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Evaluation of Measures for Comprehensive Environmental Control in Beijing–Tianjin–Hebei Region

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Abstract: Within years of environmental governance, many comprehensive environmental control measures have been taken in the Beijing–Tianjin–Hebei region to cope with air pollution, water pollution, solid waste pollution, and ecological damages. These measures could be summarized as industrial restructuring, energy structure adjustment, transportation structure adjustment, land use structure adjustment, and green transformation of agriculture and rural areas. A questionnaire survey was conducted to distinguish the comprehensive benefits of these measures, and the comprehensive benefits were evaluated using a cloud model evaluation method. Result show that these comprehensive benefits are ranked from high to low as industrial restructuring, energy structure adjustment, transportation structure adjustment, land use structure adjustment, and green transformation of agriculture and rural areas. This method and the result can provide a scientific foundation for the selection of comprehensive control measures for treating multiple pollution media in the Beijing–Tianjin–Hebei region.
Keywords: comprehensive environmental control; air pollution; water pollution; solid waste disposal; ecological environment

1 Introduction

A comprehensive environmental governance of the Beijing–Tianjin–Hebei region is difficult to realize due to numerous severe challenges, including the need for pollution control of multiple media (e.g., atmosphere and water) and ecological improvements. The pollution sources in the region are complex and in this work, they were divided into three main categories: point source pollution from industry and factories, linear pollution from road traffic, and agricultural pollution in rural areas. The following five classes of comprehensive environmental control measures have been gradually developed in the region based on several years of environmental governance experience.

Industry: The key industry mixture adjustment measures include improving the intelligent industrial manufacturing capability and level, as well as developing high–middle industrial services. The discharge standards for the following end-emission sources have been strictly enhanced and controlled in the study region: the metal industry (e.g., iron and steel), non-ferrous metal industry, nonmetal industries, building material industry, and petrochemical and chemical industry. The building material industry must implement a high-level emission standard. Backward production technology should be replaced by advanced production technologies. High consumption of water and energy, as well as heavy pollution non-essential industries will be gradually shut down.

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Energy structure: The main adjustment measures for the energy structure involve limiting the total coal consumption and encouraging the use of natural gas, thus promoting an improvement in the corresponding ratio of total energy consumption and the extension of new energy sources. Raw, low sulphur coal is selected under these measures, and new coal-fired boilers are used to improve effectiveness. The crude-oil refining capacity is improved and high-quality fuel is offered. The natural gas pipeline network should be progressively improved; the harbor liquid natural gas (LNG) receiving capacity should be promoted; natural gas resources can be expanded by domestic production and overseas imports. The ratio of non-fossil energy use (i.e., hydropower, solar energy, and wind power) to the total energy consumption is also being promoted, which requires the development of local non-fossil energy and an increase in the new energy consumption capacity.

Transportation structure: The adjustment measures for transportation include increasing the proportional use of ships and rail freight as well as the use of high-standard automobiles or electric vehicles for passenger transport. The capacity of combining railway and ship transport is improved and enhanced under these measures. High-standard fuel vehicles are fully implemented, although in key cities, the subway is the main transport mode with electric vehicles as the auxiliary transport. Accordingly, the ratio of the number of electric passenger vehicles to the total number of vehicles is enhanced. Non-road traffic engineering and high pollutant emission vehicles are kept under surveillance. Electric vehicles will be used in airports, docks, and other locations in the future.

Land utilization structure: These adjustment measures involve the control of constructive land, land hardening, and the implementation of greening projects. Land utilization should be reasonable under these measures. Greening and landscaping of road areas are carried out, and air pollution self-purification systems and settling-out regions are expanded. Disruption to the natural ecology is refrained, and the restoration of the ecological systems of forests, woods, and meadows is undertaken as soon as possible. In addition, relatively loose areas of land should be hardened and shanty-towns should be modernized into comfortable living/leisure areas.

Rural areas: The green transformation measures for rural areas include 1) introducing suitable pollution treatment methods for the local environment (e.g., instead of transporting waste water and solid waste to nearby cities, they are treated by ecological method locally), 2) the controlled application of fertilizer to agricultural land according to season/rainfall and cost, 3) the controlled application of pesticides (including the prohibition of those with large residues) and promotion of highly efficient, harmless pesticides, 4) the replacement of traditional firewood with natural gas, 5) the utilization of agriculture straw as a resource or its return to the field, and the strict management of the open burning of straw, and 6) the implementation of natural gas transformation projects and the promotion of green energy in rural areas.

Environmental pollution has become a difficult and complex problem for the implementation of a coordinated development strategy in the Beijing–Tianjin–Hebei region. The benefits of the above comprehensive control measures have not yet been determined; hence, a systematic evaluation is required to assess their effectiveness and potential. The results of such a systematic evaluation will support the ability of the Chinese government to make precise and comprehensive decisions regarding these matters.

2 Research methods

The fuzzy evaluation method [1], analytic hierarchy process [2], and computational cloud model [3] can all be used to quantitatively evaluate environmental issues as a means of developing comprehensive control measures. In particular, the cloud evaluation method can transform qualitative evaluation into a quantitative model, and its hierarchy is unlimited. Moreover, the amount of data calculation in its process is relatively small. Therefore, the cloud evaluation method was used for the analysis of the Beijing–Tianjin–Hebei region. The steps involved in this method can be summarized as qualitative to quantitative calculations, raindrop to low-level cloud, and low- to high-level cloud, as discussed in Sections 2.1–2.3.

2.1 Qualitative to quantitative calculation

Assuming that there are n number of qualitative evaluation factors (R), the *i-th* evaluation factor is expressed as R_i, and m is the hierarchy level. The double-labeling constraint method was applied to determine the qualitative variables of the cloud model. $E_{x(\text{remark})}$ and $E_{n(\text{remark})}$ express the remark expectation and entropy of the cloud model, respectively, according to Eqs. (1) and (2). Usually, the variance of the cloud model threshold is expressed by a constant, K [4], which is assumed to be equal to the excess entropy of the cloud model, $H_{e(\text{remark})}$ (Eq. 3). The effectiveness is then represented by the expectation value.

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$$E_{x(\mathrm{remark})} = \frac{1}{2}(V_{\max} + V_{\min}) \tag{1}$$

$$E_{n(\mathrm{remark})} = \frac{1}{6}(V_{\max} - V_{\min}) \tag{2}$$

$$H_{e(remark)} = K \tag{3}$$

where V_{max} and V_{min} are the maximum and minimum values of that same level, respectively, which $V_{\max}$ and $V_{\min}$ are obtained from expert investigation; therefore, $E_{x(\mathrm{remark})}$ and $E_{n(\mathrm{remark})}$ could be calculated by equation (1) and (2).

2.2 Raindrop to low-level cloud

Here, it is assumed that the remarks of t experts were obtained. As $E_{x(\mathrm{remark})}$, $E_{n(\mathrm{remark})}$, and $H_{e(\mathrm{remark})}$ are qualitative values, they were converted into quantitative indexes. The cloud generator for the qualitative evaluation was set to solve this question [5], and the quantitative expectation (E_x), the quantitative entropy (E_n), and quantitative excess entropy H_e values were calculated. The effectiveness of each environmental control measure was determined and ranked based on these calculated values.

$$E_x = \frac{E_{x1}E_{n1} + E_{x2}E_{n2} + \cdots + E_{xt}E_{nt}}{E_{n1} + E_{n2} + \cdots + E_{nt}} \tag{4}$$

$$E_n = E_{n1} + E_{n2} + \cdots + E_{nt} \tag{5}$$

$$H_e = \frac{H_{e1}E_{n1} + H_{e2}E_{n2} + \cdots + H_{et}E_{nt}}{E_{n1} + E_{n2} + \cdots + E_{nt}} \tag{6}$$

2.3 Low- to high-level cloud

A high-level cloud model was set to extract and summarize multiple low-level results. The weights of all treatments were assumed to be of equal value, and the superior cloud model expectation and entropy were calculated by Eq. (4) and (5), respectively. The expectation and entropy for the high-level cloud model was calculated in the same way, thus providing solutions for multiple levels. The five classes of governance measures in the low-level cloud, namely industry mixture adjustment, energy structure adjustment, transportation structure adjustment, land-use structure adjustment, and rural area green transformation, were then ranked by comparing the expectation and entropy. The flow diagram of the evaluation of the environmental governance measures is shown in Fig. 1.

3 Effectiveness analysis of comprehensive environmental control measures

3.1 Evaluation of control measures for single medium pollution

The evaluation of the effectiveness of the comprehensive environmental control measures was based on the expectation values. The higher the expectation, the more effective the control measure. The comprehensive environmental control measures were divided into five categories: atmospheric environment, water environment, solid waste, ecological environment, and economic benefits. Each attained effectiveness was rated into one of five levels: poor, relatively poor, normal, acceptable, or good. Experts and scholars in the corresponding research fields were consulted through questionnaires, and the cloud evaluation model was used for the data calculation and sorting. As mentioned, there were five categories of environmental governance measures (Table 1), and it was assumed that each measure could achieve the same effectiveness. Therefore, the weight of each environmental media—atmospheric environment, water environment, solid waste treatment, and ecological environment—was set at 0.25.

The main process for the cloud model evaluation was as follows. First, Eqs. (1), (2), and (3) were used to calculate the expectation, entropy, and excess entropy, respectively, of the quantitative cloud model based on the qualitative evaluation results of the questionnaires answered by experts. Second, Eqs. (4), (5), and (6) were used to calculate the quantitative expectations, entropy, and excess entropy, respectively, of the cloud model at low and high levels. The expectation value was used to express the real effectiveness of each governance measure. The evaluation of the governance measures for each single medium pollution category (i.e., environmental media) was obtained by cloud model calculations and sorting. The calculation results are shown in Table 1.

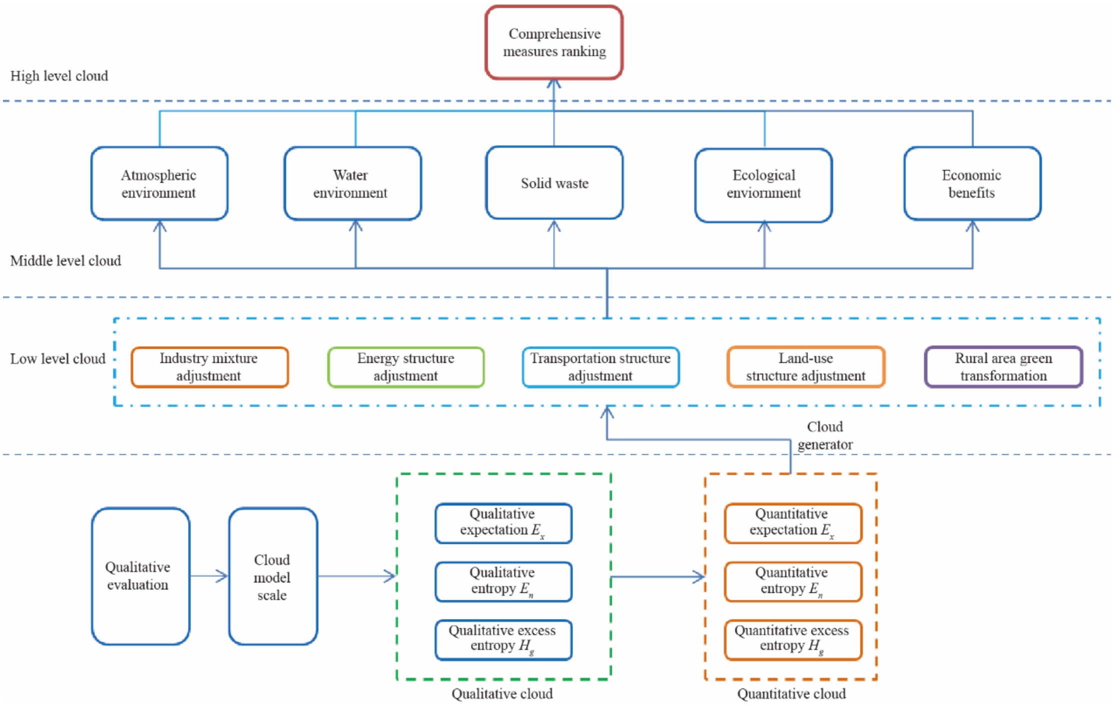

Fig. 1. Flow diagram of the evaluation of environmental governance measures.

Table 1. Evaluation of governance measures for single medium pollution.

Governance measures	Atmospheric environment	Water environment	Solid waste treatment	Ecological environment
Industry mixture adjustment	0.66	0.74	0.79	0.48
Energy structure adjustment	0.78	0.66	0.58	0.29
Transportation structure adjustment	0.54	0.26	0.36	0.32
Land-use structure adjustment	0.22	0.36	0.52	0.70
Rural area green transformation	0.33	0.33	0.37	0.48

The expectation values of the governance measures for single medium pollution are regarded as their contributions to the different media (Table 1). The contribution of each governance measure to the atmospheric environment is, in decrescent order of effectiveness: energy structure adjustment, industry mixture adjustment, transportation structure adjustment, rural area green transformation, and land-use structure adjustment.

For the water environment, the contributing sectors are, in decrescent order of effectiveness: industry mixture adjustment, energy structure adjustment, land-use structure adjustment, rural area green transformation, and transportation structure adjustment. It can be inferred from these findings that the adjustment of the energy structure directly reduces water consumption and indirectly reduces the discharge of wastewater from energy production. In addition, the adjustment of the land-use structure indirectly affects wastewater by modifying discharge standards. Agricultural and rural water pollution are relatively controllable in rural areas; hence, their contributions were relatively small compared to the other governance measures.

The effectiveness of each governance measure for solid waste treatment was ranked as: industry mixture adjustment, energy structure adjustment, land-use structure adjustment, rural area green transformation, and transportation structure adjustment. Thus, the results suggest that land-use structure adjustment indirectly reduces solid waste by changing the land-use attribution. The adjustment of the transportation structure is not related to a considerable amount of solid waste; hence, its contribution was relatively small.

The effectiveness of each measure for the ecological environment was ranked as: land-use structure adjustment, industry mixture adjustment, rural area green transformation, transportation structure adjustment, and energy

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structure adjustment.

3.2 Evaluation of measures for multi-media pollution control

As mentioned, the cloud model was used to judge the effectiveness of the five classes of governance measures (Table 1) for the atmospheric environment, water environment, solid waste treatment, and ecological environment. After the effectiveness of each governance measure was estimated for the single sources (Section 3.1), the effectiveness of comprehensive governance measures for the four environmental media were also evaluated using the same model, and the multi-media expectation values were obtained. Similarly, the economic benefits of environmental governance measures were also determined using the cloud model expectations.

Enterprises are a major factor influencing the environment. Therefore, environmental governance should be established on the basis of industrial economy and should include economic benefits. A statistical analysis showed that the average enterprise investment in environmental protection is between 5% and 10% of the annual enterprise expenses. However, there are also investments for land-use structure adjustment, ecological environment improvement, and other environmental-related issues. Therefore, the indirect costs of comprehensive environmental governance represent approximately 15% of the annual enterprise expenses. Consequently, the weight of comprehensive environmental governance is 0.15 compared to 0.85 for the industrial economics. The effectiveness of comprehensive governance measures on environmental multi-media pollution was evaluated by the cloud model, and the results are shown in Table 2.

Table 2. Effectiveness and benefits of governance measures on multi-media pollution.

Governance measures	Comprehensive governance	Economic benefits	Comprehensive benefits
Industry mixture adjustment	0.67	0.78	0.76
Energy structure adjustment	0.58	0.66	0.65
Transportation structure adjustment	0.37	0.66	0.62
Land-use structure adjustment	0.45	0.52	0.51
Rural area green transformation	0.38	0.24	0.26

The results in Table 2 show that the contribution of governance measures were ranked as: industry mixture adjustment, energy structure adjustment, land-use structure adjustment, rural area green transformation, and transportation structure adjustment. The economic benefits were ranked as: industry mixture adjustment, energy structure adjustment, transportation structure adjustment, land-use structure adjustment, and rural area green transformation.

The distribution of the comprehensive governance measures must be distinguished from the corresponding expectations. Therefore, the expectations were classified into dominant ($E_x > 0.7$), important ($0.7 > E_x > 0.5$), middle ($0.5 > E_x > 0.3$), auxiliary ($0.3 > E_x > 0.1$), and common ($E_x < 0.1$) measures. Correspondingly, the economic benefits were divided into highest, high, middle, low, and lowest levels. The effectiveness of comprehensive governance measures is closely related to the economy. Therefore, the effectiveness of measures and economic benefits were evaluated using the cloud model. The economic expectation for each comprehensive governance measure was estimated, and the effectiveness of each measure for multi-media was then determined. Subsequently, the economic and environmental variants of the comprehensive governance measures were sorted according to the corresponding expectation. The results of the effectiveness of the comprehensive governance measures are shown in Table 3.

The results in Table 3 reveal that the important environmental governance measures were for industry mixture adjustment and energy structure adjustment. The middle measures included transportation structure adjustment, land-use structure adjustment, and rural area green transformation. The results suggest that actions toward industries can benefit the atmospheric and water environments as well as solid waste treatment. In addition, the results indicate that adjustments to the energy structure can also benefit these categories, although the calculated effectiveness was lower than that for industry mixture adjustment. The transportation structure adjustment was determined to be preferable for the atmospheric environment; however, the effectiveness was low for other media. Moreover, land-use structure adjustment was found to be preferable for the ecological environment, which is because it restrains wastewater discharge and solid waste disposal by changing land-use attributions. Finally, rural area green transformation was determined to be preferable for the atmospheric environment, water environment, and ecologic environment.

Table 3. Classification and sorting of the effectiveness of comprehensive environmental governance measures.

Governance measures	Atmospheric environment	Water environment	Solid waste treatment	Ecological environment	Comprehensive governance	Economic benefits	Benefit ranking
Industry mixture adjustment	Important	Dominant	Dominant	Middle	Important	Highest	1
Energy structure adjustment	Dominant	Important	Important	Auxiliary	Important	High	2
Transportation structure adjustment	Important	Auxiliary	Middle	Middle	Middle	High	3
Land-use structure adjustment	Middle	Middle	Important	Dominant	Middle	High	4
Rural area green transformation	Auxiliary	Middle	Middle	Middle	Middle	Lowest	5

Ecological benefits are important for a comprehensive environmental governance. The results in Tables 2 and 3 show that the economic benefits of different measures were quite different. Industry mixture adjustment was classified at having the highest economic benefit. Energy structure adjustment, transportation structure adjustment, and land-use structure adjustment were classified as having a high economic benefit, whereas rural area green transformation had a low economic benefit. The reason for these results is that industry mixture adjustments can generate economic development, and new industries that are focused on environmental protection can lead to high economic benefits. Energy structure adjustments can also generate high economic benefits through the development of green energy. Transportation structure adjustments can generate good economic benefits by promoting transportation efficiency and a low empty-loading ratio. Land-use structure adjustments can generate good economic benefits by offering more land for economic development. Finally, rural area green transformation generates economic benefits by improving agricultural methods and enhancing farmers' income. Agriculture is a smaller scale economy than industry in the study region; therefore, it offers a lower economic benefit compared to the other environmental governances. Nevertheless, agriculture offers high social benefits.

On the premise of the comprehensive governance measures and associated economic benefits, the overall benefit rating of multi-media comprehensive governance measures range from high to low are as follows: industry mixture adjustment, energy structure adjustment, transportation structure adjustment, land-use structure adjustment, and rural area green transformation.

4 Evaluation results and technical feasibility analysis

4.1 Evaluation results

This work systematically evaluated the comprehensive environmental benefits of various measures by means of questionnaires. On this basis, feasible and comprehensive governance measures for the Beijing–Tianjin–Hebei region were proposed. The evaluation results for the comprehensive governance measures are summarized as follows:

(1) The effectiveness of the same governance measure varied for different environmental media. The dominant measure was also different for the various media. For instance, the dominant measure for the atmospheric environment was found to be energy structure adjustment, whereas it was industry mixture adjustment for the water environment. The dominant measure for solid waste treatment was determined to be industry mixture adjustment, whereas it was land-use structure adjustment for the ecological environment. The important or auxiliary measures also varied according to the different media.

(2) The evaluation results of the comprehensive governance measures showed that their distributions range from large to small are as follows: industry mixture adjustment, energy structure adjustment, land-use structure adjustment, rural area green transformation, and transportation structure adjustment. The important multi-media measures were found to be industry mixture adjustment and energy structure adjustment, whereas the middle measures were transportation structure adjustment, land-use structure adjustment, and rural area green transformation.

(3) By considering the industrial economic benefits, the benefits of the comprehensive governance measures for the multi-media are, from highest to lowest, in the following order: industry mixture adjustment, energy structure adjustment, transportation structure adjustment, land-use structure adjustment, and rural area green transformation.

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4.2 Feasibility analysis of comprehensive governance measures

According to the cloud model evaluation results for the Beijing–Tianjin–Hebei region, concrete and practical measures relating to the five governance measure categories were proposed. Then, the feasibilities of their subclass measures were evaluated for each environmental media, as shown in Table 4.

Table 4. Comprehensive governance measures (first and second levels) based on environmental technical feasibility.

First-level classification	Second-level classification	Targets			
		Atmosphere	Water	Solid waste	Ecology
Industry mixture adjustment	Promote green industry development	✓	✓	✓	✓
	Optimize industrial distribution	✓	✓	✓	
	Strictly control industries with high energy consumption and high pollution	✓	✓	✓	
	Abandon general manufacturing industries with high pollution	✓	✓	✓	
	Reduce overcapacity and eliminate outdated production capacity	✓	✓	✓	
Energy structure adjustment	Build a green energy system	✓	✓	✓	✓
	Reduce total coal consumption	✓	✓	✓	
	Strengthen the bulk coal market and the management and control of low-quality coal	✓		✓	
	Accelerate the comprehensive renovation of coal-fired boilers	✓	✓		
	Increase energy utilization efficiency	✓	✓	✓	
	Accelerate the construction of clean energy infrastructure	✓		✓	✓
	Effectively promote clean heating during the winter	✓	✓	✓	
	Increase the capacity to receive external electricity	✓	✓	✓	
Transportation structure adjustment	Optimize and adjust the structure of intercity transportation	✓			
	Vigorously promote vehicle electrification	✓			
	Improve the structure of urban transportation	✓			
	Enhance supervision of vehicles and tail gas	✓			
	Strengthen the control of emissions from ships and aircraft in ports and airports	✓	✓		
Land-use structure adjustment	Strengthen the protection of cultivated land, especially of basic farmlands	✓	✓	✓	✓
	Strictly control the scale of construction lands	✓	✓	✓	✓
	Reuse the land of "scattered and polluted" enterprises	✓	✓	✓	✓
	Continually promote the comprehensive improvement of open-pit mines	✓	✓	✓	✓
	Harden urban land and rehabilitate green land	✓	✓	✓	✓
Rural area green transformation	Develop water-saving agricultural practices		✓		✓
	Implement fertilizer-saving agricultural practices	✓	✓		✓
	Implement pesticide-saving agricultural practices	✓	✓		✓
	Control fecal pollution	✓	✓	✓	
	Implement the comprehensive utilization of straw	✓		✓	✓
	Implement plastic film recycling			✓	
	Strengthen ecological and circular agriculture	✓	✓	✓	✓

Table 4 presents the first and second level measures that were associated with each media. Some second level measures simultaneously affected the atmospheric, water, solid waste, and ecological media, such as promoting green industry development, building a green energy system, and strengthening ecological and circular agriculture. The results revealed that land-use structure adjustment directly and indirectly affected all four media, whereas some measures were only effective for a single media; for example, improving the structure of urban transportation and implementing plastic film recycling. Therefore, the use of comprehensive governance measures that are useful for multiple media should be carefully considered because they might improve the efficiency of comprehensive environmental governance measures.

The use of appropriate comprehensive environmental governance measures for local conditions can improve environmental governance in the Beijing–Tianjin–Hebei region. Several benefits can be achieved in the process of comprehensive environmental governance. Industry mixture adjustments can reduce pollution related to the atmosphere, water, and solid waste, and can also decrease the energy demand; hence, its benefits are higher than those of energy structure adjustment. However, energy structure adjustments can present a positive shift toward a clean energy system. Transportation structure adjustments are mainly aimed at air pollution control, whereas land-use structure adjustments aim to improve both air pollutant emissions and solid waste disposal. Rural area green transformation can be beneficial for managing air pollution, domestic sewage, and solid waste discharge in vast rural areas.

In conclusion, the comprehensive environmental governance measures presented in this work are feasible, and the analysis results represent accurate judgments for the selection of more effective measures for specific environmental pollution. The results can therefore help to improve the effectiveness of environmental governance.

5 Conclusions

The cloud model evaluation method can be used to qualitatively evaluate comprehensive environmental governance measures. The evaluation was conducted from a low- to high-level cloud, which indicates that the basic measures were evaluated before the higher level measures were evaluated. The measures were subsequently classified and their importance was adjusted according to the cloud model evaluation results. The cloud model was used to not only to evaluate the comprehensive governance measures toward single-medium pollution, but also to evaluate and grade multiple media measures, including atmospheric environment, water environment, solid waste disposal, and ecological environment. In the present study, two levels were included in the cloud model evaluation of the comprehensive environmental governance measures. However, more evaluation levels could be used to evaluate the dependency of the effectiveness of measures on the local requirements. The comprehensive evaluation results were relatively universal, and could therefore be applied to other areas of China in addition to the Beijing–Tianjin–Hebei region.

The environmental governance measures in China can differ from those of other countries as a result of regional differences. The cloud model used in the present study provides a guide for selecting accurate, feasible, and reasonable measures for specific environmental problems. The model results can be used to correctly distinguish comprehensive environmental governance measures between dominant, middle, or auxiliary levels. Moreover, the evaluation results are conducive for the implementation of efficient environmental governance by governments or enterprises. For example, measures that are simultaneously feasible and effective for multiple fields (i.e., atmosphere, water, solid waste, and ecology) include: promoting green industry development; building a green energy system; accelerating the construction of a clean energy infrastructure; strengthening the protection of cultivated land, especially of basic farmlands; strictly controlling the scale of construction lands; continually promoting comprehensive open-pit mines; hardening urban land and rehabilitating green land; and strengthening ecological and circular agriculture.

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