J. Resour. Ecol. 2020 11(6): 549–561
DOI: 10.5814/j.issn.1674-764x.2020.06.002
www.jorae.cn

Measurement and Comparison of Urban Haze Governance Level and Efficiency based on the DPSIR Model: A Case Study of 31 Cities in North China

XIAO Qinlin, TIAN Chao, WANG Yanjun, LI Xiuqing, XIAO Liming*

School of Economics and Management, Shanxi Normal University, Linfen 041000, Shanxi, China

Abstract: In the decisive stage of developing of a moderately prosperous society in all aspects, hazy weather has become a major obstacle to the further advancement of China. Therefore, improving the level and efficiency of haze governance has become essential. Based on the DPSIR model, this paper builds a haze governance level and efficiency index system using the entropy method and the super-efficiency data envelope-analysis (DEA) model to analyze the data for 31 cities in North China from 2007 to 2016. From the aspects of spatial differences and influence factors influencing the comparative analysis, the results are as follows. (1) During the investigation period, the level and efficiency of city haze governance in North China showed a trend of fluctuation and decline, with obvious stages in their characteristics. Haze governance efficiency is much higher than its level, and its mean value reaches the DEA level which indicates that it is effective. (2) A significant regional gradient difference occurs between these two aspects. The haze governance level presents a convex distribution pattern of “east low–middle high–west low”, while the haze governance efficiency presents a concave distribution pattern of “east high–middle low–west high”. (3) The regression results show that economic growth has a negative effect on both haze governance level and efficiency. By contrast, the industrial structure has a positive effect on haze governance level and efficiency, but the significance of its effect on these two is different. On this basis, policy suggestions are proposed for improving the level and efficiency of haze governance in various cities in North China.

Key words: haze governance level; haze governance efficiency; entropy method; super-efficiency DEA model

1 Introduction

Maintaining environmental integrity is critical to a culture (Chen and Wang, 2018). Since the reform and opening-up of China, its economic development has made remarkable achievements but numerous ecological environmental problems remain. In particular, as a consequence of air pollution, haze has caused widespread concern. The health cost associated with air pollution accounted for 1.16%–3.8% of the 2003 GDP (Shi et al., 2016). A survey of air conditions in the cities north of the Huai River also found that the haze pollution caused by winter heating has reduced the average life expectancy of the population there by 5.5 years (Chen et al., 2013). Therefore, haze has become the “stumbling block” in the current building of an ecological civilization, therefore, strengthening haze governance and improving the governance level are very urgent.

The formation of hazy weather results from the joint action of various factors. Studies have found that the concentration and accumulation of atmospheric pollutants and meteorological triggers are the main drivers of haze (Fu, 2018).

Received: 2020-05-28 **Accepted:** 2020-08-02
Foundation: The National Social Science Foundation of China (17BJY038).
First author: XIAO Qinlin, E-mail: x853903799@163.com
***Corresponding author:** XIAO Liming, E-mail: xiaolm1972@163.com

Citation: XIAO Qinlin, TIAN Chao, WANG Yanjun, et al. 2020. Measurement and Comparison of Urban Haze Governance Level and Efficiency based on the DPSIR Model: A Case Study of 31 Cities in North China. *Journal of Resources and Ecology*, 11(6): 549–561.

Thus, clarifying the causes of hazy weather may provide a theoretical basis for improving its governance level and efficiency. At present, studies on haze governance mainly focus on the theoretical level, involving the governance mode, governance measures, and governance bodies. In terms of the haze governance model, Bai and Nie (2017) and Cai et al. (2017) studied the impact of environmental decentralization on haze governance. In terms of governance measures, scholars have mainly proposed governance paths from the aspects of energy structure, industrial structure adjustment, and collaborative governance (Islam et al., 2016; Wang et al., 2016; Jiang et al., 2017) based on local government environmental policies and environmental governance indicators. The governance body mainly investigates the government's role in positioning and its responsibilities in haze governance (Wang and Hao, 2015). Some scholars have also investigated the restrictive factors and action paths for the public's participation in haze governance, as well as the mutual gaming among stakeholders in the governance process (Chu et al., 2017; Meng et al., 2017). Some scholars have also pointed out that many stakeholders lack enthusiasm and motivation in haze governance (Zhou and Liu, 2016). While these studies undoubtedly provide a good academic reference for the haze governance path, only a few scholars have been involved in the study of governance quantification. For example, based on the fuzzy comprehensive evaluation method, Wang et al. (2018) constructed a performance evaluation index system for haze management in Beijing, Tianjin, and Hebei. Chen and Wang (2018) measured the haze governance index of cities in the Yangtze River Delta based on the DPSIR model and proposed an innovative governance path.

In summary, although previous studies have made beneficial explorations of haze treatment, the corresponding quantitative research is lacking in most theories. Only a few scholars have measured the level of haze management and the governance indexes that are less involved in governance efficiency. Comparisons based on spatial differences and factors influencing the haze management level and management efficiency are few. The ultimate goal of haze governance is to achieve economic, social, and environmental coordination while improving the quality of urban air. If increasing the investment in governance is the only focus, while neglecting the efficiency of governance, it may eventually lead to the inefficiency of the inputs and outputs of such an approach to governance. Therefore, when measuring and evaluating haze governance, we should not only consider its governance level but also pay attention to its governance efficiency. In addition, as a typical region of haze pollution in China, North China has more days of heavy pollution in winter, which seriously threatens people's physical and mental health. Thus, investigating the governance status of haze is necessary.

In general, common comprehensive evaluation methods include the entropy weight method, analytic hierarchy process, and the fuzzy evaluation method (Chen and Jin, 2014; Fang et al., 2014; Li et al., 2014), but these methods cannot effectively reflect the internal causal relationships between the evaluation indicators, causing the measurement results to lack theoretical bases. The DPSIR model based on causal connections can compensate for this shortcoming. This model is put forward in the Organization for Economic Cooperation and Development's Pressure–State−Response model and the United Nations Commission on Sustainable Development's Drivers–Pressure–Response model. These models evolved on the basis of the ecological environment and human economic activities, mainly by depicting the causal relationship between a certain factor and a comprehensive evaluation metric, making the results more real and effective (Zhang et al., 2019). Furthermore, the DPSIR model evaluation indexes of a system are divided into driver, pressure, state, influence, response, and other dimensions. Based on the different evaluation objects, each dimension can be subdivided into a number of indicators. This approach has the advantages of wide coverage and a strong logical basis. Thus, it is widely used by most scholars in environmental management and policy evaluation research (Yu and Lu, 2004).

On this basis, this paper uses 2007–2016 panel data for 31 cities in North China as samples. Based on the fact that the DPSIR model constructed a haze index system of governance and governance efficiency, the entropy value method and the super-efficiency data envelope-analysis (DEA) model are used to measure these two components. Then, they are compared from the aspects of spatial differences and effects to comprehensively evaluate haze governance. Some feasible policies and suggestions are then put forward, encouraging further research on haze governance.

2 Research methods

2.1 DPSIR model

To comprehensively evaluate the haze governance of cities in North China, this paper uses the DPSIR model to carry out the haze governance evaluation at the city level. The driving force, pressure, state, influence, response, and other dimensions in the model constitute a complete causal chain. Specifically, from the perspective of haze governance, the causal relationship in the DPSIR model is shown as the driving force that is powering the engine of haze governance. Pressure will have a negative effect on haze governance. The state plays a two-way role in haze governance, with positive and negative effects. The influences and responses of haze governance have an interactive coupling relationship, in that they interact and influence each other. In addition, the response can positively influence the driving force, stress, and state through inhibition, mitigation, and improvement (Fig. 1). Therefore, based on the theoretical analysis framework of the DPSIR model, this paper uses the entropy and DEA methods to evaluate the haze governance effect of cities in North China from the perspectives of "level" and "efficiency".

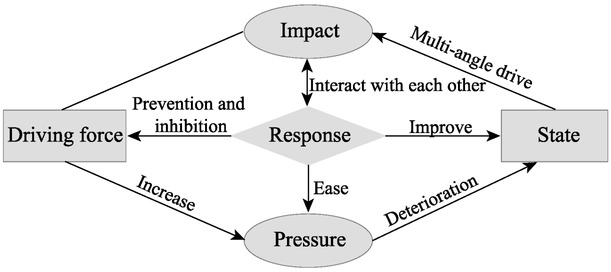

Fig. 1 DPSIR model as applied to haze governance

2.2 Entropy method

The entropy method is an objective evaluation method of weight assignment. It can achieve dimensionality reduction by calculating the weight of each index, and provide a basis for multi-index evaluation. The specific steps are as follows.

1) The initial matrix $\{x_{ijk}\}_{m\times n}$ is constructed, where m is the number of prefecture-level cities, n is the number of indicators of the evaluation system, and x_{ijk} is the original value corresponding to the j indicators of the prefecture-level cities in k years.

2) To eliminate the influence of different dimensions, the data for each index are standardized. Considering that the normalized data might be zero, all values are shifted to the right by M, with the value of M being 0.001.

$$\text{Positive index: } X_{ijk}=\frac{x_{ijk}-\min\{x_{jk}\}}{\max\{x_{jk}\}-\min\{x_{jk}\}}+M \tag{1}$$

$$\text{Negative index: } X_{ijk}=\frac{\max\{x_{jk}\}-x_{ijk}}{\max\{x_{jk}\}-\min\{x_{jk}\}}+M \tag{2}$$

3) The proportion of the index value of city i under index j in k year(s) is calculated as:

$$p_{ijk}=\frac{X_{ijk}}{\sum_{i=1}^{m}X_{ijk}} \tag{3}$$

4) The information entropy of index j in k year(s) is calculated as:

$$H_{jk}=-\frac{1}{\ln m}\sum_{i=1}^{m}p_{ijk}\ln p_{ijk} \tag{4}$$

5) The weight of index j in k year(s) is calculated as:

$$w_{jk}=\frac{1-H_{jk}}{n-\sum_{j=1}^{n}H_{jk}} \tag{5}$$

6) The comprehensive score of each city is then calculated as:

$$s_{ik}=\sum_{j=1}^{n}w_{jk}p_{ijk} \tag{6}$$

On this basis, the relevant index data for 31 prefecture-level cities in North China were processed to obtain a comprehensive score of the haze governance level.

2.3 Super-efficiency DEA model

Efficiency measurement mainly involves parametric and non-parametric methods, namely, DEA and stochastic frontier analysis (SFA). SFA needs to set a production function in advance and has limitations in dealing with the problem of "multi-input and multi-output". However, DEA can effectively compensate for this deficiency because of various advantages, such as no need to set the form of a production function, non-subjective weighting, and no requirement for index dimensions, making the measurement results more aligned with the objective reality. As a result, DEA is widely used at present. First proposed by Charnes et al. (1978), DEA is a non-parametric method for evaluating the relative efficiency of multi-input and multi-output factors. Based on different scale return assumptions, DEA can be divided into CCR and BCC models. However, these two models measure the efficiency from the radial (increase or decrease the input and output in the same proportions) and angular (input and output) perspectives, respectively, and fail to consider the slack of input and output, which leads to inaccurate measurement results. Therefore, to overcome these deficiencies, Tone (2001) proposed a non-radial and non-angular model based on relaxation variables, namely, the SBM model. Although this model offers a great improvement over the traditional model, it is unable to sort the decision unit with an efficiency value of 1. Therefore, Tone (2002) subsequently improved it and proposed the super-efficiency SBM model. On this basis, the super-SBM model is adopted in this paper to calculate the haze governance efficiency. The specific form is as follows:

$$\begin{cases}\min\theta_{se}=\dfrac{\frac{1}{m}\sum_{i=1}^{m}\overline{x}_i/x_{i0}}{\frac{1}{s}\sum_{q=1}^{s}\overline{y}_q/y_{rk}}\\ \text{s.t.}\quad \sum_{j=1}^{n}x_j\lambda_j\leqslant\overline{x};\ \sum_{j=1}^{n}y_j\lambda_j\geqslant\overline{y}\\ \qquad\sum_{j=1,j\neq k}^{n}x_{ij}\lambda_j+s_i^-=x_{i0},\quad i=1,2,3,\cdots,m\\ \qquad\sum_{j=1,j\neq k}^{n}y_{qj}\lambda_j-s_q^+=y_{q0},\quad q=1,2,3,\cdots,s\\ \qquad\sum_{j=1,j\neq k}^{n}\lambda_j=1,\ \overline{x}\geqslant x_0,\ \overline{y}\leqslant y_0,\ j=1,2,3,\cdots,n\quad(j\neq k)\\ \qquad\overline{y}\geqslant 0,\ \lambda\geqslant 0,\ s_i^-\geqslant 0,\ s_q^+\geqslant 0\end{cases} \tag{7}$$

In the formula, θ_{se} is the relative efficiency value of each decision-making unit, while x, y, and λ represent the input variable, output variable, and weight vector, respectively. $(\bar{x}, \bar{y})$ is the reference point of the decision variable, and s_i^- and s_q^+ are the relaxation variables (input and output). The basic conditions for determining whether a decision-making unit is effective are very straightforward. When $\theta_{se} \geqslant 1$ and $s^- = s^+$, the decision-making unit is relatively effective. When $\theta_{se} \geqslant 1$ and $s^- \neq 0$ or $s^+ \neq 0$, the decision unit is weakly effective. When $\theta_{se} < 1$, the decision unit is relatively invalid, so the input–output variables need to be adjusted and improved. In short, the higher the θ_{se} value, the higher the efficiency of haze governance.

2.4 Panel econometric model

To explore and compare the action mechanisms of haze governance level and efficiency, this paper further established a panel metering model. First, it chose between the variable intercept panel data model and the mixed data panel model, as determined mainly by the Chow and F tests. If the null hypothesis was rejected, the model would be changed to the variable intercept panel model. On this basis, the Hausman test is also needed to determine whether to use the random effect or the fixed effect model, according to the formula:

$$y_{it} = \alpha_0 + \beta_1 x1_{it} + \beta_2 x2_{it} + \cdots + \beta_9 x9_{it} + u_i + v_t + \varepsilon_{it} \quad (8)$$

In the formula, y_{it} represents the explained variable. To compare the differences of the influencing mechanisms between haze treatment and efficiency, this paper takes the haze treatment level and efficiency as the explained variables, respectively, to investigate the significance of each influencing factor. α_0 is the intercept term of the model. $x1_{it}, x2_{it}, \cdots, x9_{it}$ is the explanatory variable, respectively corresponding to the specific index values of each dimension of the DPSIR model. $\beta_1, \beta_2, \cdots, \beta_9$ is the regression coefficient of each explanatory variable. u_i is the individual fixed effect term, v_t is the time-point fixed effect term, and ε_{it} is the random disturbance term, which obeys the independently identical distribution.

3 Evaluation system construction and data source

3.1 Index system of haze governance level

Haze governance refers to the governance activities of relevant stakeholders to reduce the hazards of hazy weather by adopting a series of environmental protection measures. From this perspective, quantitative indicators of environmental governance with similar connotations and relatively wider scope can provide reference values for the selection of haze governance indicators (Gan and Wang, 2018). At the same time, haze governance is a complex systematic project that requires a high degree of coordination among the economic, social, and environmental levels. Therefore, the haze governance index system should also include various indicators such as population, resources, economy, and the environment. On this basis, this paper follows the principles of science, comparability, and accessibility. It uses the theoretical framework of the DPSIR model to select indicators from the target, criterion, and index layers, and then constructs the haze governance level index system, as shown in Table 1. The selections of specific indicators in each dimension are as follows.

Table 1 Index system of haze governance level

Target layer	Rule layer	Index layer	Unit	Direction
Haze governance level	Driving force	Municipal public infrastructure investment	$\times 10^4$ yuan	positive
		Urban personnel in the management of water conservancy, environment, and public facilities	$\times 10^4$ person	positive
		Energy consumption per unit of GDP	tons of standard coal $(\times 10^4$ yuan$)^{-1}$	negative
	Pressure	Effluent discharge	t	negative
		Sulfur dioxide emission	t	negative
		Dust discharge	t	negative
	State	Proportion of secondary industry	%	negative
		Mean of $PM_{2.5}$	μg m^{-3}	negative
	Impact	Domestic tourism revenue	$\times 10^4$ yuan	positive
		Comprehensive utilization rate of solid waste	%	positive
		Green coverage in built-up areas	%	positive
	Response	Spending on science and technology as a share of GDP	%	positive
		Spending on education as a share of GDP	%	positive
		Number of patent applications granted in different regions	number	positive

Driving force (D): Driving force is the driving factor that induces the practice of haze governance, and mainly involves economic and social drivers. In terms of economic drivers, this paper believes that the increase in investment in environmental infrastructure can provide funds and guarantee the implementation of haze governance. However, obtaining the index data for environmental infrastructure investment that is limited to the city level is difficult. Thus, municipal public infrastructure investment is chosen to serve as an approximate replacement. The increase in full-time environmental protection personnel driven by society and energy consumption per unit GDP are also key factors for haze governance. On the one hand, the increase in full-time environmental protection personnel provides high-quality environmental protection talents for haze governance. On the other hand, the scale of energy consumption is an important factor in promoting haze governance in various regions. Therefore, this paper further chooses urban personnel and energy consumption per unit GDP in water conservancy, the environment, and public facility management to represent the driving force at the social level.

Pressure (P): Pressure reflects the load of haze governance activities on the environment, mainly the discharge of selected pollutants. Based on the research of Gan and Wang (2018), this paper specifically selects industrial wastewater, industrial sulfur dioxide, and industrial dust emissions to measure the pressure.

Status (S): Status refers to the status of haze governance under the above forces and pressures, which can be used to quantitatively calculate the current status of haze governance in each city. Based on the research of Zhang et al. (2017), this paper further argues that haze governance is mainly manifested in regional industrial structure and the emissions of major pollutants. The industrial structure is measured by the proportion of the secondary industry within GDP. Collectively, major pollutant emissions are measured using $PM_{2.5}$ averages.

Impact (I): Impact refers to the impact on the urban economic and social development and the ecological environment caused by the haze governance activities. In terms of the economy, various cities have improved local air quality by carrying out haze government practices, enabling a large number of tourists to travel to the local areas leading to an increase in local tourism income. Therefore, this paper refers to Chen and Wang (2018) and includes the measure of domestic tourism income. In terms of the environment, attention should be paid to improving the resource utilization rate and the living environment. Therefore, the solid waste disposal rate and the green coverage rate of built-up areas are selected in this paper.

Response (R): Response refers to positive measures and countermeasures implemented by individuals, groups, or governments that are conducive to haze governance activities. This paper believes that improving the science and technology level and the quality of environmental protection personnel are important factors for the smooth development of haze governance activities. Therefore, by referring to relevant studies (Zhang et al., 2017), the proportion of science and technology expenditure, the proportion of education expenditure, and the number of patent applications granted are selected as the measurements of these factors.

3.2 Index system of haze governance efficiency

To scientifically measure the conversion efficiency of the inputs in haze governance, and on the basis of following the principles comparable to the level of haze governance (as described above), this paper selects the relevant indexes for each dimension in the DPSIR model. It then establishes the input–output evaluation index system of haze governance efficiency based on the input–output perspective and the knowledge production function (Table 2). In terms of inputs, the indicators are mainly selected from the four dimensions of capital, labor, technology, and resources. However, because the haze governance efficiency index system research is still developing and not yet mature, this paper uses the indicators with similar connotations that are related to environmental governance efficiency (Wang et al., 2012). Therefore, city municipal public infrastructure investment, expenditure proportion for science and technology, and education expenditure proportion are selected to represent the haze urban governance in the capital, human resources, technology, and investment considerations.

The output index of haze governance is the same as that in existing efficiency evaluation research (Dong et al., 2008), and it is mainly considered from the two dimensions of expected output and non-expected output. The expected output dimension is represented by the two indicators of economic benefit and environmental benefit. In general, economic benefit output is mainly reflected in regional economic growth. Most scholars (Dong et al., 2008) use regional GDP to represent this output. However, this paper believes that the economic benefits resulting from haze governance activities should be directly reflected in the revenue of specific tourism departments, so domestic tourism revenue is chosen as the measurement. The environmental benefit output is reflected in the improvement of urban greening and the living environment quality. This paper uses the relevant indicators in the "Green Development Index System" issued by the state for reference, and chooses the comprehensive utilization rate of solid waste and the green coverage rate of built-up areas as the indicators. In the dimension of undesired output, considering that $PM_{2.5}$ is the main pollutant targeted by haze governance activities, this paper uses the mean value of $PM_{2.5}$ in addition to the traditional industrial "three wastes" index (Table 2). However, because environmental pollutants are an unpaid input, we hope that less input is desirable. Therefore, information from the relevant literature (Cao and Yu, 2015) was used for reference, and

Table 2 Index system of haze governance efficiency

Index type	Primary index	Secondary indicators	Unit	Direction
Input indicators	Capital investment	Municipal public infrastructure investment	$\times 10^4$ yuan	positive
		Spending on science and technology as a share of GDP	%	positive
		Spending on education as a share of GDP	%	positive
	Labor input	Urban personnel in the management of water conservancy, the environment, and public facilities	$\times 10^4$ person	positive
	Technology input	Number of patent applications granted in different regions	number	positive
	Resources input	Energy consumption per unit of GDP	tons of standard coal ($\times 10^4$ yuan)$^{-1}$	negative
Output indicators	Desirable output	Domestic tourism revenue	$\times 10^4$ yuan	positive
		Comprehensive utilization rate of solid waste	%	positive
		Green coverage in built-up areas	%	positive
	Undesirable output	Industrial wastewater discharge	t	negative
		Industrial sulfur dioxide emissions	t	negative
		Industrial dust emission	t	negative
		$PM_{2.5}$	μg m^{-3}	negative

was included in the input index for the specific efficiency measurement.

3.3 Data source

This article uses North China for the study area, where haze pollution is more serious. According to the administrative divisions, this area includes Beijing, Tianjin, Hebei, Shanxi, and Inner Mongolia. A total of 31 cities are used as the basic spatial units of analysis: Taiyuan, Datong, Shuozhou, Yangquan, Changzhi, Jincheng, Jinzhong, Yuncheng, Xinzhou, Linfen, Lvliang, Shijiazhuang, Tangshan, Qinhuangdao, Handan, Xingtai, Baoding, Zhangjiakou, Chengde, Cangzhou, Langfang, Hengshui, Hohhot, Baotou, Wuhai, Tongliao, Chifeng, Ordos, Hulun Buir, Bayan Nur, and Ulanqab.

Relevant data are mainly from the *China Statistical Yearbook*, *China Urban Statistical Yearbook*, and statistical yearbooks of the various provinces and cities from 2008 to 2017. Some data missing from those sources are obtained from the statistical bulletin of national economic development of relevant prefecture-level cities and the authoritative data released by official government departments.

4 Results and analysis

4.1 Overall evaluation of the level and efficiency of urban haze governance in North China

Based on the entropy method and the super-efficiency DEA model, this paper calculates the haze governance level and efficiency of 31 prefecture-level cities in North China from 2007 to 2016. For the haze governance efficiency, we select the super-SBM model with a constant return to scale based on the relevant data of the input and output indexes listed in Table 2, and we use DEA-SOLVER PRO 5.0 software to calculate it.

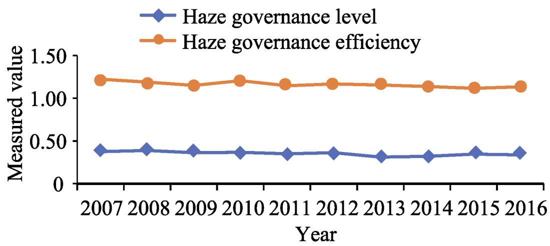

Fig. 2 Overall changes in the level and efficiency of urban haze governance in North China from 2007 to 2016

Figure 2 shows the overall changes in the urban haze governance level and efficiency in North China from 2007 to 2016. During the study period, the level and efficiency of urban haze governance in North China each showed a trend of fluctuation and decline overall, with relatively obvious characteristics of phased changes. 1) From 2007 to 2010, the governance level (blue line) showed an upward trend, the level value increased from 0.373 in 2007 to 0.367 for a change range of −1.69%, and the inflection point appeared in 2008. The inflection point of governance efficiency (orange line) occurred in 2009, which was slightly later than the governance level. The reason may be that the global financial crisis in 2008 led to an economic downturn in the region. Therefore, all the cities were busy restoring their local economies, and they paid little attention to governance, leading to the continuous decline of governance level thereafter. 2) In 2011–2013, a falling volatile trend is seen in governance. The horizontal value changed from 0.349 to 0.311, which is a drop of 10.94%. However, 2012 was a turning point because of the gradual convening of the The Eighteenth National Congress of the Communist Party of China. Five key strategies, such as development concepts, were successively put forward in response to active calls from the countries for action into environmental governance. Thus, the governance level began to ascend from this point onward. However, the efficiency of haze governance showed a rising trend in this stage. 3) From 1.144 in 2011 to 1.154 in 2013, an increase of 0.88%. From 2014 to 2016, the haze governance level shows an inverted V-shaped trend of change, increasing from 0.321 to 0.337. By contrast, the haze governance efficiency showed a V-shaped trend, with the efficiency value changing from 1.137 to 1.133. During this period, although the trends of the two were in opposite directions, the ranges of change are small. Generally, a positive trend of improvement occurred year by year, which may be related to the introduction of policies which promoted environmental quality improvement, such as the "national blue sky protection war" in recent years.

Table 3 shows the results of the evaluation and rankings of haze governance levels and efficiencies of the cities in North China. On the provincial scale, Hebei, Shanxi, and Inner Mongolia are ranked in order in terms of the average level of haze governance in North China ranks. In terms of city area, Taiyuan, Shijiazhuang, and Hohhot are the top three, while Bayannur, Tongliao, and Hengshui are ranked as the bottom three. The table also shows that the overall average level of haze governance is only 0.351. The governance levels of only 11 cities, including Taiyuan, exceed that of the whole region. By contrast, Hulunbuir, Ulanqab, and Ordos are ranked as the top three in governance efficiency, respectively. All three of these cities achieve DEA effectiveness. Changzhi, Tongliao, and Yuncheng are ranked as the bottom three. In addition, the mean value of the overall governance efficiency in North China is 1.161, which meets the DEA effective state, indicating a relatively high degree of input–output matching of haze governance in the cities in North China. Despite these results, individual cities in North China should continue to make efforts to improve haze governance, technologies, products, and input, so that they can cross the inflection point as soon as possible and realize continuous improvement of haze governance efficiency. In addition, note that the haze governance efficiency of cities in North China is far higher than its governance level. Therefore, to ensure haze governance efficiency in the future, improving the haze governance level should also be a top priority of all cities.

Table 3 Comparisons of haze governance level and efficiency for 31 cities in North China

Region	Haze governance level						Haze governance efficiency						Indifference between rank of level versus efficiency
	2007	2010	2013	2016	Mean	Ranking for level	2007	2010	2013	2016	Mean	Ranking for efficiency	
Taiyuan	0.736	0.696	0.871	0.855	0.777	1	1.042	1.066	1.212	1.279	1.165	16	↑
Shijiazhuang	0.652	0.604	0.524	0.650	0.629	2	1.003	1.036	1.040	1.029	1.011	24	↑
Hohhot	0.458	0.456	0.364	0.483	0.471	3	1.334	1.427	1.398	1.117	1.401	4	↑
Tangshan	0.485	0.510	0.339	0.342	0.448	4	1.023	1.033	1.022	1.013	0.945	26	↑
Baotou	0.434	0.407	0.342	0.392	0.419	5	1.235	1.328	1.183	1.242	1.214	13	↑
Handan	0.422	0.433	0.353	0.362	0.409	6	1.009	1.031	1.040	0.764	0.963	25	↑
Baoding	0.433	0.413	0.366	0.414	0.401	7	1.109	1.089	1.353	1.668	1.275	9	↑
Qinhuangdao	0.488	0.393	0.305	0.406	0.382	8	1.605	1.240	1.208	1.044	1.278	8	no change
Changzhi	0.354	0.378	0.336	0.361	0.365	9	1.006	0.733	0.691	1.006	0.810	29	↑
Datong	0.368	0.390	0.319	0.334	0.362	10	1.001	1.053	1.049	1.144	1.028	22	↑
Ordos	0.328	0.379	0.276	0.248	0.359	11	1.468	1.672	1.345	1.364	1.437	3	↓
Zhangjiakou	0.380	0.324	0.284	0.355	0.343	12	1.004	1.038	1.096	1.152	1.053	21	↑
Jinzhong	0.334	0.352	0.318	0.342	0.340	13	1.072	1.200	1.374	1.370	1.194	14	↑
Xinzhou	0.350	0.376	0.366	0.303	0.339	14	1.729	1.297	1.125	0.738	1.157	18	↑
Langfang	0.464	0.373	0.258	0.358	0.336	15	1.280	1.049	1.069	1.091	1.088	20	↑
Hulun Buir	0.312	0.321	0.282	0.289	0.327	16	2.251	2.394	1.955	1.211	1.912	1	↓
Chifeng	0.389	0.331	0.266	0.323	0.321	17	1.361	1.138	1.135	1.206	1.170	15	↓
Linfen	0.330	0.352	0.290	0.299	0.319	18	1.039	1.053	0.721	0.701	0.839	28	↑
Chengde	0.362	0.330	0.264	0.319	0.316	19	1.012	1.094	1.212	1.104	1.159	17	↓
Lvliang	0.285	0.320	0.314	0.313	0.313	20	1.398	1.058	0.725	1.001	1.138	19	↓
Jincheng	0.329	0.315	0.287	0.261	0.309	21	1.080	1.007	1.018	1.049	1.026	23	↑

(*Continued*)

Region	Haze governance level						Haze governance efficiency						Indifference between rank of level versus efficiency
	2007	2010	2013	2016	Mean	Ranking	2007	2010	2013	2016	Mean	Ranking for efficiency	
Ulanqab	0.290	0.277	0.251	0.248	0.282	22	1.835	1.224	1.473	1.748	1.580	2	↓
Xingtai	0.309	0.305	0.211	0.296	0.275	23	1.084	1.048	1.003	0.562	0.865	27	↑
Wuhai	0.290	0.305	0.257	0.306	0.273	24	1.591	1.238	1.319	1.318	1.283	7	↓
Cangzhou	0.333	0.281	0.207	0.271	0.269	25	1.389	1.577	1.078	1.029	1.249	11	↓
Yuncheng	0.274	0.261	0.258	0.242	0.264	26	0.494	1.010	0.664	1.001	0.799	31	↑
Shuozhou	0.251	0.270	0.258	0.196	0.256	27	1.390	1.248	1.328	1.236	1.345	5	↓
Yangquan	0.285	0.302	0.227	0.210	0.255	28	1.106	1.132	1.251	1.232	1.263	10	↓
Bayan Nur	0.257	0.353	0.232	0.225	0.255	29	1.008	1.473	1.139	1.117	1.216	12	↓
Tongliao	0.281	0.303	0.229	0.219	0.252	30	0.662	1.182	1.081	0.840	0.808	30	no change
Hengshui	0.298	0.256	0.177	0.237	0.222	31	1.268	1.137	1.459	1.745	1.323	6	↓
Hebei	0.421	0.384	0.299	0.365	0.366	I	1.162	1.125	1.144	1.109	1.110	II	↑
Shanxi	0.354	0.365	0.349	0.338	0.354	II	1.123	1.078	1.014	1.069	1.069	III	↑
Inner Mongolia	0.338	0.348	0.278	0.304	0.329	III	1.416	1.453	1.337	1.240	1.336	I	↓
North China	0.373	0.367	0.311	0.337	0.351	–	1.222	1.203	1.154	1.133	1.161	–	–

Note: Due to the length of this table, only the calculation results of some years are shown. ↑ and ↓ represent the rise and fall of the rankings, respectively.

4.2 Spatial differences of urban haze governance level and efficiency in North China

Exploring the spatial differences in the level and efficiency of haze governance in cities in North China is helpful for understanding the spatial distribution law of the two, which is of great significance for targeted haze governance work. In this paper, based on the calculated mean values of the two during the investigation period, ArcGIS 10.2 software was used to express the spatial visualization (Fig. 3). At the same time, to facilitate the analysis and comparison of the spatial difference characteristics of these two aspects, based on the mean values during the investigation period, the "Natural break point classification method" cluster analysis function of ArcGIS software was used to analyze the regional divisions. Among them, the average level of haze governance is divided into high-, medium-, and low-level zones with 0.327 and 0.471 as the break points. Similarly, the mean value of haze government efficiency was divided into high-, medium-, and low-efficiency zones with 1.09 and 1.44 as the break points.

The spatial pattern of haze governance levels in various cities in North China during the investigation period shows low levels in the east, high in the middle, and low in the

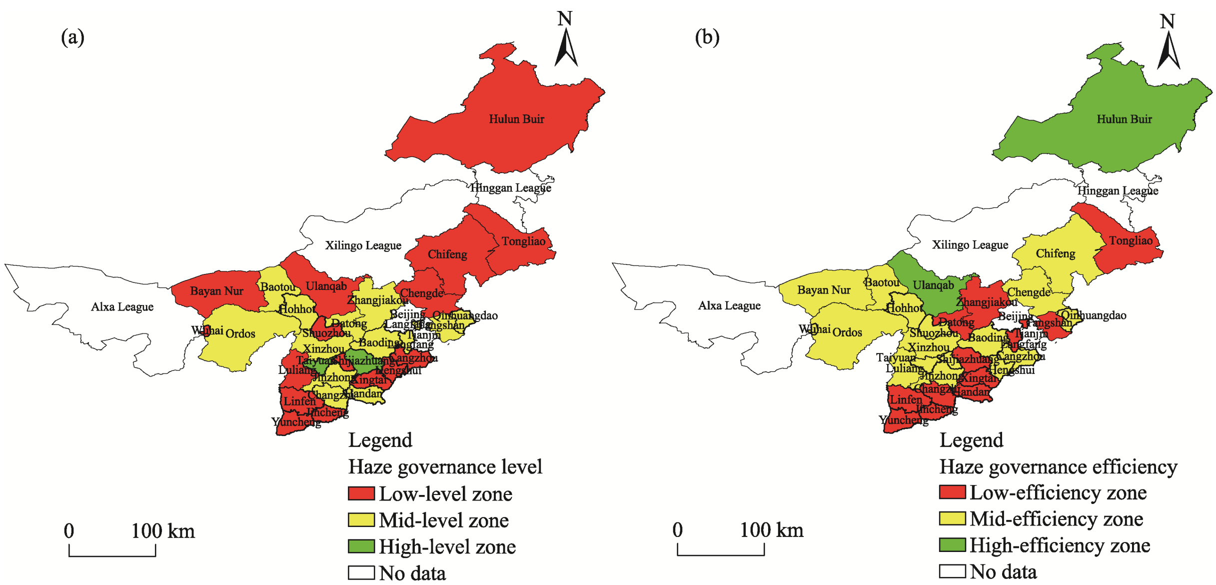

Fig. 3 Distribution of urban haze governance level (a) and efficiency (b) in North China from 2007 to 2016

west (Fig. 3a). Specifically, the urban distribution in the middle-level area is concentrated and shows a state of continuous distribution. The 13 cities located in low-level areas also show an agglomerated distribution, such as Lvliang, Linfen, Yuncheng, Jincheng, and Shuozhou. Most of these are resource-based cities. Abundant energy resources lead to a high dependence on the energy industry, and haze pollution is also relatively serious, thereby lowering the governance level. By contrast, the spatial distribution of haze governance efficiency is concave (Fig. 3b), at high levels in the east, low in the middle, and high in the west. One possible reason for this result is that some cities in the east have a good economic foundation and can provide better financial and technical support for haze governance. In addition, the skewed national policies tend to increase haze governance efficiency. On the other hand, some of these areas, such as Bayinnaoer and Ordos to the west of the city, have animal husbandry as the leading industry. So the cities themselves may do minimal damage to the environment with deep green policies, and they actively promote the integration of tourism development and ecological protection which increase their tourism income, resulting in high governance efficiency. Notably, the cities located in the low-efficiency areas are generally distributed in a concentrated manner, mainly those in the southern part of Shanxi Province and the southwest part of Hebei Province. The possible reason for this distribution is that these cities are faced with great transformation pressures and low resource utilization rates, lowering their haze government efficiency. Only a few cities are located in the high-efficiency area, namely, Ulanqab and Hulunbuir.

4.3 Analysis of factors affecting the level and efficiency of urban haze governance in North China

Through the analysis of relevant literature on haze pollution (Wang et al., 2020), the factors that may influence the haze governance level and efficiency are considered, and the significance of each factor's effects on these two measures are analyzed and compared. For this analysis, this paper chooses five indicators at different levels, and the descriptions of each indicator are as follows.

(1) Economic growth (*pgdp*). Economic growth is measured by GDP per capita. According to the environmental Kuznets curve (EKC) hypothesis, environmental pollution is accelerated by economic growth, presenting an inverted U-shaped change trend. However, experience shows that China remains on the left side of the EKC. Under the traditional extensive development model, the rapid economic development in North China will aggravate the emission of haze pollutants, which is not conducive to the improvement of haze governance efficiency and level. On the other hand, the rapid development of the economy will enable local cities to have sufficient money to invest in haze pollution control, which would improve the level and efficiency of haze pollution control. Therefore, the expected coefficient of this factor is uncertain.

(2) Industrial structure (*is*). The industrial structure determines the proportion of the secondary industry in GDP. The industrial structure is closely related to haze pollution. Rapidly advancing industrialization, to a certain extent, has promoted the economic development of North China. However, some of the steel, coking, energy, and heavy chemical enterprises that were established also brought serious pollution to the environment and were harmful to the physical and mental health of residents, hindering the haze management level and efficiency. Thus, these factor coefficients are expected to be negative.

(3) Level of openness (*fdi*). The actual amount of foreign capital used to represent FDI is selected, and the actual exchange rate for each year is converted into RMB. Studies have shown (Chen, 2009; Zhou et al., 2019) that FDI expansion has two effects on the ecological environment: pollution shelter (negative) and pollution halo (positive). Since the reform and opening-up of China, North China has achieved rapid economic development, and opening up to the outside world has become an indispensable and important factor for solving the environmental problems in North China. Therefore, the sign of the expected coefficient of this factor is uncertain.

(4) Population density (*ds*). To avoid the incompatibility caused by the large differences in the areas and population sizes of each district, this paper chooses the value of population per unit area to measure the population density. At the same time, an increase of population density means that people's production and living activities between regions are more intensive, increasing pollutant emissions, exacerbating haze pollution, and hindering the improvement of haze governance level and efficiency (Tong and Wang, 2014). Therefore, the expected coefficient of this factor is negative.

(5) Urban built-up area ratio (*js*). The ratio of urban built-up area to urban area is selected to represent this factor. In general, built-up areas tend to have high levels of energy

Received: 2020-05-28 **Accepted:** 2020-08-02
Foundation: The National Social Science Foundation of China (17BJY038).
First author: XIAO Qinlin, E-mail: x853903799@163.com
***Corresponding author:** XIAO Liming, E-mail: xiaolm1972@163.com

Citation: XIAO Qinlin, TIAN Chao, WANG Yanjun, et al. 2020. Measurement and Comparison of Urban Haze Governance Level and Efficiency based on the DPSIR Model: A Case Study of 31 Cities in North China. *Journal of Resources and Ecology*, 11(6): 549–561.

consumption and land exploitation, resulting in more pollutants and reduced air quality. Correspondingly, with the expansion of the built-up area, the regional vegetation will also be destroyed, resulting in the weakening of environmental carrying capacity and purification capacity, trends which are not conducive to the improvement of haze governance level and efficiency. Therefore, this factor is expected to have a negative sign.

It should be noted that the original data of the above socio-economic indicators are all from China Urban Statistics Yearbook, China Urban and Rural Construction Statistics Yearbook and China Regional Economic Statistics Yearbook. The descriptive statistical analysis of each variable is shown in Table 4.

Table 4 Descriptive statistics of the main variables

Variable	Variable name	Unit	Observations	Mean	S.D.	Minimum value	Maximum value
hgl	Haze governance level	–	310	0.35	0.12	0.177	0.87
hge	Haze governance efficiency	–	310	1.16	0.31	0.484	2.66
pgdp	GDP per capita	yuan $person^{-1}$	310	48973.99	46015.47	8395	371725
is	Proportion of secondary industry	%	310	51.74	8.30	27.87	73.71
fdi	Actual utilization of foreign capital	$\times 10^4$ yuan	310	228000	245000	1328.46	1300000
ds	Population density	person km^{-2}	310	4467.28	3429.06	248	12968
js	Proportion of construction land in urban area	%	310	13.15	14.21	0.67	97.18

To eliminate heteroscedasticity, a logarithmic transformation is applied to each variable[1]. Before panel regression, the applicability of the model should be tested first. Here, the Chow and Hausman tests indicated that selecting the individual fixed-effect variable-intercept panel data model is reasonable. Furthermore, regression was performed with Stata 15.1 software (Table 5), and the results led to the following observations.

Table 5 Analysis of factors affecting the level and efficiency of haze governance

Variables	ln *hgl*		ln *hge*	
	Regression coefficient	*T* statistic	Regression coefficient	*T* statistic
C	0.2759**	2.35	0.4642	0.74
ln *pgdp*	−0.0141***	−3.48	−0.0786***	−3.63
ln *is*	0.0530**	2.19	0.1264	0.98
ln *fdi*	−0.0067**	−2.15	0.0174	1.04
ln *ds*	0.0052	1.09	−0.0125	−0.49
ln *js*	−0.0008	−0.14	−0.0604**	−2.02
R^2	0.0935		0.0723	
F-statistic	5.65		4.27	
Prob(*F*-statistic)	0.0000		0.0000	
N	310		310	

Note: *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

(1) Among the indicators of economic growth (ln *pgdp*), per capita GDP has a significant negative effect on haze governance level and efficiency. All cities in North China are on the left side of the EKC, indicating that the rapid economic growth will aggravate environmental pollution, thereby inhibiting the level and efficiency of haze governance. The reason for this result is that in cities in North China the proportion of coal consumption is too high and the energy consumption structure is unreasonable, both of which hinder the improvement of governance level and efficiency. This finding also shows that the haze pollution in North China has not been "decoupled" from economic development. In the process of managing the economic development in the future, increasing the investment of haze governance and promoting the win-win situation between economic growth and environmental protection should also be the priorities for North China.

(2) For the index of industrial structure (ln *is*), the proportion of the secondary industry is significantly positively correlated with the haze governance level, indicating that adjusting the industrial structure will promote the improvement of haze governance level, which is contrary to expectations. The reason for this result is that the transformation of urban industrial structure from the traditional secondary industry dominated by "three high" to the green, clean, and high value-added emerging tertiary industry will also reduce resource consumption and pollutant emission. Thus, the improvement of haze governance level will be promoted. However, the regression results of haze governance efficiency show that the proportion of the secondary industry is positively correlated with it, but not significantly. This finding indicates that the optimization and upgrading of the industrial structure have improved the utilization efficiency of resources and energy to a certain extent, greatly reducing the output of the haze governance system, against expectations. Thus, continuous power for transforming the effectiveness of haze governance is provided. However, some time will be needed to transform the input–output efficiency of haze governance, which cannot produce significant results in the short term.

(3) Regarding the level of opening to the outside world index (ln *fdi*), the haze governance regression results show that the level of opening up has reached the level of significant inhibition. This finding confirms the existence of the North China "pollution haven" hypothesis, that foreign direct investment would make the high pollution industries transfer to the host country among developed countries, damaging the ecological environment. In addition, in the process of introducing foreign capital, cities are more inclined to choose foreign-funded enterprises with low cost and high added value that are prone to high environmental pollution generation. If the environmental entry threshold is also relatively low, these cities will easily become the pollution shelters of these enterprises, which is not conducive to the improvement of regional haze governance. The results of the governance efficiency analysis show a positive correlation between opening up and haze governance efficiency, but it is not significant. This finding indicates that the increase of foreign direct investment has brought advanced environmental governance technologies and management experience to the local area, which has promoted the improvement of haze governance efficiency to some extent. However, time is needed to adjust the local adaptation and integration of these experiences and technologies, which will not produce immediate effects in the short term.

(4) For the index of population density (ln *ds*), the regression results of haze governance level show that population density has a positive effect on promoting it, but this effect is not significant, which is inconsistent with expectations. One possible explanation is that the increase in the population density was beneficial to the improvement of the regional human capital. A higher level of human capital accumulation results in stronger haze in a city where the governance body is integrating new technology, new products, new ideas and knowledge innovation abilities. These changes will speed up regional haze governance technology diffusion and improve haze governance. However, this process needs long-term accumulation to fully realize its proper role in the promotion of haze governance. Population density increase has a negative impact on the regression results of governance efficiency, which is consistent with expectations, but it fails to pass the significance test. The reason for this result is that the scale effect caused by the increase of population will lead to increases of energy and consumption demands, increasing the emission of pollutants and lowering the efficiency of haze governance.

(5) As for the proportion of construction land area (ln *js*), the ratio of construction land area has negative effects on haze governance level and efficiency. The former fails to pass the significance test, whereas the latter does pass the test, which is consistent with expectations. One possible reason lies in the rapid development of the construction industry in all cities in North China. On the one hand, the construction industry occupies a large amount of land area. On the other hand, construction also introduces considerable dust into the urban atmosphere, thereby degrading the urban environment. With these factors combined, controlling the haze in various cities is difficult, inhibiting the improvement of haze governance level and efficiency. Notably, due to the large spatial differences among cities in North China, the construction land area ratio does not have a significant impact on haze governance level.

5 Conclusions

Haze governance is an important way to transform China's approach to ecological governance and a key link in environmental protection. Based on the DPSIR model using data from 31 cities in North China from 2007 to 2016, the haze management level and efficiency show the following characteristics. 1) In North China cities, haze management level and efficiency show a wave of decline overall, with obvious characteristics of different stages. The haze governance level marked a turning point before the governance efficiency, the governance efficiency is far higher than the level of management, and it achieved the DEA effective state, guaranteeing haze governance efficiency in the future. Thus, the level of haze governance should be a major focus of the cities of North China. 2) Significant spatial differences occur in haze governance level and efficiency. The haze governance level presents a convex distribution pattern of "east low–middle high–west low," whereas haze governance efficiency presents a concave distribution pattern of "east high–middle low–west high." The number of cities with moderate level in haze governance is significantly higher than the number with moderate level. 3) The effects of various factors on haze governance level and efficiency are not the same. Among these factors, economic growth and the level of opening to the outside world have significant negative effects hindering haze governance, whereas industrial structure has significant positive effects promoting it. However, economic growth and the proportion of construction land have significant negative effects on haze governance efficiency.

On these bases, the following suggestions are proposed.

First, considering that the haze governance level and the overall governance efficiency are not high, cities should continue to optimize their industrial structure based on supply-side structural reform in the future and promote the transformation of the economic development mode to an intensive and ecological process. Therefore, each stake-

[1] Since the haze governance level measured in this paper based on entropy value method is all less than 1, negative results will appear when the logarithm is taken. Therefore, referring to relevant research (Hao et al., 2018), the overall measurement result is shifted to the right by 1 unit, and then the logarithm is taken.

holder should adopt active and effective adjustments to fundamentally curb the trend of increasing haze pollution. We will establish and improve a governance community featuring government supervision, self-inspection by enterprises and public supervision by the media, accelerate the transformation from a single governance model dominated by the government, and ensure that all parties participate and coordinate in the governance. These steps will also create a new situation of public co-governance featuring "breathing together and striving together," and we will attempt to make the inflection points of the governance level and efficiency appear in advance.

Second, according to the spatial distribution characteristics of the haze governance level and efficiency, cities should strengthen mutual cooperation in the future, establish a regional joint prevention and control mechanism, and form a broad united front for environmental protection. The key is to promote the core technology of air pollution reduction, strengthen regional scientific research cooperation and exchanges, focus on energy conservation and emissions reduction technology research and development, establish effective punishments, and set the admittance threshold for enterprises of research and development of environmental protection facilities and high pollution. These steps will minimize the haze governance cost, ultimately achieving the control of compound haze pollution. Each city should also clarify the governance responsibilities, establish unified regional environmental management laws and regulations, and improve the ecological and environmental compensation mechanism. We will improve the joint prevention and early warning mechanisms for environmental pollution. Thus, when problems arise, cities can cooperate and form a synergy that is conducive to effective haze governance.

Third, according to the results of the analysis of various dimensions of DPSIR, the level and efficiency of haze treatment can be improved in the future in terms of driving force, pressure, state, impact, and response. Specific measures include the following. 1) Cities should be based on green development targets which include the transformation of the mode of their economic development. In particular, places such as Shanxi and Inner Mongolia with coal resource-based provinces should be prioritized, actively promoting the green transformation of their industrial structures. Economic development through innovative modes boosts the green transformation of local economic development, so that the haze promotes the efficiency of governance and provides economic support, helping to move the city over the EKC inflection point. 2) Top priorities include increasing investments in pollution prevention and control as well as research and development of clean technologies and using government research and development funds to shift to research and development of haze governance technologies. At the same time, active responses to the "The Belt and Road" initiative and stepped up foreign direct investment should allow these cities to better reflect the "halo effect of pollution." We also need to effectively adjust and optimize the mix of energy consumption and encourage the development of green, clean, and renewable energy sources as alternatives to traditional sources of energy, mainly coal. Supplementary economic measures should be adopted, when necessary, to speed up the green adjustment of the energy consumption structure. These measures include the collection of a resource tax on coal, a carbon tax, an environmental tax, and an emissions tax. 3) Each city should carry out energy conservation and emission reduction activities according to its own real situation for reducing pollutant emission and improving energy efficiency. For example, relevant departments can recommend the use of smart power terminals and conduct research and development on new materials to improve the insulation effect of buildings and achieve the emission reduction targets. We actively advocate low-carbon lifestyles such as "green travel" and "public transport" and promote emission reduction. 4) In areas where the population density is concentrated, attention should be paid to the professional skills training of environmental protection administrators so that they can further serve the work of haze governance.

References

Bai J H, Nie L. 2017. Is environmental decentralization really exacerbating haze pollution? *China Population*, *Resources and Environment*, 27(12): 59–69. (in Chinese)

Cai W, Li K, Liao H, et al. 2017. Weather conditions conducive to Beijing severe haze more frequent under climate change. *Nature Climate Change*, 7(4): 257–262.

Cao X, Yu J. 2015. Regional innovation efficiency in China from the green low-carbon perspective. *China Population*, *Resources and Environment*, 25(5): 10–19. (in Chinese)

Charnes A, Cooper W W, Rhodes E. 1978. Measuring the efficiency of decision making units. *European Journal of Operational Research*, 2(6): 429–444.

Chen G. 2009. The competition for FDI, environmental regulation, and pollution haven. *World Economy Study*, (6): 5–9, 45, 89. (in Chinese)

Chen L L, Jin L H. 2014. An improved fuzzy comprehensive evaluation method of eutrophication for lakes and reservoirs. *China Environmental Science*, 34(12): 3223–3229. (in Chinese)

Chen S Y, Wang J M. 2018. Evaluation and policy innovation of urban haze governance in China: Taking the Yangtze River Delta Area as an example. *China Population*, *Resources and Environment*, 28(10): 71–80. (in Chinese)

Chen Y Y, Ebenstein A, Greenstone M, et al. 2013. Evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River policy. *Proceedings of the National Academy of Sciences of the USA*, 110(32): 12936–12941.

Chu Z P, Liu C X, Zhu J. 2017. Evolutionary game analysis on cooperative governance of haze in Beijing-Tianjin-Hebei based on the logic of collective action. *China Population*, *Resources and Environment*, 27(9): 56–65. (in Chinese)

Dong X H, Hu Y L, Li W X. 2008. A international comparisons and historical analysis on China's environmental governance efficiency: Based on the model of DEA. *Studies in Science of Science*, 26(6): 1221–1230.

(in Chinese)

Fu P. 2018. The realistic path choice of urban haze management in the New Normal. *Manage World*, 34(12): 179–180. (in Chinese)

Fang Y L, Huang Z F, Zhang H, et al. 2014. The asynchronous phenomenon and relative efficiency of tourism resources in China: Taking the 31 provinces' panel data from 2001 to 2009 for an example. *Journal of Natural Resources*, 5(3): 280–288. (in Chinese)

Gan T, Wang Z L. 2018. Measurement on the efficiency of urban environment governance in the Yangtze River Delta Area. *Urban Problems*, (1): 81–88. (in Chinese)

Hao G C, Xu Y L, Zhang X M, et al. 2018. Spillover effect and decomposition of green economic performance of the city in the Yangtze River Economic Belt. *China Population*, *Resources and Environment*, 28(5): 75–83. (in Chinese)

Islam M, Pei Y H, Mangharm S. 2016. Trans-boundary haze pollution in southeast Asia: Sustainability through plural environmental governance. *Sustainability*, 8(5): 499. DOI: 10.3390/su8050499.

Jiang C H, Song Z Y, Feng Z. 2017. Haze governance and it's economic and social effect: An analysis of CGE model based on "Coal Restricted Area" policy. *China Industrial Economics*, (9): 44–62. (in Chinese)

Li S, Wei H, Ni X L, et al. 2014. Evaluation of urban human settlement quality in Ningxia based on AHP and the entropy method. *Chinese Journal of Applied Ecology*, 25(9): 2700–2708. (in Chinese)

Meng Q G, Du H T, Wang J Z. 2017. The analysis of local governments' behavior in haze control from the perspective of interest demand. *China Soft Science*, (11): 66–76. (in Chinese)

Shi Q L, Guo F, Chen S Y. 2016. "Political Blue Sky" in fog and haze governance — Evidence from the local annual "Two Sessions" in China. *China Industrial Economics*, (5): 40–56. (in Chinese)

Tone K. 2001. A slacks-based measure of efficiency in data envelopment analysis. *European Journal of Operational Research*, 130(3): 498–509.

Tone K. 2002. A slacks-based measure of super-efficiency in data envelopment analysis. *European Journal of Operational Research*, 143(1): 32–41.

Tong Y F, Wang Y Y. 2014. The interaction mechanism of urban population and haze in China. *Social Sciences of Beijing*, (5): 4–10. (in Chinese)

Wang J M, Yang W P, Yang L. 2016. Estimation of China's energy structure adjustment with the win-win goal constraints. *China Population*, *Resources and Environment*, 26(3): 27–36. (in Chinese)

Wang B, Hao F. 2015. Innovations in legislation on haze environmental responsibility: Perspective of modern environmental responsibility. *China Soft Science*, (3): 1–8. (in Chinese)

Wang Q, Li H F, Ao J H. 2018. Research on the evaluation index system of smog governance mechanism through Beijing-Tianjin-Hebei tripartite linkage. *Contemporary Economy & Management*, 40(3): 25–31. (in Chinese)

Wang Q, Guo F, Xu X Y, et al. 2012. The evaluation of urban environmental governance efficiency of China and its temporal-spatial changes study. *World Regional Studies*, 21(4): 153–162. (in Chinese)

Wang S J, Gao S, Chen J. 2020. Spatial heterogeneity of driving factors of urban haze pollution in China based on GWR model. *Geographical Research*, 39(3): 651–668. (in Chinese)

Yu B H, Lu C H. 2004. Application of DPSIR framework for analyses of sustainable agricultural development. *China Population, Resources and Environment*, (5): 68–72. (in Chinese)

Zhang L J, Li N, Qin Y C, et al. 2019. The low-carbon city evaluation and its spatial differentiation based on the DPSIR. *World Regional Studies*, 28(3): 85–94. (in Chinese)

Zhang J Q, Zhang L, Wang S, et al. 2017. Study on regional sustainable development efficiency measurement and influencing factors: Based on DPSIR-DEA Model. *China Population*, *Resources and Environment*, 27(11): 1–9. (in Chinese)

Zhou W J, Liu W L. 2016. Haze governance from the ecological civilization perspective. *Journal of Xinjiang University*: *Philosophy*, *Humanities & Social Sciences*, 44(5): 30–35. (in Chinese)

Zhou Z Q, Xia N X, Liang W G. 2019. FDI, independent innovation and haze pollution: Evidence from China. *R&D Management*, 31(2): 82–94. (in Chinese)

基于 DPSIR 模型的城市雾霾治理水平与效率的测度及比较——以华北 31 个城市为例

肖沁霖，田　超，王彦君，李秀清，肖黎明

山西师范大学经济与管理学院，山西临汾　041000

摘　要：在全面建成小康社会的决胜阶段，雾霾天气已成为美丽中国建设的一大障碍，因此提升雾霾治理水平及效率就成为其中的关键。本文基于 DPSIR 模型构建了雾霾治理水平及效率的指标体系，借助熵值法和超效率 DEA 模型分别测算了 2007–2016 年华北地区 31 个城市的雾霾治理水平与效率，从空间差异及影响因素方面对二者进行了比较分析，结果表明：(1) 考察期内华北地区城市雾霾治理水平及效率整体均呈现波动下降之态势，具有明显的阶段性特征；雾霾治理效率远高于其水平，且其均值达到了 DEA 有效。(2) 二者存在显著的地区梯度差异，雾霾治理水平呈现出"东低–中高–西低"的凸字型分布格局，而雾霾治理效率却呈现与之相反的"东高-中低-西高"的凹字型分布格局。(3) 就回归结果而言，经济增长对雾霾治理水平及效率具有负向阻碍作用；而产业结构则对雾霾治理水平及效率具有正向促进作用，但其对二者作用的显著性有所不同。本文据此针对性地给出了改进华北各市雾霾治理水平及效率的政策建议。

关键词：雾霾治理水平；雾霾治理效率；熵值法；超效率 DEA 模型