrm{A}_1\mathrm{B}_1}, \frac{z_3}{\mathrm{A}_1\mathrm{B}_1}, \frac{z_4}{\mathrm{A}_1\mathrm{B}_1}, \frac{z_5}{\mathrm{A}_1\mathrm{B}_1}, \frac{z_6}{\mathrm{A}_1\mathrm{B}_1}\right] \tag{13}$$

$$C_{II} = [C_7, C_8, C_9, C_{10}, C_{11}, C_{12}] = \left[\frac{z_7}{A_1B_2}, \frac{z_8}{A_1B_2}, \frac{z_9}{A_1B_2}, \frac{z_{10}}{A_1B_2}, \frac{z_{11}}{A_1B_2}, \frac{z_{12}}{A_1B_2}\right] \tag{14}$$

$$C_{VIII} = \left[\frac{z_{30}}{A_4B_8}, \frac{z_{31}}{A_4B_8}, \frac{z_{32}}{A_4B_8}\right] \tag{15}$$

(2) Comprehensive evaluation of primary indicators

The combined weights of the secondary indicators relative to the primary indicators are multiplied by the secondary index score matrix to calculate the comprehensive evaluation scores of the primary indicators of the $PM_{2.5}$ pollution control performance assessment. The function expression is as follows:

$$S_{(\mathrm{A}_i)} = \mathrm{B}_i \times R_{B_i}^{T} (i = I, II, III, IV) \tag{16}$$

Where B_i is the weight value of the second-level indicator relative to the primary-level indicator; $R_{B_i}^{T}$ is the normalized matrix of the second level index data;

The formula for calculating the comprehensive weight of the second -level indicator relative to the primary -level indicator is:

$$\mathrm{B}_{\mathrm{I}} = [\mathrm{B}_1, \mathrm{B}_2] = \left[\frac{\sum_{1}^{6} z_i}{\mathrm{A}_1}, \frac{\sum_{7}^{12} z_i}{\mathrm{A}_2}\right] \tag{17}$$

$$\mathrm{B}_{\mathrm{II}} = [\mathrm{B}_3, \mathrm{B}_4] = \left[\frac{\sum_{13}^{17} \mathrm{Z}_\mathrm{i}}{\mathrm{A}_2}, \frac{\sum_{18}^{20} z_i}{\mathrm{A}_3}\right] \tag{18}$$

$$\mathrm{B}_{\mathrm{III}=}[\mathrm{B}_5, \mathrm{B}_6] = \left[\frac{\sum_{21}^{24} z_i}{\mathrm{A}_3}, \frac{\sum_{25}^{26} z_i}{\mathrm{A}_3}\right] \tag{19}$$

$$\mathrm{B}_{\mathrm{IV}} = [\mathrm{B}_7, \mathrm{B}_8] = \left[\frac{\sum_{27}^{29} z_i}{\mathrm{A}_4}, \frac{\sum_{30}^{32} z_i}{\mathrm{A}_4}\right] \tag{20}$$

(3) Comprehensive assessment

The comprehensive evaluation value of the PM2.5 pollution control performance evaluation is calculated by multiplying the primary-level index matrix by the composite weight of the primary-level index relative to the target layer. The function expression is as follows:

$$S = \mathrm{A}_i \times R_{A_i}^{T} (i = 1, 2, 3, 4) \tag{21}$$

Where A_i is the weight value of the primary -level indicator relative to the target layer; $R_{A_i}^{T}$ is the normalized matrix of the primary level index data;

The formula for calculating the composite weight of the primary-level index relative to the target layer is:

$$A_i = [A_1, A_2, A_3, A_4] = \left[\sum_{1}^{12} z_i, \sum_{13}^{20} z_i, \sum_{21}^{26} z_i, \sum_{27}^{32} z_i\right] \tag{22}$$

2.3. BP neural network

In order to display the evaluation results in multiple angles, this paper introduces the back propagation (BP) neural network to predict future atmospheric environmental performance, so as to elaborately put forward the countermeasures and suggestions.

The back propagation (BP) neural network is used to simulate the trend of the comprehensive level of government performance management of smog pollution control in the next five years. BP neural network is a multi-layer feedforward network trained by back propagation, which adopts gradient descent method. Through back propagation, the weights and thresholds of the network are continuously adjusted to minimize the sum of squared errors of the network. After the training is completed, the neural network can simulate the smog pollution control of the government performance management level trend through the input sample data. Considering that the single-calculation layer feedforward neural network can only solve the linear separable problem, and the smog pollution control government performance management level trend prediction is not limited to this, so the paper chooses the multilayer neural network with hidden layer, as shown in Fig. 1. After several experiments and trainings, a three-layer neural network and elastic gradient descent method are selected for simulation.

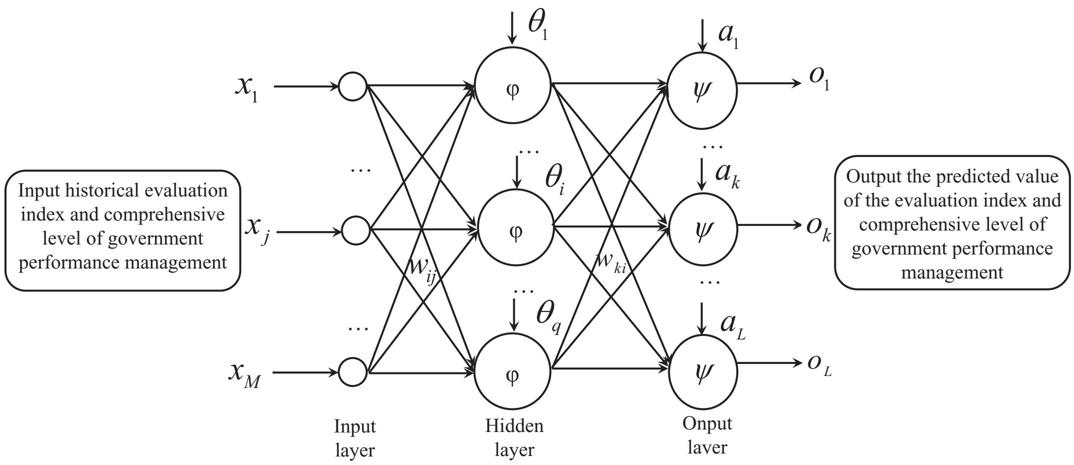

Fig. 1. Structural design of BP neural network.

3. Results and discussion

3.1. Air pollution control performance evaluation of Beijing

The weights of air pollution control performance indicators of Beijing are shown in Table 4, and the evaluation scores for the 4 dimensions, including economic benefit, public service, environmental management and development potential, are shown in Fig. 2. The comprehensive scores of air pollution control performance in Beijing are increasing from 2010 to 2016, 0.0816, 0.1704, 0.3328, 0.3763, 0.5015, 0.8384, 0.904 in turn, which indicates that the air pollution control measures taken by the local government have been fruitful and effective.

During 2010 and 2011, the performance scores were far less than the years since 2012, and the same trend was true for the Level I index scores of the development quality, government management and development potential. The main reason is that Beijing began to enter the post industrialization period since the recent years, and the extensive development mode of resource consumption led to significantly negative impact on the atmospheric environment for the first 2 years. The high-energy consumption, high-pollution and high-emission industries had a relatively large proportion in this period, which exacerbated the atmospheric environment. In addition, the high proportion of the coal consumption and the low rate of the clean energy brought about a large amount of air pollutant emissions from discharge source. Introducing the Fuel Standard V

Table 4
Index weights of air pollution control performance in Beijing.

Level III	AHP Weights	Entropy Weights	Combinatorial Weights
Actual GDP	0.0199	0.0019	0.00151
GDP Per Capita	0.0199	0.0022	0.00174
Proportion of the Tertiary Industry	0.0363	0.00004	0.00006
Urbanization Rate	0.0167	0.0003	0.0002
Energy Consumption	0.0271	0.00011	0.00014
Motor Vehicle	0.058	0.00036	0.00083
Proportion of Coal	0.0267	0.0696	0.07404
NOx Emissions from Motor Vehicles	0.0295	0.0593	0.0697
Industrial Gas Emissions	0.0336	0.0604	0.08086
Average Annual Concentration of $PM_{2.5}$	0.0294	0.0606	0.07099
Average Annual Concentration of NO_X	0.0294	0.0998	0.11691
Average Annual Concentration of SO_2	0.0294	0.0737	0.08633
Engel Coefficient	0.0057	0.14188	0.03222
Disposable Income Per Capita	0.0112	0.0037	0.00165
Motor Vehicle Per Capita	0.0679	0.00006	0.00016
Public Transport	0.0609	0.0027	0.00655
Environmental Petition	0.0168	0.0291	0.01948
Air Quality Compliance Rate	0.0957	0.0048	0.0183
Public Green Area Per Capita	0.0409	0.00006	0.0001
Urban Greening Coverage	0.0259	0.00007	0.00007
Industrial Waste Gas Governance Facilities	0.0091	0.0061	0.00221
Investment of Industrial Pollution Management	0.0091	0.0388	0.01407
Environmental Petition Cases	0.0222	0.00002	0.00002
Implementation Rate of EIA	0.0222	0.0001	0.00009
Environmental Enforcement	0.0156	0.0014	0.00087
Environmental Monitoring Expenditure	0.0469	0.0056	0.01046
Elasticity Coefficient of Energy Consumption	0.0103	0.0398	0.01633
Energy Consumption Per GDP	0.0252	0.0601	0.06034
Proportion of Environmental Investments	0.0615	0.0076	0.01862
Emission Intensity of Industrial SO_2	0.032	0.0912	0.11628
Emission Intensity of Industrial NO_x	0.033	0.0541	0.07113
Emission Intensity of Industrial Smoke	0.032	0.0845	0.10774

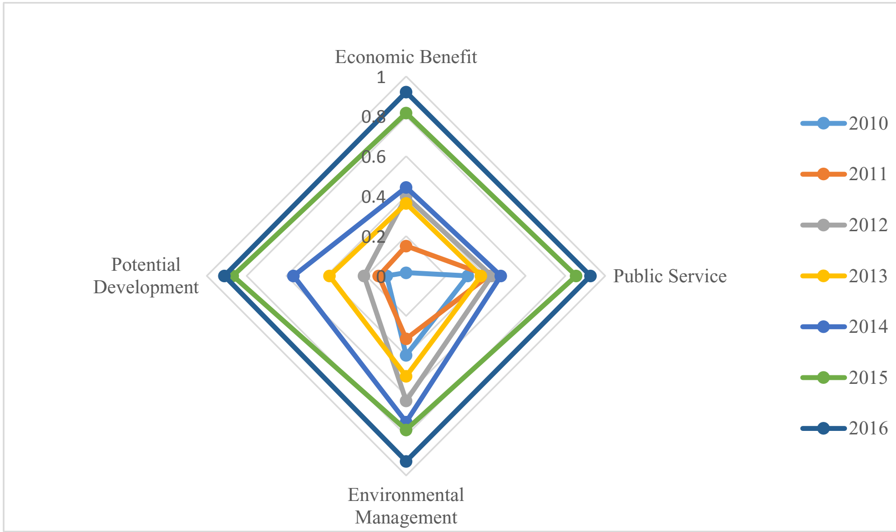

Fig. 2. Arachnoid map of air pollution control performance evaluation in Beijing.

and subway jointly can reduce PM2.5 pollution. The government should consider the coordination of policy instruments to reduce the air pollution (H. Wei, 2019). The local government used to mainly focus on economic development. Although GDP was still one of the most important indicators for performance assessment, this kind of development mode would lead to the distortion of industrial structure and energy structure, so that the ecological environment, especially the atmospheric environment, continued to deteriorate.

With the increasing demand for better air quality, the local government used the experience of air pollution control abroad from long-term development perspective, including formulating air pollution control policies and regulations, restructuring and upgrading industrial structure, optimizing energy structure, improving the public transport system, cultivating and developing clean energy and a series of tough measures, to make sure the environmental quality gradually improved. However, compared with the Yangtze River Delta (W. Yang et al., 2019) and the Pearl River Delta (G. Yang et al., 2018) at a similar stage of development, the air quality in Beijing and the surrounding areas still have a large potential.

Over the past 6 years, the energy structure, environmental management and public service in Beijing had ameliorated year by year. Up to now, the performance of all the 4 dimensions have been preliminarily improved and maintained in a relatively stable level. The results of this part show that the adjustment of industrial structure and energy structure fundamentally improves the environmental performance of regional air pollution control.

3.2. Air pollution control performance evaluation of Tianjin

The weights of air pollution control performance indicators of Tianjin are shown in Table 5, and the evaluation scores for Level I indexes are shown in Fig. 3. The comprehensive scores of air pollution control performance in Tianjin increased from 2011 to 2016, 0.3948, 0.3977, 0.4304, 0.4862, 0.6873, 0.9435in turn. The overall trend of the performance in Tianjin is on the rise, which indicates that the air pollution control measures taken by the local government have been fruitful and effective.

Among all the index weights, the proportion of environmental protection investment and the environmental supervision expenditure are relatively high, which highlights the importance of the air environmental governance input and effective monitoring system. The environmental investment of Tianjin and many other Chinese cities are still far below the ideal level of 3%. Therefore, how to motivate the government to increase environmental investment and improve the utilization efficiency of environmental funds turns into an important measure to solve the current domestic haze problem. As the status quo of air pollution in Tianjin is in the middle reaches of Beijing-Tianjin-Hebei, its economic development is also between Beijing and Hebei. The local industrial waste gas is emitted in large quantities, and the same is true of the dust pollution. Although the government has been advocating cleaner production, it has not yet reached the ideal emission expectations. At this point, coercive and strict regulatory measures could mitigate this problem to a certain extent.

In the past 5 years, the potential of air pollution control in Tianjin had been increasing year by year with the promotion of science and technology. However, the environmental management capacity and public service capacity were still in an unstable fluctuant state. On the one hand, air quality was consistently higher than prescribed limits in the past 5 years. On the other hand, the industrial intensity of air pollutants had not been controlled effectively. The amelioration of environmental supervision and environmental law enforcement is an important guarantee for air quality improvement of Tianjin in the future. The imperfection of public service mainly reflects in the lack of atmosphere comfort, and the public can hardly feel the amelioration of the atmosphere quality in a short term. Compared with the governance intensity of air pollution control in Beijing, the enforcement management and input of Tianjin are still insufficient.

3.3. Air pollution control performance evaluation of Hebei

The weights of air pollution control performance indicators of Hebei are shown in Table 6, and the evaluation scores for Level I indexes are shown in Fig. 4. The comprehensive scores of air pollution control performance in Hebei show a trend of minor fluctuations from 2010 to 2016, 0.166, 0.198, 0.210, 0.185, 0.242, 0.161, 0.287 in turn. In terms of performance score, the air pollution governance in Hebei is in the early stage of air pollution condition in Beijing, and its atmospheric environment has not been substantially improved. According to Kuznets's theory, the relationship between environmental pollution and economic development

Table 5
Index weights of air pollution control performance in Tianjin.

Level III	AHP Weights	Entropy Weights	Combinatorial Weights
Actual GDP	0.0199	0.0045	0.0122
GDP Per Capita	0.0199	0.0015	0.0107
Proportion of the Tertiary Industry	0.0363	0.0005	0.0184
Urbanization Rate	0.0167	0.0001	0.00835
Energy Consumption	0.0271	0.0003	0.0137
Motor Vehicle	0.0580	0.0028	0.0304
Proportion of Coal	0.0267	0.0018	0.01425
NOx Emissions from Motor Vehicles	0.0295	0.0005	0.015
Industrial Gas Emissions	0.0336	0.0003	0.01695
Average Annual Concentration of $PM_{2.5}$	0.0294	0.0067	0.01805
Average Annual Concentration of NO_X	0.0294	0.0022	0.0158
Average Annual Concentration of SO_2	0.0294	0.0205	0.02495
Engel Coefficient	0.0057	0.0007	0.0032
Disposable Income Per Capita	0.0112	0.0008	0.006
Motor Vehicle Per Capita	0.0679	0.0033	0.0356
Public Transport	0.0609	0.0008	0.03085
Environmental Petition	0.0168	0.0135	0.01515
Air Quality Compliance Rate	0.0957	0.2981	0.1969
Public Green Area Per Capita	0.0409	0.0002	0.02055
Urban Greening Coverage	0.0259	0.0001	0.013
Industrial Waste Gas Governance Facilities	0.0091	0.0031	0.0061
Investment of Industrial Pollution Management	0.0091	0.0131	0.0111
Environmental Petition Cases	0.0222	0.0001	0.0111
Implementation Rate of EIA	0.0222	0.0001	0.0111
Environmental Enforcement	0.0156	0.0493	0.03245
Environmental Monitoring Expenditure	0.0469	0.0404	0.04365
Elasticity Coefficient of Energy Consumption	0.0615	0.0325	0.047
Energy Consumption Per GDP	0.0252	0.0018	0.0135
Proportion of Environmental Investments	0.0103	0.3848	0.19755
Emission Intensity of Industrial SO_2	0.0320	0.0607	0.04635
Emission Intensity of Industrial NO_x	0.0330	0.0417	0.03735
Emission Intensity of Industrial Smoke	0.0320	0.0135	0.02275

presents an inverted U shape. Hebei is in the middle stage of economic development, and still relies on resource and labor consumption to maintain economic growth. Therefore, environmental performance improvement of Hebei is difficult to achieve in the short term, unless its industrial structure and energy structure change fundamentally (Ahmed et al., 2018).

The weight distribution of the evaluation indexes in Hebei province is uneven and obviously varied from each other. The research result shows that there are leading indicators of evaluation, and the large-weighted indicators that play a leading role in air pollution control environmental performance are ranked in succession. The top 5 indicators are air quality compliance rate, the proportion of coal, implementation rate of EIA, investment of industrial pollution management and environmental enforcement, which shows that air pollution control of environmental performance and air quality closely related to the economic developing stage and regulatory effectiveness. As the primary pollutants in Hebei Province, $PM_{2.5}$ directly determines the air quality compliance rate. In other words, how to efficiently control the $PM_{2.5}$ pollution is the biggest obstacle to the prevention of air pollution in Hebei province. According to the official $PM_{2.5}$ component analysis of Hebei, atmospheric pollutants mainly come from industrial emission and coal emission directly or indirectly. Thus, reducing the proportion of coal in Hebei province is the effective mean to

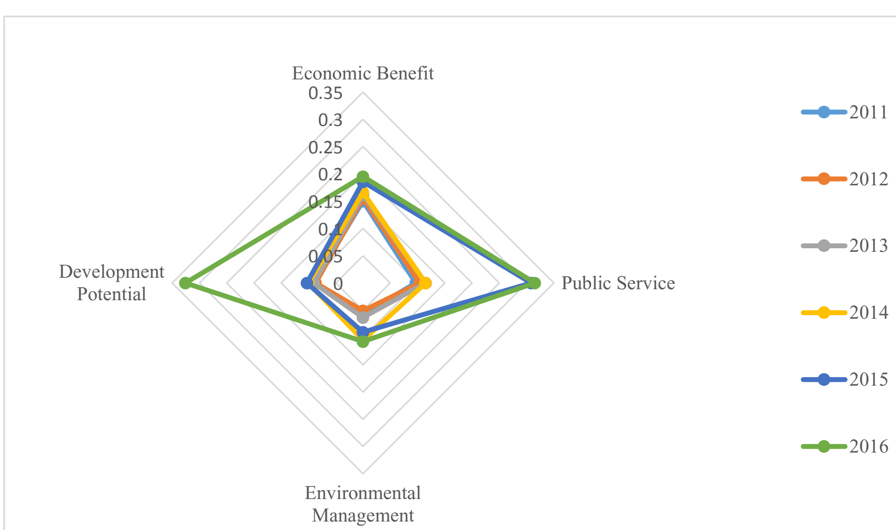

Fig. 3. Arachnoid map of air pollution control performance evaluation in Tianjin.

Table 6
Index weights of air pollution control performance in Hebei.

Level III	AHP Weights	Entropy Weights	Combinatorial Weights
Actual GDP	0.0053	0.0223	0.0142
GDP Per Capita	0.005	0.0191	0.0122
Proportion of the Tertiary Industry	0.0002	0.0326	0.0380
Urbanization Rate	0.0005	0.0243	0.013
Energy Consumption	0.0007	0.0185	0.0161
Motor Vehicle	0.0175	0.0251	0.0228
Proportion of Coal	0.1691	0.0161	0.0113
NOx Emissions from Motor Vehicles	0.0015	0.025	0.0197
Industrial Gas Emissions	0.0052	0.0186	0.0172
Average Annual Concentration of $PM_{2.5}$	0.0074	0.0577	0.0454
Average Annual Concentration of NO_X	0.0282	0.0364	0.0286
Average Annual Concentration of SO_2	0.0244	0.0549	0.0432
Engel Coefficient	0.0034	0.0343	0.0063
Disposable Income Per Capita	0.0073	0.0219	0.0079
Motor Vehicle Per Capita	0.0178	0.0249	0.055
Public Transport	0.0011	0.0363	0.071
Environmental Petition	0.03	0.0233	0.0126
Air Quality Compliance Rate	0.0572	0.0341	0.1904
Public Green Area Per Capita	0.0002	0.0157	0.0207
Urban Greening Coverage	0.0001	0.0331	0.0275
Industrial Waste Gas Governance Facilities	0.0049	0.0368	0.0106
Investment of Industrial Pollution Management	0.1726	0.0397	0.0115
Environmental Petition Cases	0.0145	0.0843	0.0601
Implementation Rate of EIA	0.1211	0.0169	0.012
Environmental Enforcement	0.1444	0.0402	0.0132
Environmental Monitoring Expenditure	0.0044	0.0313	0.0339
Elasticity Coefficient of Energy Consumption	0.0112	0.0289	0.0569
Energy Consumption Per GDP	0.0117	0.0476	0.0385
Proportion of Environmental Investments	0.0744	0.0181	0.006
Emission Intensity of Industrial SO_2	0.0055	0.0308	0.0316
Emission Intensity of Industrial NO_x	0.0086	0.0273	0.0281
Emission Intensity of Industrial Smoke	0.0446	0.0237	0.0244

enhance environmental management level. Air pollution control expenditures and industrial pollution control investment in environmental enforcement, which represent the core environmental management and monitoring indexes, reflect that the local government should emphasis how to make effective use of air pollution control budgetary funds and investment in industrial pollution sources. Environmental enforcement should be further enhanced by increasing the frequency of environmental monitoring.

During 2010–2016, environmental performance level of air pollution control in Hebei province showed a fluctuating state. In 2010, the overall performance of air pollution control was relatively low, and then increased slightly in 2012, but slightly declined to 0.185 in 2013. The level of air pollution control performance climbed to a peak in 2014, and then declined to the lowest level in 2015. The law of this change is in accordance with the proportion of the tertiary industry in Hebei. The main reason for this result is the air quality compliance rate in 2014 increased significantly, and the air pollution expenditure & investment, as well as environmental enforcement, did not significantly increase, and then pulled down comprehensive level of air pollution control performance in Hebei in 2015. In 2016, the air pollution control performance reached to a higher level among the years. It reveals that the “Implementation plan of strengthening measures for air pollution control in Hebei Province (2016–2017)” take effect.

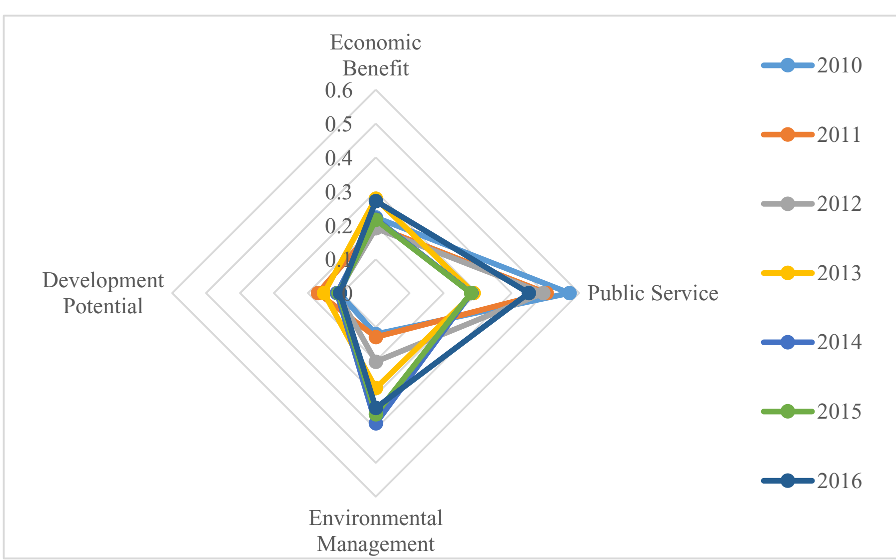

Fig. 4. Arachnoid map of air pollution control performance evaluation in Hebei.

3.4. Comparative analysis

Fig. 5 is a comprehensive horizontal line map of air pollution control performance in Beijing, Tianjin and Hebei from 2010 to 2020. The comprehensive level of 2010–2016 is calculated on the basis of the established evaluation model, while the comprehensive level of 2017–2020 is estimated by applying the BP neural network according to the historical index data. It is worth noting that if the original environmental input and environmental protection measures remain unchanged, the comprehensive level of air pollution control in Hebei would have no obvious improvement. The significant regional difference of air pollution level in Hebei province makes it difficult to mobilize all the cities in Hebei to implement strong and continuous air-pollution prevention measures, which is the main reason of the fluctuation trend of its comprehensive level. In these three provinces, Beijing maintains steady and healthy development momentum. The higher level of GDP per capita, steady income growth, and higher proportion of the tertiary industry provide better economic foundation for air pollution control in Beijing. The concentrations of the main pollutants, such as $PM_{2.5}$, SO_2, NO_2, decreased in the past few years, but the annual average concentrations of most pollutants failed to reach the national standard set. The results of multi-layer fuzzy comprehensive evaluation model shows that the environmental performance level of Beijing increased from 2010 to 2015, indicating that the environmental protection work has proved highly successful. In the next five years, this good situation would continue to remain in Beijing according to the predictions of BP neural network. This evaluation model is also suitable for developing areas, such as Tianjin and Hebei. According to the index weights of Tianjin, the performance evaluation of air pollution control is mainly affected by the large industrial emissions due to the unreasonable industrial institutions. Secondly, the ferrous metal smelting and rolling processing industry, chemical raw materials and manufacturing industry is the main pillar industry in Tianjin, which are account for relatively large energy consumption. Thirdly, the motor vehicle in Tianjin increase year by year, and most of them have not used clean energy up to now. In addition, smoke dust in the majority of construction areas I s emitted in large quantities in this developing province. As a whole, Tianjin has great potential for air pollution control because of increasing environmental supervision and environmental investment.

4. Conclusions and countermeasures

4.1. Conclusions

By building the environmental performance evaluation model of air pollution control, which combines BSc and multi-layer fuzzy comprehensive evaluation model, this paper measures the environmental performance level of air pollution control in Beijing-Tianjin-Hebei region, and introduces BP neural network to simulate the future trend. The environmental performance evaluation model built in this paper is applicable to cities in different stages of development. The framework of the index system provides inspirations for other types of environmental performance assessment, such as water pollution, radiation pollution, solid-waste pollution and so on. For Beijing, which has already entered the post-industrial era, the difficulties of its air pollution management are mainly concentrated on the tertiary industry and vehicle exhaust. The effective control of vehicle emission and the elasticity coefficient of energy consumption in the tertiary industry, which is equal to the annual growth rate of energy consumption divided by the annual growth rate of national economy, directly determines the local air quality. In addition, because Beijing is surrounded by Hebei province which has large industrial emission, the regional transmission is also deteriorated the air quality of Beijing to a certain extent. Tianjin is between Beijing and Hebei in terms of economic development, pollution discharge and environmental management, and for that reason, its development potential is quite large. In the future, if the government can balance the relationship between environmental investment and economic growth in a better way, the quality of atmospheric environment in Tianjin would gradually enter a virtuous circle stage. This conclusion could provide reference for other cities in this kind of developing stage. In a short period of time, the upgrading and the transformation of industrial structure, energy structure, motor vehicle emission, and building dust are difficult to be improved in Hebei Province, which has long been driven by the consumption of resources, the backwardness of the environmental infrastructure and the illegal gas emission of small enterprises. The solution of the air pollution problem in Hebei requires a thorough change and a large amount of environmental investment, including capital, technology and talent, otherwise it is difficult to bring about fundamental improvement.

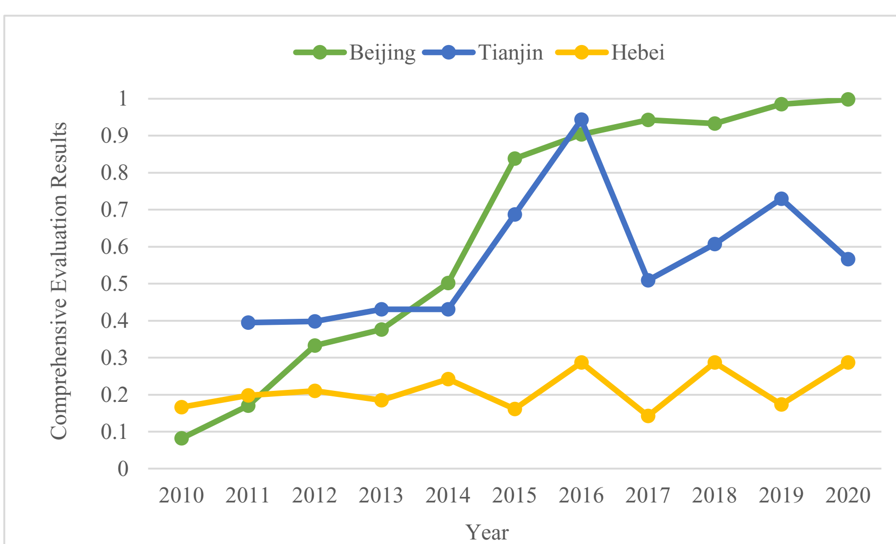

Fig. 5. Comprehensive evaluation of air pollution control performance in Beijing-Tianjin-Hebei.

The purpose of this paper is to provide reference for the construction of air-pollution control evaluation system. It is necessary to take into account the environmental protection work of the whole region, as well as coordinate development plan and break the regional restrictions. The evaluation of air-pollution control performance finds the disadvantages of environmental protect work and avoids the possible mistakes in the future. On the other hand, it urges the local government to ensure the implementation of more effective environmental enforcement measures (Li et al., 2018).

4.2. Countermeasures

4.2.1. Improve multi-level market investment system to help optimize the allocation of resources

The lack of environmental protection input is one of the major bottlenecks of environmental pollution control and the introduction of new environmental protection technology in Hebei Province, and it has particularly restricted the green development space for SMEs(small and medium-sized enterprises). Speeding up the industrial green transformation requires that the energy saving, environmental protection and clean production technology be applied to the production process, and the mechanism of transforming knowledge into economic income should be established to realize the knowledge capitalization of environmental technology personnel or the option of intellectual property rights (Krishnakumar et al., 2018). The government should speed up the establishment of multi-level financial markets with wide coverage, multiple channels, low cost, high efficiency and strict supervision to attract more private capital to the field of environmental innovation. The government should also increase the effective supply of environmental protection capital and improve the efficiency of investment in environmental protection. It is crucial to strengthen the innovation ability of enterprises, especially the ability of SMEs (small and medium-sized enterprises). The labor productivity should be improved by innovation and the clean supply should be increased with innovation. At the same time, the government should reasonably reduce the cost of enterprises, reduce the burden of the enterprise, and let the Enterprise carry out business lightly and develop in a healthy and orderly manner, in order to realize the smooth and orderly transformation of the real economy. Through decentralization and optimizing the approval process, a relatively loose development environment for enterprises can be created. Maximizing the role of private capital and forming a more complete capital investment mechanism and a matching intermediary service system can help to accelerate the transformation of scientific and technological achievements to realistic productivity. The goal is to promote scientific and technological innovation enterprises and start-ups from scratch, from small to large, and then form a new economic growth point and enhance the vitality of the whole economy (Huguet Ferran et al., 2018). The focus should be on innovation to promote employment, build environmental protection Innovation Entrepreneurship Platform, perfect environment innovation service and accelerate the conversion of innovation achievements into clean productivity; should also be on perfecting the post-event supervision and use effective management to promote decentralization. The government should deepen the reforms such as the commercial system and multi-regulation and integration to minimize the government intervention in environmental entrepreneurship innovation activities. Moreover, the government should explore and establish the government management system that conforms to the laws of environmental protection and innovation. Actively guide private investment and promote environmental protection, cleaning and high-tech industry development.

Increasing capital Investment guidance, guiding the idle capital flows to clean products processing enterprises and environmental protection infrastructure, promoting industrial restructuring, guiding idle capital flow to new technologies, new materials, new products, environmental protection projects and industries, promoting the industrial structure adjustment in various districts, guiding the capital flow to tourism and service industry, promoting the development and growth of tertiary industry in Hebei province. Managing green credit strictly, strengthening the prevention and control of loan risk. The financial institutions should control the access to loans strictly, strengthen the green credit management, and prevent credit risks arising from changes in environmental protection requirements of construction projects. When granting loans, the corporate compliance with environmental protection laws as a necessary conditions for loan approval (Lyu et al., 2018). Investigating the situation of non-performing loans caused by corporate environmental problems and timely formulating loan risk prevention plan for high pollution high energy consumption and overcapacity industries, in particular, using the right time to compress or recover the loans, or take measures to improve the procedures for guaranteed mortgage and reduce the loan risk is necessary. Strengthening the window guidance and financial supervision, controling the direction of loans strictly. Functional departments should strengthen the supervision of financial institutions to lend prudently, implement the national macro-control policies and industrial policies resolutely, approve green credit strictly. The supervision departments at all levels should include implementation of the environmental protection policies and regulations, cooperation with the Environmental Protection Department and the control of credit risk of polluting enterprises into the supervision and inspection scope, prohibit the credit funds entering the industries and fields which are restricted by the national policy, and prohibit entering into the fields that do not meet environmental requirements and the fields with high energy consumption.

4.2.2. Strengthen environmental protection information platform construction and implement vertical management system reform

The channel of information resources in Hebei province is relatively single, and environmental information is not fully disclosed and not timely, and the role of public opinion supervision has not been fully realized. Relatively sufficient supervision of public opinion can promote more rigorous and detailed environmental monitoring and environmental management; multi-angle and comprehensive environmental protection data can help experts in the relevant fields to make timely reference and accelerate the pace of industrial green transformation (Lopez-Valeiras et al., 2018). At the same time, measures should be taken to perfect the system of evaluation and supervision and establish a standardized environmental information service platform and change the supervision of public opinion as a driving force for environmental protection. Through the establishment of a long-term mechanism and supervision mechanism of environmental protection information publicity, public awareness of environmental protection has become a conscious awareness and behavior. Efforts should be made to promote environmental supervision information disclosure. The information publicity work is included in the performance assessment indicators, the information public responsibility should be fully implemented, the examination bulletin should be strengthened, and the work should be done systematically and standardized. First is to further clarify the subject of information disclosure. Follow the principles of ‘who gets and makes the information, who public it is to further clarify the subject of the disclosure of information. Second, further refine the information disclosure content. According to the ‘Environment Supervision Information Disclosure Catalogue of Pollution Source’, all information that should be disclosed, such as basic information on pollution information, total control, pollution control, sewage charges, supervision of law enforcement, administrative penalties, and environmental emergency. Thirdly, further tighten the information disclosure time limit. The disclosure shall be made within 20 working days from the date of formation or alteration of environmental supervision information of pollution source, and the summary information shall be made public within 20 working days after the end of the year or quarter. The Fourth is to further standardize the information public way. The information openness takes the network as the main public way. According to the environmental supervision information of different pollution source, various methods are adopted for disclosure. The Fifth is to further strengthen day-to-day supervision and inspection. The Office of Information public leading group irregularly supervises and informs the disclosure of pollution sources supervision information, praises advanced, supervises backwardness, and effectively promotes the safe and effective operation of environmental information publicity work.

The vertical management system reform should be embedded in the whole system of ecological civilization reform, and it is a powerful measure to promote the prevention of air pollution in Hebei province. The reform of vertical management system, which is a fundamental change of integrity, synergy and comprehensiveness of local environmental protection management system, involves the reformation of the system, organization and personnel of grass-roots environmental protection institutions, as well as the reconstruction of supervision, supervision, law enforcement and licensing. The vertical management system reform would vigorously promote the local environmental management system innovation, clear responsibility, perfect system, support policies, which would greatly promote the overall efficiency of environmental management (Tam et al., 2002).

4.2.3. Expand the use of new energy vehicles and improve the proportion of clean utilization of coal

The emission of motor vehicles in Hebei province include the emission of petrol vehicles and diesel vehicles, and the amount of petrol vehicles is huge. It contributes significantly to urban areas under static conditions, while the diesel vehicle emit large amounts of pollutant per vehicle, causing significant emissions of particulate matter. The industrial sources of air pollution mainly include the main industrial processes of steel, petrochemical and building materials in the local and surrounding areas, especially the commencement of ignition after the spring Festival, which has a great impact on the air. Increasing the proportion of new energy and clean utilization of coal will have obvious effect on improving the air quality of Hebei province (Chen et al., 2010). Renewable energy is the ultimate substitute for fossil fuels, but the huge problem of renewable energy development is intermittent and unpredictable. There are two key breakthroughs in solving this problem: one is to improve the ability of in depth peak load cycling, the other is to actively develop the application of energy storage technology. Coal-based energy structure and heavy chemical industrial structure are the direct cause of air pollution in Hebei province. Compared to the Yangtze River Delta and the Pearl River Delta region, the pillar industries in Hebei Province are steel, cement, thermal power, flat glass, petrochemical and other high-energy industries. The total amount of pollutants emitted is large, and the emission intensity per unit of GDP is large. In Hebei province, the sulfur dioxide emission intensity is 3.5 times of the national average level, and the NOx emission intensity is 4.3 times of the national average level. In particular, central and southern Hebei province, it is necessary to concentrate on the control of coal, the implementation of eight coal control projects, and the organization of province environmental inspection, and to severely punish environmental violations and environmental supervision of inaction, disorderly acts, dereliction of duty. Innovation of coal clean utilization technology should focus on key practical technologies such as integrated gasification combined cycle (IGCC), 'nearly zero emission' technology in the treatment of flue gas, etc. The early development of clean coal technology needs a large amount of fixed investment and a high price, and the commercialization is more difficult. Thus, government investment should be given priority, and enterprises and social capital investment should be encouraged to establish a platform for clean coal technology innovation. It would be helpful to improve the efficiency of energy utilization and control the pollutant emission of coal by vigorously developing urban central heating and using coal comprehensively (Schmidt et al., 2018). At present, the rural areas in Hebei Province and some small towns generally use individual heating with large heating energy consumption and energy waste, and there are a large number of direct-discharge small boilers or home-burning furnaces. In addition, centralized heating is more conducive to energy conservation and emission reduction, the total energy consumption would be reduced for Hebei province. The future of Hebei province would have a large number of people concentrated in urban areas, especially such as Shijiazhuang, Baoding and other large and medium-sized cities, the population carrying capacity still has a lot of space. The population in these cities would focus on the construction of urban agglomeration, which could improve the intensive and compact city operation capacity. The transformation of municipal infrastructure would be also be more powerful and the effect would be more obvious.

4.2.4. Enhance haze forecast & warning and strengthen synergistic control of multi-pollutants

The monitoring of atmospheric contaminants indicated that there are very few air pollutant particles during 2008 Olympic Games, and $PM_{1\sim2.5}$ was less than 50 $\mu g/m^3$. Odd-even license plate policy and "yellow label" vehicle(that doesn't meet exhaust emission standards)limitation can control the $PM_{1\sim2.5}$ below 100 $\mu g/m^3$, while in unrestricted period this data is up to 200 $\mu g/m^3$. Similarly, the fourth strong haze process analysis for the 2016 year 1 Month shows that the emission of nitrogen oxides from cars and sulfur emissions from coal combustion contributed more than 100 $\mu g/m^3$, which accounted for half of the pollutant concentrations at that time. These conditions indicate that, considering the atmospheric circulation of external pollutants, local pollution control could be enhanced by early prediction & warning, and the air pollution in Hebei province can be reduced under the climate condition of static stability and temperature inversion (Fei et al., 2018). Through early warning and temporary precautions, the five powerful incidents in January 2016 was mitigated three times. Lowering The $PM_{2.5}$ was not enough and all pollutant gases and particles should be eliminated. It is important not only to focus on sulfide emissions, but also to reduce NO_x and ozone. Because the concentration of the PM_{10} (particle size smaller than the 10 μm) drops and the concentration of $PM_{2.5}$ remains high, regional air pollution control should be dominated by the emission reduction of fine particulate matter and a variety of air pollution control, and control the source of CO, SO_2, NO_x, VOCs and NH_3 emissions. In the power industry, simultaneously controls SO_2, NO_x, VOCs and dust can help reduce the cost of pollution control. The control of direct pollution source should have different emphases. First, control from the source and vigorously reduce the emissions of the main gaseous SO_2, NO_x, CO, NH_3 and VOCs before the formation of $PM_{2.5}$. The focus of control so $_2$ is on industrial, heating and coal-fired power plants. The priority of NO_x control is motor vehicles, coal-fired power plants, and industry. The priority of CO control is the motor vehicle industry and coal-fired power plants. VOCs control should be based on motor vehicles, non-organized (kitchen, dry cleaners, etc.) emissions and industrial emissions. In addition, due to the impact of large-scale coal-fired heating in winter, SO_2, NO_x, CO and fine particles are on the rise compared to non-heating periods in Hebei province. Therefore, pollutants control should be tightened during winter heating periods, while the VOCs should be controlled throughout the year. The government should strictly implement the system for controlling the total discharge of atmospheric pollutants, continuously improve pollutant emission standards, establish a strict environmental protection standards system, and promote polluting enterprises to reduce pollutant emissions.

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.

CRediT authorship contribution statement

Yunyan Li: Conceptualization, Writing - review & editing, Supervision. **Shan Huang:** Writing - review & editing, Writing - original draft. **Chenxi Yin:** Writing - original draft, Formal analysis. **Guihua Sun:** Writing - review & editing. **Chang Ge:** Writing - review & editing.

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Appendix A. Expert survey questionnaire for the performance of air pollution control

Dear expert:

We are the research group of environmental economics of Beijing University of Technology. We are currently carrying out the research on " Construction and Countermeasure Discussion on Government Performance Evaluation Model of Air Pollution Control: A Case Study from Beijing-Tianjin-Hebei Region". Part of the data needs to be scored based on your experience, so we very much hope to get you support.

The indicator system in the topic contains three levels of indicators. You need to score according to the importance of each level of the indicator relative to the higher-level indicator to which it belongs (first-level indicators are scored relative to the subject's research object). The score is divided into five levels of 1, 3, 5, 7, and 9, which in turn represent that the scored indicator is equally important, slightly more important, obviously more important, strongly important, or absolutely important compared to higher-level indicator to which it belongs. As the score increases, the importance increases. As the score increases, the importance increases. If the importance is between the two scores, please fill in 2, 4, 6, or 8. The following is the main body of the questionnaire:

Question 1: How familiar are you with this field?

A. Very familiar
B. Generally familiar
C. Not very familiar

Question 2: Please rate the importance of the indicators at each level.

Level I	Score	Level II	Score	Level III	Score
Economic benefit		Economic development		Actual GDP	
				GDP Per Capita	
				Proportion of the Tertiary Industry	
				Urbanization Rate	
				Energy Consumption	
				Motor Vehicle	
		Environmental quality		Proportion of Coal	
				NOx Emissions from Motor Vehicles	
				Industrial Gas Emissions	
				Average Annual Concentration of PM2.5	
				Average Annual Concentration of NOX	
				Average Annual Concentration of SO2	
Public service		Life satisfaction		Engel Coefficient	
				Disposable Income Per Capita	
				Motor Vehicle Per Capita	
				Public Transport	
				Environmental Petition	
		Environmental comfort		Air Quality Compliance Rate	
				Public Green Area Per Capita	
				Urban Greening Coverage	
Environmental management		Government management		Industrial Waste Gas Governance Facilities	
				Investment of Industrial Pollution Management	
				Environmental Petition Cases	
				Implementation Rate of EIA	
		Environmental monitoring		Environmental Enforcement	
				Environmental Monitoring Expenditure	
Development potential		Technology support		Elasticity Coefficient of Energy Consumption	
				Energy Consumption Per GDP	
				Proportion of Environmental Investments	
		Pollution control		Emission Intensity of Industrial SO2	
				Emission Intensity of Industrial NOx	
				Emission Intensity of Industrial Smoke	

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