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# Assessment of the Efficiency of Synergistic Management of Urban Domestic Waste Management and Carbon Emission Reduction in China

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## Abstract

The development of domestic waste governance in terms of reduction, resourcing and low carbon is a necessary path to promote urban green development and achieve carbon neutrality. Using the DEA-BCC model and Malmquist index analysis, this paper evaluates the static and dynamic two-dimensional evaluation of the synergistic management efficiency of municipal domestic waste governance and carbon emission reduction in China from 2017 to 2022 at the inter-provincial level. The results show that (1) the spatial difference in waste governance and carbon emission reduction co-management efficiency is more significant at the provincial level, and this difference is related to factors such as different levels of economic development, policy effectiveness, industrial structure and population base among regions. (2) An important reason for the lack of significant improvement in co-management efficiency in recent years is the low transformation efficiency of new technologies in the field of domestic waste management and carbon emission reduction.

**JEL classification numbers:** Q50, Q53.
**Keywords:** domestic waste management, carbon emission, DEA-BCC model, Malmquist index analysis, co-management efficiency.

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# 1. Introduction

In recent years, with the rapid development of urban and rural construction and urbanization, China's municipal domestic waste production has continued to rise. According to the China Statistical Yearbook, China's municipal domestic waste production has reached 244 million tons in 2022 and is expected to reach 480 million tons in 2030(Ramachandra et al., 2018). At the same time, the process of handling MSW produces a large amount of greenhouse gases such as $CH_4$, $NO_X$, and $CO_2$, which seriously affects climate change. China's municipal waste management and ecological civilization are under great pressure. In response, the State Council of China issued the Peak Carbon Action Program by 2030 in October 2021, and the Ministry of Ecology and Environment and seven other departments jointly issued the Implementation Plan for Pollution Reduction, Carbon Reduction and Synergistic Enhancement in June 2022, which are committed to constructing a "1+N" policy system of peak carbon reduction and carbon neutrality, and make specific tasks for the synergistic management of pollution reduction, carbon reduction and synergistic enhancement. Specific tasks are required for the synergistic management of pollution reduction and carbon reduction. Therefore, driven by both reality and policy, there is an urgent need for a systematic assessment of the synergistic management efficiency of China's municipal waste management and carbon emission reduction, to reveal the problems and deficiencies in the current management environment, and to provide an optimal path for the development of waste management in a reduced quantity and low carbon manner.

The evaluation of the efficiency of synergistic management of domestic waste management and carbon emission reduction mainly involves the measurement of carbon emissions and efficiency assessment of domestic waste management. For the measurement of carbon emissions, the IPCC inventory guideline method and the Life Cycle Assessment (LCA) method are widely used in the academic field, and the IPCC inventory guideline method usually takes the country, region, province and city as the research objectives (Lou et al., 2017; Kumar et al., 2018; Liu et al., 2021). The IPCC Inventory Guide Method usually takes national, regional, provincial, and municipal as the research target, adopts source data of solid waste treatment or regional yearbook data as the research data, and uses the IPCC National Greenhouse Gas Inventory Guide Method as the research data (Cai et al.,2018; Du et al.,2017). The IPCC Inventory Guidelines for National Greenhouse Gas Emission Inventories provide a classification of carbon emission sources and greenhouse gas accounting methods to account for the GHG emissions from regional waste treatment (Xiao et al.,2021; Zhao et al.,2023). A long-term assessment of municipal solid waste management was conducted with an impact assessment limited to GHG emissions. The Life Cycle Assessment (LCA) methodology covers the entire life cycle of MSW management, measuring carbon emissions from collection, transport, waste treatment, infrastructure for waste treatment facilities, and production of ancillary materials, and is a more comprehensive approach that takes into account all aspects of waste management (Zhao et al.,2009). It is a more comprehensive approach to considering carbon emissions from the entire waste management process, including collection, transport, waste treatment, infrastructure of waste treatment facilities and production of ancillary materials (Assamoi and Lawryshyn, 2012). It is a more comprehensive way to consider the carbon emissions of the entire waste treatment process. However, in the calculation of regional carbon emissions, compared with the IPCC inventory guideline method, the LCA method is subject to the constraints of many regions and links involved in the whole process of waste treatment, which makes it more difficult to obtain the data, and the system boundary conditions are more uncertain, so its applicability is weaker. In terms of efficiency assessment, there are single indicator evaluation, indicator evaluation system method and model analysis (LIU et al., 2020). The three types of methods are indicator evaluation system method and model analysis (HUANG et al., 2018; Wang and Shi, 2018). The single-indicator evaluation is more targeted, and the model analysis is less applicable. Individual indicator evaluation is more targeted and only applies to individual projects or technologies, and is not applicable to the assessment of collaborative management efficiency. Indicator evaluation system method involves a wider scope and has a complicated internal system, which makes it difficult to scientifically adjust the balance of each indicator and assign parameters (YIN et al.,2011). The model analysis method is not suitable for evaluating the efficiency of collaborative management. Among the model analysis methods, Data Envelopment Analysis (DEA) can evaluate the relative efficiency of similar decision-making units with multiple inputs and outputs (Charnes et al., 1978). DEA has been widely used in the fields of environmental management and efficiency research (LIU et al., 2020; YANG et al., 2010; WANG and SHAO, 2012; Halkos and Petrou, 2019; Callao et al., 2019). DEA has been widely used in the fields of environmental management and efficiency research. In the specific efficiency evaluation, DEA can achieve the static study of regional management efficiency based on panel data, and at the same time, it can also explore the dynamic change of management efficiency through further analysis of Malmquist index (Yang et al., 2015; YANG et al., 2018). DEA is also able to investigate the dynamic change of management efficiency through further analysis of Malmquist index. In addition, there are fewer studies on the synergistic management efficiency of domestic waste management and carbon emission reduction in the current academic world. Based on the above factors, this paper adopts the IPCC guideline method to calculate the carbon emissions generated by municipal domestic waste treatment, and applies the DEA-Malmquist index analysis method to evaluate the synergistic management efficiency of municipal domestic waste governance and carbon emission reduction in China in the inter-provincial dimension, with a view to providing theoretical references on how to promote the synergistic governance of pollution reduction and carbon emission reduction.

# 2. Research methodology

## 2.1 Selection of indicators and data sources

Considering comprehensively the three major links involved in the process of domestic waste treatment, namely source collection, intermediate transfer and end treatment, as well as the social and environmental impacts, and the scientific nature of the indicators, the indicators selected in this paper finally include five inputs and three outputs (ZHOU and CHEN, 2012), and the social and environmental impacts, as well as the scientific nature of the indicators and the availability of data, the indicators selected in this paper finally include five inputs and three outputs (Table 1). Among them, the amount of rubbish removal reflects the source collection link, the number of rubbish removal vehicles and the number of sanitation workers reflect the intermediate transfer link, the investment in fixed assets for municipal waste treatment and the inverse scale transformation index of net carbon emissions (obtained by inverse transformation and scale transformation of net carbon emissions to ensure that all the outputs are positive outputs) reflect the end treatment link, and the number of existing effective municipal waste management policies in inter-provincial years reflects the policy capital inputs, and the number of urban population density and the number of urban waste management policies currently in force reflect the policy capital inputs. reflecting policy capital inputs, and urban population density and road sweeping area reflecting the overall environment and level of urban development.

**Table 1: Evaluation index system for efficiency of synergistic management of municipal domestic waste management and carbon emission reduction**

| Form | Indicator name |
|---|---|
| **Throw oneself into** | Number of rubbish removal vehicles |
| | Number of sanitation workers |
| | Investment in fixed assets for municipal waste disposal |
| | Number of existing and effective policies on municipal waste management during the year |
| | Urban population density |
| **Outputs** | Rubbish removal |
| | Inverse Scale Transformation Index for Net Carbon Emissions |
| | Road sweeping area |

This paper is an assessment of management efficiency carried out at the inter-provincial level, and for the regional differences in the DEA static analysis, the paper is divided into five major regions based on the geographical location of the provinces. Northern region: Inner Mongolia, Liaoning, Jilin, and Heilongjiang. Central region: Beijing, Tianjin, Hebei, Shanxi. Eastern region: Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei. Southern region: Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan. Western region: Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang,

The research data (excluding the number of policies) was obtained after collation and calculation based on China Statistical Yearbook (2018-2023), China Urban Construction Statistical Yearbook (2017-2022), and China Population and Employment Statistical Yearbook (2018-2023), while the data on the number of inter-provincial urban domestic waste management policies was obtained from the Peking University magic weapon database.

### 2.2 Calculation of Carbon Emissions from Municipal Domestic Waste Treatment

This study takes the IPCC waste treatment carbon emission accounting model as a specific framework, taking into account the specific availability and complexity of the data and the wide range of the study area, and mainly accounts for the greenhouse gases generated from landfill and incineration treatment (in the official data, the amount of composting of domestic rubbish in each province is not classified in the statistics and accounts for a small proportion of the treatment volume, so it is not included in the accounting), and the greenhouse gases generated from the waste transfer are not included in the accounting system. Indirect GHG emissions from waste transfer are not included in the accounting system. Secondly, due to the offsetting effect of waste incineration and power generation on GHG emissions, this study defines the carbon emissions from landfill and incineration as the total carbon emissions from waste treatment, the carbon emissions offset by incineration and power generation as the carbon emission offset, and the difference between the two as the net carbon emissions from waste treatment. In addition, in order to harmonize the GHG scales, non-$CO_2$ emissions were converted to $CO_2$ equivalent based on GWPs in this study.

**1)** Carbon Emissions from Municipal Domestic Waste Landfill Disposal.

The $CH_4$ produced during the landfill process is the main carbon source and is calculated according to equation (1) (Cai et al., 2018; Eggleston et al., 2006).

$$E_{CH_4} = \sum_{i=1}^{n} MCF_{LF} \times MCF \times DOC_i \times DOC_f \times (1-R) \times (1-OX) \times F \times \frac{16}{12} \qquad (1)$$

$E_{CH4}$ denotes the $CH_4$ emissions from landfilling of municipal domestic waste. $MCF_{LF}$ is the landfill volume, and $MCF$ is the $CH_4$ correction factor, and $DOC_i$ is the proportion of degradable organic carbon in component $i$ of the waste, and $DOC_f$ is the proportion of degradable organic carbon in waste, and $R$ is the $CH_4$ recovery rate, the $OX$ is the oxidation factor . $F$ is the proportion of $CH_4$ in landfill gas, and $\frac{16}{12}$ is the molecular mass ratio of $CH_4$ to C.

**2)** Carbon emissions from the incineration of municipal waste.
$CO_2$ from incineration calculated from equation (2) (Fan et al., 2023; Cui et al., 2021; Ding et al., 2021).

$$E_{CO_2} = MSW_F \times \sum_{i=1}^{n} W_i \times d_i \times CF_i \times FCF_i \times O_i \times \frac{44}{12} \tag{2}$$

$E_{CO_2}$ represents the $CO_2$ emissions from municipal domestic waste incineration, and $MSW_F$ represents the quantity of waste incinerated, and $W_i$ represents the proportion of component $i$ in waste, and $d_i$ represents the proportion of dry matter mass in component $i$, and $CF_i$ represents the proportion of carbon mass in component $i$, and $FCF_i$ represents the mass proportion of mineral carbon in component $i$ in the total carbon, and $O_i$ is the complete combustion efficiency of component $i$, and $\frac{44}{12}$ is the molecular mass ratio of $CO_2$ to C.

**3)** Carbon offsets
Carbon offsets for power generation from incineration are calculated according to equation (3) (Chen et al., 2020; Wang et al., 2021).

$$E_C = MSW_{LF} \times \frac{LHV}{3600Kj/kWh} \times R_e \times O_e \tag{3}$$

$E_C$ is the carbon offset for incineration power generation, and $LHV$ is the low heat bit value, and $R_e$ is the electric power generation recovery rate, and $O_e$ is the electricity $CO_2$ emission factor.

**4)** Calculation of net carbon emissions.
The warming potential of $CH_4$ is 25 times higher than that of $CO_2$ (Tian et al., 2011). Therefore, the net carbon emissions in this study were calculated according to equation (4).

$$E_{cl} = E_{CH_4} \times 25 + E_{CO_2} - E_C \tag{4}$$

$E_{cl}$ is net carbon emissions.

**5)** Inverse Scale Transformation Index for Net Carbon Emissions.
In the model analysis, net carbon emissions are inverted and indexed to ensure that all outputs are positive, as in equation (5).

$$E_{in} = \frac{1}{E_{cl}} \times 10^5 \tag{5}$$

$E_{in}$ is the inverse scale transformation index of net carbon emissions.

## 2.3 DEA-BCC model

There are two main basic models of DEA, CCR and BCC, the former assuming constant returns to scale and proportional changes in inputs and outputs, and the latter assuming variable returns to scale and taking into account scale effects (Charnes et al., 1978). The latter assumes variable returns to scale and takes into account the scale effect. For the evaluation of the efficiency of collaborative management of MSW management and carbon emission reduction in different regions, the scale efficiency cannot be ignored, so the BCC model is used in this analysis. The BCC model, by constructing the set of production possibilities and adopting the linear programming technique, identifies the maximum output of each decision unit under the given input conditions, or the minimum input under the given output conditions. By calculating relative efficiency values, the BCC model is able to identify efficient units located at the efficiency frontier and diagnose inefficient units, providing specific recommendations for improvement.

## 2.4 Malmquist exponential analyses

Malmquist exponential analysis is a non-parametric method for measuring changes in productive efficiency by comparing the displacement of the production possibilities frontier at different points in time. Its core lies in its ability to decompose total factor productivity (TFPCH) into changes in integrated technical efficiency (EFFCH) and changes in technical progress (TECHCH), and to decompose changes in integrated technical efficiency (EFFCH) into changes in pure technical efficiency (PECH) and changes in scale efficiency (SECH), to provide a more in-depth analysis of changes in and reasons for production efficiency at different points in time. In addition, combining the DEA-BCC model with the Malmquist index analysis method can provide a more comprehensive evaluation of the synergistic management efficiency of MSW governance and carbon emission reduction from both static and dynamic perspectives.

# 3. Management efficiency evaluation

## 3.1 DEA static model analysis

**1)** Analysis of the efficiency of synergistic management of municipal domestic waste management and carbon emission reduction.

This paper adopts the DEA method, selects the BCC variable returns to scale model, and analyses the efficiency of synergistic management of MSW governance and carbon emission reduction in 31 provinces in China from 2017 to 2022 with an input orientation (Figure 1). The study shows that the average comprehensive efficiency of the 31 provinces is 0.794, the average pure technical efficiency is 0.820, and the average scale efficiency is 0.966. It can be seen that, on the whole, the synergistic management efficiency of MSW governance and carbon emission reduction in China is higher, with a larger scale of investment in capital and equipment, and a higher level of resource allocation; however, as a decision-making unit, provinces still have a high level of efficiency in achieving the common goals of effective MSW management and carbon emission reduction under the common goal of achieving effective MSW management and carbon emission reduction, there is still a large space for technical improvement. In the DEA static model analysis, there are 11 provinces with effective integrated efficiency, namely Beijing, Inner Mongolia, Liaoning, Zhejiang, Anhui, Shandong, Guangdong, Chongqing, Tibet, Qinghai and Ningxia (Figure 1), accounting for 35.5% of the total number of cities studied. These 11 provinces constitute the frontier of synergistic management efficiency of MSW management and carbon emission reduction, and with the existing input resources and scale, can achieve the common goal of effective MSW management and carbon emission reduction. Under the existing input resources and scale, they are able to obtain corresponding results in the reduction of urban household waste and carbon emissions, as well as the greening of roads, and efficiently realize the output transformation of resources to inputs, which is of high reference significance in the synergistic management of urban household waste management and carbon emission reduction.

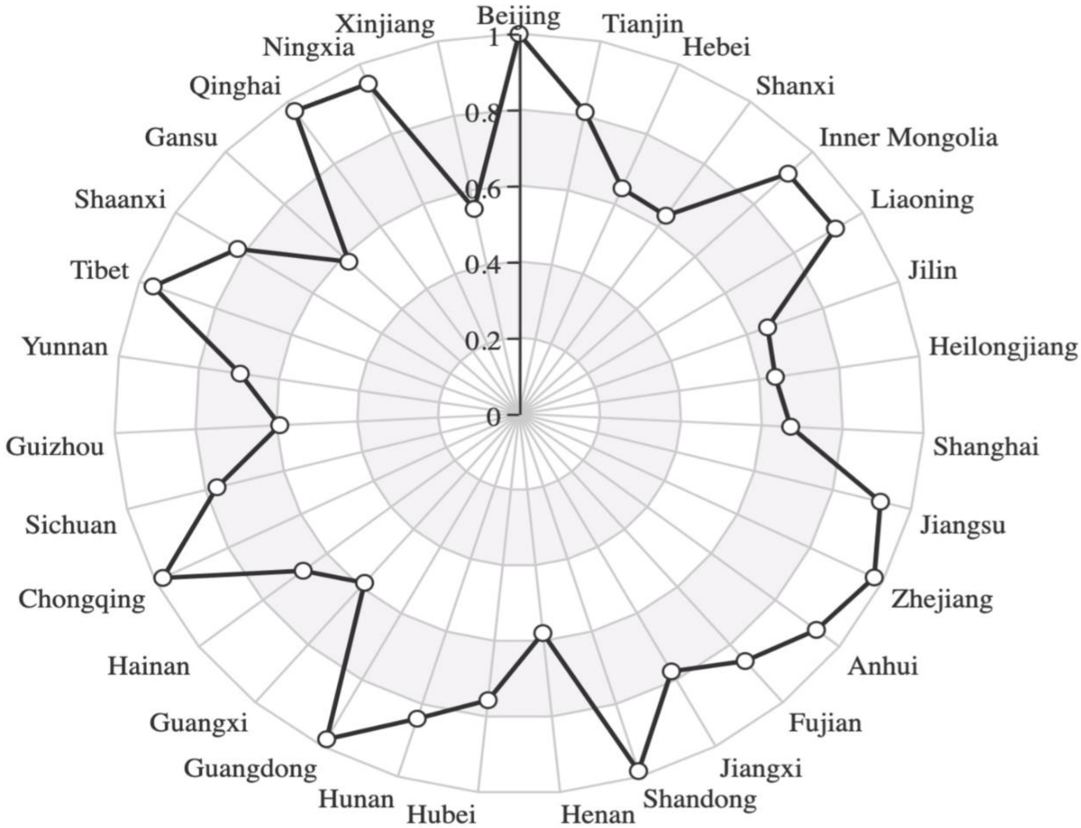


**Figure 1: Average Municipal Domestic Waste Management and Carbon Emission Reduction Synergistic Management Efficiency in China's Provincial Areas, 2017-2022**

**2)** Analysis of Regional Differences in the Efficiency of Synergistic Management of Municipal Domestic Waste Management and Carbon Emission Reduction.

In terms of regional differences (Table 2), in terms of the performance of each region in terms of average management efficiency and average pure technology management efficiency, the Eastern region > Western region > Northern region > Central region > Southern region, and in terms of an average perspective, the East and West regions are more mature in terms of technology application, which is higher than the national average, and the synergistic management efficiency of MSW management and carbon emission reduction is relatively high and exceeds the national average, while the central and north-south regions are below the national average. In terms of average scale efficiency, the average scale efficiency of each region is basically maintained at the national average level, with an upward and downward fluctuation of no more than 1 per cent, indicating that the efficiency of resource allocation in the synergistic promotion of MSW management and carbon emission reduction is extremely high. It can be seen that for most regions, the technical element is the main factor affecting the efficiency of synergistic management of MSW governance and carbon emission reduction. The eastern region, with its developed economy and perfect infrastructure, has significant advantages in technological innovation, management model optimization and policy implementation, such as Shanghai, Zhejiang, Jiangsu and Shandong, which all have relatively perfect waste classification and recycling systems, and the application of carbon emission reduction technologies is also relatively mature, so the efficiency of synergistic management of municipal waste management and carbon emission reduction is relatively high. Although the western region has a lower level of economic development than the east, based on the implementation of the 13th Five-Year Plan for the Development of the Western Region, the western region has invested more in infrastructure construction and environmental protection policies in recent years, and introduced a large number of advanced technologies and management experience, which has allowed waste management and carbon emission reduction to be vigorously promoted. The northern region has been in the process of revitalizing old industrial bases in recent years, and has always been facing the problems of industrial restructuring and resource allocation optimization, which requires technological upgrades and management innovations to improve the efficiency of synergistic management of municipal waste management and carbon emission reduction. The comprehensive management efficiency in the central and southern regions is lower than the national average, which is mostly attributed to two reasons: firstly, the relatively large population base in cities and the high amount of domestic waste generated, which makes the management of domestic waste more complicated and affects the management efficiency; and secondly, the imbalance of inter-provincial development, e.g., the average management efficiency in Beijing in the central region is 0.999, but in Hebei it is 0.645, and in Guangdong in the southern region it is 0.979, but in the southern region it is 0.979, which is 0.645. For example, in the central region, Beijing's average management efficiency is 0.999, but Hebei's is 0.645, and in the southern region, Guangdong's average management efficiency is 0.979, but Guangxi's is 0.586, and the imbalance of inter-provincial management efficiency has lowered the regional average. Taken together, the eastern and western regions should continue to improve the technical level of MSW management and carbon reduction at the current scale level. The northern, central and southern regions should focus on both technological upgrading and resource allocation in their subsequent development, and gradually realize the efficient transformation of resource inputs and outputs so as to improve the average management efficiency.

**Table 2: Regional differences in synergistic management efficiency of MSW management and carbon reduction**

| District (not necessarily formal administrative unit) | Average management efficiency | Average pure technical efficiency | Average scale efficiency |
|---|---|---|---|
| Northern part | 0.783 | 0.814 | 0.959 |
| Eastern part | 0.828 | 0.849 | 0.975 |
| Central section | 0.772 | 0.794 | 0.973 |
| Western part | 0.805 | 0.835 | 0.960 |
| Southern part | 0.765 | 0.791 | 0.960 |
| Nationwide | 0.794 | 0.820 | 0.966 |

### 3.2 Analysis of the dynamics of the Malmquist index

In order to provide a more comprehensive evaluation of the inter-provincial MSW governance and carbon emission reduction co-management efficiency in China, this paper uses the Malmquist index to dynamically analyze the MSW governance and carbon emission reduction co-management efficiency in China (Table 3).

**1)** Analysis of regional differences in management efficiency.

From the results in Table 3, it can be seen that during the period of 2017-2022, the provinces of Liaoning, Jilin, Zhejiang, Shandong, Hunan, Hainan, Yunnan, and Qinghai have seen an increase in technical efficiency and technological progress (EFFCH>1, TECHCH>1), and significant growth in technological progress in the field of synergistic management of municipal waste management and carbon emission reduction, which shows a good potential for development. Beijing, Tianjin, Heilongjiang, Shanghai, Jiangsu, Anhui, Henan, Guangdong, Sichuan, Chongqing and Xinjiang have seen a decline in technological progress (TECHCH<1) despite an increase in technological efficiency (EFFCH>1), suggesting that these provinces are doing a good job of optimizing the use of existing technologies, but still need to strengthen their technological innovation or technological upgrading. Shanxi, Inner Mongolia, Jiangxi, Hubei, Guangxi, Guizhou and Tibet show a slight decrease in technical efficiency (EFFCH<1) but an increase in technological progress (TECHCH>1), indicating that these provinces have done well in introducing new technologies but still have room for optimization in utilizing these new technologies to improve efficiency. Hebei, Fujian, Shaanxi, Gansu and Ningxia have seen a decline in both technical efficiency and technological progress (EFFCH<1, TECHCH<1), indicating that there is still much room for improvement in the synergistic management of MSW management and carbon emission reduction in these provinces, and that more improvement measures are needed in the allocation of resources and application of technologies as well as upgrading. Overall, most provinces have significant changes in technological efficiency and technological progress, and China's technological progress and application and management efficiency in MSW governance and carbon emission reduction have fluctuated considerably in recent years. Meanwhile, there are more significant regional differences in China's synergistic management of MSW governance and carbon emission reduction under the three perspectives of the EFFCH, TECHCH, and TFPCH indices, and each province should tailor their policies and focus on improving technical efficiency and technological progress in order to achieve the common goal of emission reduction and carbon reduction.

**Table 3: Efficiency of synergistic management of MSW management and carbon reduction in China, 2017-2022**

| District (not necessarily formal administrative unit) | EFFCH | TECHCH | PECH | SECH | TFPCH |
|---|---|---|---|---|---|
| Beijing | 1.000 | 0.864 | 1.000 | 1.000 | 0.864 |
| Tianjin | 1.000 | 0.916 | 1.000 | 1.000 | 0.916 |
| Hebei | 0.936 | 0.952 | 0.938 | 0.999 | 0.893 |
| Shanxi | 0.970 | 1.005 | 0.963 | 1.010 | 0.971 |
| Inner Mongolia | 0.980 | 0.944 | 0.986 | 0.994 | 0.922 |
| Liaoning | 1.030 | 1.067 | 1.004 | 1.026 | 1.121 |
| Jilin | 1.041 | 1.177 | 1.030 | 1.008 | 1.258 |
| Heilongjiang | 1.041 | 0.949 | 1.035 | 1.002 | 0.975 |
| Shanghai | 1.040 | 0.855 | 1.029 | 1.007 | 0.873 |
| Jiangsu | 1.001 | 0.991 | 1.000 | 1.001 | 0.993 |
| Zhejiang | 1.000 | 1.066 | 1.000 | 1.000 | 1.066 |
| Anhui | 1.014 | 0.990 | 1.011 | 1.002 | 1.002 |
| Fujian | 0.943 | 0.970 | 0.947 | 0.996 | 0.913 |
| Jiangxi | 0.997 | 1.005 | 0.992 | 1.002 | 1.000 |
| Shandong | 1.000 | 1.028 | 1.000 | 1.000 | 1.028 |
| Henan | 1.008 | 0.946 | 0.989 | 1.011 | 0.924 |
| Hubei | 1.042 | 0.962 | 1.045 | 0.997 | 1.002 |
| Hunan | 1.014 | 1.014 | 1.010 | 1.005 | 1.022 |
| Guangdong | 1.000 | 0.862 | 1.000 | 1.000 | 0.862 |
| Guangxi | 1.033 | 0.993 | 1.004 | 1.032 | 1.027 |
| Hainan | 1.073 | 1.301 | 1.013 | 1.024 | 1.318 |
| Chongqing | 1.000 | 0.965 | 1.000 | 1.000 | 0.965 |
| Sichuan | 1.001 | 0.945 | 1.007 | 0.994 | 0.948 |
| Guizhou | 1.036 | 0.995 | 1.038 | 1.000 | 1.028 |
| Yunnan | 0.998 | 1.070 | 0.995 | 1.001 | 1.073 |
| Tibet | 1.000 | 0.738 | 1.000 | 1.000 | 0.738 |
| Shaanxi | 0.980 | 0.972 | 0.975 | 1.003 | 0.949 |
| Gansu | 0.995 | 0.933 | 0.979 | 1.014 | 0.912 |
| Qinghai | 1.000 | 1.584 | 1.000 | 1.000 | 1.584 |
| Ningxia | 0.984 | 0.853 | 0.984 | 1.000 | 0.854 |
| Xinjiang | 1.016 | 0.995 | 1.027 | 1.029 | 0.992 |

**2)** Characterization of time-varying features.

Table 4 shows the year-to-year changes of each index in the synergistic management efficiency of MSW management and carbon reduction in China. Overall, the comprehensive technical efficiency change index develops from 0.998 to 0.999 from 2017 to 2022, with little change before and after, indicating that the efficiency of urban emission reduction and carbon reduction co-management improves limitedly during this period. Meanwhile, during this period, the technical progress index increases by 50.1%, the pure technical efficiency change index decreases by 2.5%, the scale efficiency index increases by 2.9%, and the total factor productivity index increases by 50.3%, indicating that technical progress is the main cause of the change in total factor productivity in 2017-2022, but due to the low effectiveness of the transformation of technology optimization and application, the technical progress as well as the increase in total factor productivity However, due to the low effectiveness of technology optimization and application transformation, technological progress and the increase in total factor productivity have not been fully transformed into an increase in the comprehensive technological efficiency change index, indicating that China has made remarkable achievements in technological innovation or technological upgrading in the field of carbon emission reduction and mitigation in recent years, but it has not achieved an efficient transformation of inputs and outputs by relying on new technologies, and that there is still a great deal of room for optimizing the use of new technologies to improve efficiency.

**Table 4: Yearly data on the efficiency of synergistic management of MSW management and carbon reduction in China, 2017-2022**

| Vintages | Composite technical efficiency change index | Technological progress index | Index of change in pure technical efficiency | Scale efficiency change index | Total factor productivity index |
|---|---|---|---|---|---|
| 2017-2018 | 0.998 | 0.921 | 1.016 | 0.980 | 0.922 |
| 2018-2019 | 0.967 | 0.915 | 0.955 | 1.019 | 0.881 |
| 2019-2020 | 1.069 | 0.856 | 1.035 | 1.029 | 0.901 |
| 2020-2021 | 0.994 | 0.911 | 1.003 | 0.990 | 0.909 |
| 2021-2022 | 0.999 | 1.382 | 0.991 | 1.008 | 1.386 |

## 4. Conclusion

By applying the DEA-BCC model and Malmquist index analysis to statically and dynamically analyze the synergistic management efficiency of MSW management and carbon emission reduction in China during the period of 2017-2022, the conclusions of this study are as follows.

1) China's municipal waste reduction and decarbonization management during the period 2017-2022 has seen a large scale of investment in funding and equipment overall, with resource allocation at a high level in all provinces.
2) In both static and dynamic analyses, there are significant spatial differences in the co-management efficiency of waste management and carbon emission reduction, which are reflected at the level of the five major regions and at the level of specific provinces. Different levels of economic development, policy effectiveness, industrial structure and population base among provinces are important factors leading to the spatial differences in co-management efficiency. In this regard, each region should take into account its own actual situation and formulate technical and management strategies according to local conditions in order to comprehensively improve the synergistic management efficiency of MSW management and carbon emission reduction.
3) In the dynamic perspective, the year-to-year change in the synergistic management efficiency of municipal domestic waste management and carbon emission reduction was relatively small during the period of 2017-2021, and the effect of the comprehensive waste classification policy, which started to be implemented in 2019, lagged behind, with a rapid increase in the technological progress index starting to appear during the period of 2021-2022, but the sustainability of this change has yet to be verified. In addition, changes in technological progress have not been fully translated into changes in total factor productivity due to the low effectiveness of technology optimization and application transformation, and the lack of efficiency in landing new technologies. Therefore, provinces should strengthen technological innovation and technological upgrading, optimize the application of technology, and enhance the transformation efficiency of resource inputs and outputs, so as to further improve management efficiency.

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