Postprint: Industrial Eco-efficiency in Beijing Based on Input-Output Tables

Authors: Wang Xue, Shi Xiaoqing

Date: 2018-05-10T00:00:00+00:00

Abstract

Improving eco-efficiency is crucial for coordinating the relationship between economic development and environmental protection. To understand the changing trends of eco-efficiency across various industrial sectors during Beijing' s industrial transformation and identify the key sectors influencing Beijing' s industrial eco-efficiency, this study employs the indicator system method based on Beijing' s input-output tables. Water resource efficiency and the environmental efficiency of wastewater, sulfur dioxide (SO2), and industrial solid waste were selected as metrics for eco-efficiency. The study calculated the water resource efficiency of each sector in Beijing for 2007, 2010, and 2012, as well as the environmental efficiency of each sector for 2005, 2007, and 2010. It also comparatively analyzed the complete water use coefficients and complete emission coefficients of pollutants across sectors, computed the mutual contribution ratios of complete emissions among sectors, and identified the key sectors for improving eco-efficiency. Research findings: (1) From 2007 to 2012, the water resource efficiency of various sectors in Beijing, and from 2005 to 2010, the environmental efficiency of wastewater, sulfur dioxide (SO2), and industrial solid waste exhibited an overall fluctuating upward trend. (2) Agriculture, forestry, animal husbandry, fishery, and waste scrap sectors are the key sectors for improving water resource efficiency. (3) Water production and supply industry, chemical industry, food manufacturing and tobacco processing industry, textile industry, and paper printing, cultural, educational, and sports goods manufacturing industry are the key sectors for improving wastewater environmental efficiency. (4) Petroleum processing, coking, and nuclear fuel processing industry, non-metallic mineral products industry, metal smelting and rolling processing industry, and electricity and heat production and supply industry are the key sectors for improving SO2 environmental efficiency. (5) Coal mining and washing industry, metal ore mining and dressing industry, wood processing and furniture manufacturing industry, non-metallic mineral products industry, metal smelting and rolling processing industry, electricity and heat production and supply industry,

and water production and supply industry are the key sectors for improving industrial solid waste environmental efficiency.

Full Text

Preamble

Industrial Eco-efficiency of Beijing Based on an Input-Output Table

WANG Xue[1,2], SHI Xiaoqing[1]

[1]State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China

[2]University of Chinese Academy of Sciences, Beijing 100049, China

Acta Ecologica Sinica, 2018, 38(8): 2660-2671

DOI: 10.5846/stxb201705150898

Abstract

Improving eco-efficiency is crucial for coordinating the relationship between economic development and environmental protection. To understand the eco-efficiency of various sectors during Beijing' s industrial transformation and identify key sectors for improving industrial eco-efficiency, this study employed the index system method based on Beijing' s input-output tables. Water resource efficiency and the environmental efficiency of industrial solid waste were selected as indicators to measure eco-efficiency. The study calculated water resource efficiency for each sector in Beijing for 2007, 2010, and 2012, and environmental efficiency for each sector in 2005, 2007, and 2010. The complete water use coefficients and pollutant total discharge coefficients were compared across sectors, and the mutual contribution ratios of total emissions between sectors were analyzed to identify key sectors for improving eco-efficiency.

The main conclusions are as follows: (1) Between 2007 and 2012, water resource efficiency in Beijing showed an overall upward trend, while the environmental efficiency of wastewater, SO_2, and industrial solid waste for each sector increased between 2005 and 2010, though this increase was variable. (2) Agriculture, livestock, forestry, fishery, and waste material industries are key sectors for improving water resource efficiency. (3) Water production and supply, the chemical industry, food manufacturing and tobacco processing, textiles and paper printing, and cultural and educational sporting goods manufacturing are key sectors for improving wastewater environmental efficiency. (4) Petroleum processing, coking and nuclear fuel processing, non-metallic mineral products, metal smelting and rolling, and electricity and heat production and supply are key sectors for improving SO_2 environmental efficiency. (5) Coal mining and washing, metal mining, wood processing and furniture manufacturing, non-metallic mineral products, metal smelting and rolling, electricity and heat production and supply, and water production and supply are key sectors for improving industrial solid waste environmental efficiency.

Keywords: resource efficiency; environmental efficiency; total water use coefficient; total discharge coefficient; contribution ratio

1. Introduction

Eco-efficiency is a commonly used method for quantitative analysis of sustainable development. The concept was first proposed by Schaltegger and Sturm in 1990. The World Business Council for Sustainable Development (WBCSD) defines eco-efficiency as creating competitive-priced products and services that satisfy human needs and improve quality of life while reducing environmental impacts and resource intensity to levels compatible with Earth' s carrying capacity. The European Environment Agency defines it as "obtaining more welfare from fewer resources." Although definitions vary across organizations, eco-efficiency can generally be understood as the ratio of economic value to environmental impact, representing the resource and energy utilization efficiency and environmental pressure caused by enterprises, industries, or economies.

Eco-efficiency accounting methods can be summarized into three main categories: the model method, environmental single-ratio method, and index system method. The model method integrates eco-efficiency indicators into a single value by assigning weights. The environmental single-ratio method provides a simple ratio between economic and environmental dimension indicators. Both methods ultimately aggregate all environmental impacts into a specific value, making it impossible to distinguish different environmental impacts. The index system method, composed of independent yet interconnected eco-efficiency indicators, can clearly represent different environmental impacts. Different industrial sectors have distinct characteristics and environmental impacts. To identify key sectors for improving resource efficiency or pollutant environmental efficiency, this study adopts the index system method to calculate eco-efficiency indicators.

Foreign research on eco-efficiency has primarily focused on enterprises and product systems, with fewer studies at the industry scale. Dahlsröm and Ekins argue that both the ratio of economic output to pollution output and the ratio of output to input can serve as eco-efficiency indicators. Ingramo analyzed the eco-efficiency of the sugar industry by selecting water resource efficiency and wastewater environmental efficiency as indicators. Domestic research on eco-efficiency emphasizes the industry scale. Mao Jiansu et al. defined the eco-efficiency of 38 Chinese industrial sectors using energy consumption and wastewater, waste gas, and dust indicators. Dai Tiejun et al. used energy efficiency, resource efficiency, and environmental efficiency as indicators for steel enterprise eco-efficiency and conducted empirical analysis. Wang Feier et al. defined eco-efficiency as $\sqrt{}$(resource efficiency^2 + environmental efficiency^2) and calculated the eco-efficiency of the textile industry. Du Yanchun et al. selected energy consumption and pollutant emissions as environmental loads to calculate the sectoral eco-efficiency of Jiaozuo City.

Most existing studies use the ratio of economic output to direct pollutant output to measure eco-efficiency and identify sectors with low eco-efficiency. However, during production processes, sectors not only generate direct resource use and pollutant emissions but also indirect use and emissions. Total use or emission coefficients can more comprehensively measure resource use and pollutant emissions. Liu Shulin analyzed China' s industrial total carbon emissions based on input-output tables, identifying sectors with hidden carbon emissions. Zhang Wei calculated total water use coefficients for Chinese industrial sectors, finding significant gaps between direct and total water use coefficients in many sectors. Eco-efficiency indicators based on direct resource use and pollutant direct emissions can identify sectors with obvious resource consumption and pollutant emissions, while comparing direct and total emission coefficients can identify sectors with hidden pollutant emissions. Only by combining both can we comprehensively reflect the resource efficiency and pollutant environmental efficiency of various industrial sectors and identify key sectors for improvement.

This study, based on Beijing' s input-output tables, selects water resource efficiency and the environmental efficiency of wastewater, SO_2, and solid waste as eco-efficiency indicators. On the basis of comparing and analyzing the eco-efficiency of various industrial sectors, we conduct comparative analysis of total water use coefficients and total emission coefficients for wastewater and solid waste, and further analyze the mutual contribution ratios of total use or emissions between sectors to more comprehensively identify key sectors for environmental management and control, providing scientific theoretical basis and methods for improving resource and environmental efficiency in Beijing.

2. Eco-efficiency Indicator Selection

Industry-scale eco-efficiency analysis typically employs the index system method. Indicators in the eco-efficiency index set mainly include resource consumption, pollutant emissions, and land use to comprehensively reflect the development level and coordination degree of economic, natural, and social subsystems. Beijing is a city with relatively scarce water resources, and large amounts of wastewater discharge have caused varying degrees of pollution to suburban rivers and groundwater. Therefore, this study selects water resources and wastewater as eco-efficiency indicators. Air pollution problems such as acid rain and haze are prominent in Beijing. Considering data limitations, this study selects atmospheric pollutant SO_2 as an indicator. Industrial solid waste storage poses hidden dangers of soil pollution and resource waste, so solid waste is also selected as an indicator.

This study defines resource efficiency as the value created per unit of resource used by the industrial system, and environmental efficiency as the value created per unit of pollutant discharged. To examine the input-output efficiency of resources and pollutants during industrial transformation, we calculate the resource efficiency and environmental efficiency of each sector.

3. Resource Efficiency and Environmental Efficiency Accounting Methods

The calculation of resource efficiency and environmental efficiency is as follows:

- Resource efficiency:
  $r_{ij} = v_i / R_{ij}$
  where R_{ij} is the direct use of resource j by sector i, r_{ij} is the resource efficiency of resource j in sector i, and v_i is the added value of sector i in the input-output table.
- Environmental efficiency:
  $e_{ik} = v_i / E_{ik}$
  where E_{ik} is the direct emission of pollutant k by sector i, and e_{ik} is the environmental efficiency of pollutant k in sector i.

In the industrial ecological network, sectors have not only direct production connections but also indirect connections. This means sectors generate not only direct resource use and emissions but also indirect resource consumption and pollutant emissions. Total use coefficients reflect both direct and indirect resource use, while total emission coefficients comprehensively reflect both direct and indirect pollutant emissions. This study analyzes total resource use coefficients and total pollutant emission coefficients to comprehensively identify the resource and environmental efficiency of each industrial sector.

Taking total emission coefficients as an example, the formula is:

$L = P(I - A)^{-1}$

where L is the total emission coefficient matrix, P is the direct emission coefficient matrix, I is the identity matrix, and A is the direct consumption coefficient matrix. The direct emission coefficient p_i for sector i is calculated as:

$p_i = P_i / x_i$

where P_i is the direct pollutant emission of sector i, and x_i is the total output of sector i.

Based on total emission coefficients, the total emission E'_{ik} of pollutant k from sector i (including indirect emissions) is calculated as:

$E'_{ik} = P_i (I - A)^{-1} f_i$

where f_i is the final use value of sector i. The calculation methods for total resource use coefficients and total use amounts are the same.

In Beijing’ s input-output table, final use includes consumption, capital formation, and exports. This study further analyzes the mutual contribution ratios of resource use and pollutant emissions between sectors. Taking water resources as an example, let W_i be the total water use of sector i, representing the total direct and indirect water resources used per unit of product in sector i, which results from the influence of all sectors in the network. The total water use w_{ij} in sector i caused by the direct water use of sector j is:

$w_{ij} = k_j(I - A)^{-1}$

where $k_j = (0, 0, ..., P_j, 0, ..., 0)$, and P_j is the direct water use coefficient of sector j.

The contribution ratio s_{ij} of sector i' s total water use caused by sector j' s direct water use to sector i' s total water use is:

$s_{ij} = w_{ij}/W_i$

4. Data Sources

This study used Beijing' s input-output tables for 2005, 2007, and 2010 to calculate water resource efficiency and the environmental efficiency of industrial wastewater and industrial solid waste for 2005, 2007, and 2010. Data were obtained from the Beijing Municipal Bureau of Statistics website. Direct water use data for agriculture came from the Beijing Water Resources Bulletin. Water resources data for the water production and supply sector came from environmental protection bureau surveys. Construction industry water use was calculated based on annual completed floor area multiplied by water use quotas per unit building area. Service industry water use data were obtained through literature surveys.

Pollutant emission data by sector came from environmental protection bureau surveys. To facilitate analysis, this study aggregated the 42 sectors in the input-output tables into 8 sectors, combining the national economic industry classification with modern service industry statistical standards (Table 1).

5. Water Resource Efficiency

Beijing is one of China' s most water-scarce major cities. Understanding water use across industries is crucial for water conservation. This study calculated water resource efficiency for 8 sectors in Beijing from 2007 to 2012 and the overall water resource efficiency for Beijing during this period (Figure 1).

[Figure 1: see original paper]

Agriculture, forestry, animal husbandry, and fishery had the lowest direct water use efficiency, significantly below Beijing' s overall water resource efficiency. Over time, water resource efficiency in most sectors showed an upward trend, except for the waste material sector and construction industry, which showed fluctuations. In 2010, the waste material sector' s water resource efficiency was exceptionally high, likely because 2010 was a structural adjustment year for this sector—before 2005, the waste material sector had no intermediate use by other sectors, but began to have intermediate use by other sectors in 2005.

The direct water use coefficient refers to the direct water consumption per unit of output in a sector. The total water use coefficient refers to the total direct and indirect water consumption per unit of value added in a sector. To further understand direct and indirect water use across sectors, this study compared direct and total water use coefficients for 8 sectors in 2012 (Table 2). Manufacturing and modern service sectors had the highest total water use coefficients, but their direct water use coefficients were not particularly high, indicating these are sectors with hidden water use.

To further analyze the sources of total water use in manufacturing and modern service sectors, this study analyzed the mutual contribution ratios of total water use between sectors (Table 3). The first row shows the proportion of water use in other sectors caused by direct water use in agriculture, forestry, animal husbandry, and fishery. The first column shows the proportion of water use in agriculture, forestry, animal husbandry, and fishery caused by other sectors' water use. The contribution ratio from agriculture, forestry, animal husbandry, and fishery far exceeds other sectors due to its significantly higher direct water use coefficient.

The analysis shows that in the total water use of each sector, 89.41% of manufacturing' s total water use comes from agriculture, forestry, animal husbandry, and fishery, and 11.88% from the waste material sector. Modern service sector' s total water use comprises 85.25% from agriculture, forestry, animal husbandry, and fishery and 12.00% from the waste material sector.

Conclusion: Agriculture, forestry, animal husbandry, and fishery is the sector with the lowest water resource efficiency, below Beijing' s overall level. Manufacturing and modern service sectors are sectors with hidden water use, and their total water use mainly comes from agriculture, forestry, animal husbandry, and fishery and the waste material sector. Therefore, these two sectors are key for improving water resource efficiency.

6. Wastewater Environmental Efficiency

This study calculated the environmental efficiency of wastewater for 24 industrial sectors and Beijing' s overall wastewater environmental efficiency for 2005, 2007, and 2010 (Figure 2). Over time, wastewater environmental efficiency in all sectors showed an upward trend, except for non-metallic mineral mining and apparel products manufacturing. Sectors with efficiency below Beijing' s overall level included water production and supply, food manufacturing and tobacco processing, textiles, and paper printing and cultural/educational sporting goods manufacturing.

[Figure 2: see original paper]

The direct emission coefficient refers to the amount of pollutants directly emitted per unit of output. The total emission coefficient refers to the total direct and indirect pollutants emitted per unit of value added. To further understand wastewater discharge across sectors, this study compared direct and total emission coefficients for industrial wastewater and industrial solid waste in 2010. The electricity and heat production and supply sector, computer and other electronic equipment manufacturing, and electrical machinery and equipment manufacturing had high total emission coefficients but relatively low direct emission coefficients, indicating these are sectors with hidden emissions.

To analyze the sources of total emissions across sectors, this study further analyzed the mutual contribution ratios of total emissions between sectors (Figure 3). The analysis shows that the water production and supply sector contributed significantly to the total wastewater emissions of sectors with hidden emissions. For special equipment manufacturing, transportation equipment manufacturing, electrical machinery and equipment manufacturing, and computer and other electronic equipment manufacturing, the water production and supply sector' s contribution to total wastewater emissions reached 73.14%, 58.19%, 45.93%, 60.53%, and 61.77%, respectively.

[Figure 3: see original paper]

Conclusion: Water production and supply, food manufacturing and tobacco processing, textiles, and paper printing and cultural/educational sporting goods manufacturing have low wastewater environmental efficiency. The water production and supply sector is a sector with hidden wastewater emissions and is the main source of total wastewater emissions for sectors like electricity and heat production and supply, computer and other electronic equipment manufacturing, and electrical machinery and equipment manufacturing. Therefore, these sectors are key for improving wastewater environmental efficiency.

7. SO_2 Environmental Efficiency

This study calculated the environmental efficiency of SO_2 for 24 industrial sectors and Beijing' s overall SO_2 environmental efficiency for 2005, 2007, and 2010 (Figure 4). Over time, SO_2 environmental efficiency in all sectors showed an upward trend, except for petroleum processing, coking and nuclear fuel processing. Sectors with efficiency below Beijing' s overall level included non-metallic mineral products, metal smelting and rolling, and electricity and heat production and supply.

[Figure 4: see original paper]

To better analyze SO_2 emissions across sectors, this study further analyzed direct emission coefficients, total emission coefficients, and mutual contribution ratios of total emissions between sectors in 2010. Petroleum processing, coking and nuclear fuel processing, non-metallic mineral products, and metal smelting and rolling had high direct emission coefficients. Metal products, special equipment manufacturing, transportation equipment manufacturing, electrical machinery and equipment manufacturing, computer and other electronic equipment manufacturing, and other manufacturing had high total emission coefficients but low direct emission coefficients, indicating these are sectors with hidden emissions.

For sectors with hidden emissions, the sectors contributing most to their total emissions were metal smelting and rolling, with contribution ratios of 90.44%, 88.81%, 82.59%, 99.09%, 71.51%, and 90.63% for metal products, special equipment manufacturing, transportation equipment manufacturing, electrical machinery and equipment manufacturing, computer and other electronic equipment manufacturing, and other manufacturing, respectively.

Conclusion: Petroleum processing, coking and nuclear fuel processing, non-metallic mineral products, metal smelting and rolling, and electricity and heat production and supply have low SO_2 environmental efficiency. Metal smelting and rolling has high direct emission coefficients and contributes significantly to the total emissions of sectors with hidden emissions. Therefore, these sectors are key for improving SO_2 environmental efficiency.

8. Industrial Solid Waste Environmental Efficiency

This study compared the environmental efficiency of industrial solid waste across 24 sectors for 2005, 2007, and 2010 (Figure 5). Over time, the environmental efficiency of industrial solid waste in most sectors showed an upward trend, except for metal smelting and rolling, computer and other electronic equipment manufacturing, apparel manufacturing, coking and nuclear fuel processing, and water production and supply, which showed fluctuations.

[Figure 5: see original paper]

Sectors with efficiency below Beijing' s overall level included coal mining and washing, metal mining, non-metallic mineral products, metal smelting and rolling, and electricity and heat production and supply. To more comprehensively analyze the environmental efficiency of industrial solid waste across sectors, this study further analyzed direct emission coefficients, total emission coefficients, and mutual contribution ratios of total emissions between sectors in 2010.

Metal products, special equipment manufacturing, transportation equipment manufacturing, electrical machinery and equipment manufacturing, computer and other electronic equipment manufacturing, and other manufacturing had high total emission coefficients but low direct emission coefficients, indicating these are sectors with hidden emissions. For these sectors with hidden emissions, metal mining contributed the most to their total industrial solid waste emissions, with contribution ratios of 62.82%, 59.68%, 59.06%, 66.44%, 61.79%, and 58.20%, respectively. Metal smelting and rolling was the second-largest contributor, with contribution ratios of 35.85%, 38.33%, 36.84%, 31.79%, 31.96%, and 39.08%, respectively.

[Figure 6: see original paper]

Conclusion: Coal mining and washing, metal mining, wood processing and furniture manufacturing, non-metallic mineral products, metal smelting and rolling, electricity and heat production and supply, and water production and supply have low industrial solid waste environmental efficiency. Metal mining and metal smelting and rolling contribute significantly to the total emissions of sectors with hidden emissions. Therefore, these sectors are key for improving industrial solid waste environmental efficiency.

[Figure 7: see original paper]

9. Conclusions

Based on Beijing' s input-output tables, this study calculated eco-efficiency indicators for industrial sectors, including water resource efficiency and the environmental efficiency of wastewater, SO_2, and industrial solid waste. The study calculated total water use coefficients and total emission coefficients for each sector and analyzed the mutual contribution ratios of total emissions between sectors. The main conclusions are:

1. **Temporal trends:** From 2007 to 2012, water resource efficiency in all sectors except manufacturing and construction showed clear upward trends. From 2005 to 2010, the environmental efficiency of wastewater, SO_2, and industrial solid waste in most industrial sectors showed fluctuating upward trends.
2. **Water resource efficiency:** Agriculture, forestry, animal husbandry, and fishery has the largest direct water use coefficient and the lowest water resource efficiency, below Beijing' s overall level. Manufacturing and modern service sectors have the highest total water use coefficients, with their total water use mainly contributed by agriculture, forestry, animal husbandry, and fishery and the waste material sector. Therefore, these two sectors are key for improving water resource efficiency.
3. **Wastewater environmental efficiency:** Water production and supply, food manufacturing and tobacco processing, textiles, and paper printing and cultural/educational sporting goods manufacturing have high direct wastewater emission coefficients and low environmental efficiency. Water production and supply is a sector with hidden emissions and the main source of total wastewater emissions for sectors like electricity and heat production and supply. These sectors are key for improving wastewater environmental efficiency.
4. **SO_2 environmental efficiency:** Petroleum processing, coking and nuclear fuel processing, non-metallic mineral products, metal smelting and rolling, and electricity and heat production and supply have high direct SO_2 emission coefficients and low environmental efficiency. Metal smelting and rolling contributes significantly to the total emissions of sectors with hidden emissions. These sectors are key for improving SO_2 environmental efficiency.

5. **Industrial solid waste environmental efficiency:** Coal mining and washing, metal mining, wood processing and furniture manufacturing, nonmetallic mineral products, metal smelting and rolling, electricity and heat production and supply, and water production and supply have high direct industrial solid waste emission coefficients and low environmental efficiency. Metal mining and metal smelting and rolling contribute significantly to the total emissions of sectors with hidden emissions. These sectors are key for improving industrial solid waste environmental efficiency.

References

[1] Willis J H M, Côté R P. Counting biodiversity waste in industrial eco-efficiency: fisheries case study. *Journal of Cleaner Production*, 2009, 17(3): 348-353.

[2] Willard B. *The Sustainability Advantage: Seven Business Case Benefits of A Triple Bottom Line*. Gabriola Island: New Society Publishers, 2002.

[3] Jollands N, Lermit J, Patterson M. Aggregate eco-efficiency indices for New Zealand: a principal components analysis. *Journal of Environmental Management*, 2004, 73(4): 293-305.

[4] Organization for Economic Co-operation and Development. *Eco-Efficiency*. Paris: OECD, 1998.

[5] Vogtländer J G, Bijma A, Brezet H C. Communicating the eco-efficiency of products and services by means of the eco-costs/value model. *Journal of Cleaner Production*, 2002, 10(1): 57-67.

[6] [Chinese reference on eco-efficiency accounting methods]

[7] Dahlström K, Ekins P. Eco-efficiency trends in the UK steel and aluminium industries: differences between resource efficiency and resource productivity. *Journal of Industrial Ecology*, 2005, 9(4): 171-188.

[8] Ingramo A, Heluane H, Colombo M, Cesca M. Water and wastewater eco-efficiency indicators for the sugar cane industry. *Journal of Cleaner Production*, 2009, 17(4): 487-495.

[9] Van Caneghem J, Block C, Cramm P, Mortier R, Vandecasteele C. Improving eco-efficiency in the steel industry: the ArcelorMittal Gent case. *Journal of Cleaner Production*, 2010, 18(8): 807-814.

[10] [Chinese reference on industrial eco-efficiency in China]

[11] [Chinese reference on steel enterprise eco-efficiency]

[12] [Chinese reference on textile industry eco-efficiency]

[13] [Chinese reference on Jiaozuo industrial eco-efficiency]

[14] [Chinese reference on total carbon emissions]

[15] [Chinese reference on virtual water trade]

[16] [Chinese reference on input-output models]

[17] [Chinese reference on construction and tertiary industry water use]

[18] [Chinese reference on Beijing tertiary industry water use characteristics]

Note: Figure translations are in progress. See original paper for figures.