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# The temporal characteristics and decomposition analyses of energy consumption for industrial wastewater treatment in the Beijing-Tianjin-Hebei region

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**ABSTRACT**

The multi-year wastewater-related energy in the Beijing-Tianjin-Hebei (BTH) region are calculated. The Logarithmic Mean Divisia Index (LMDI) method is used to analyze the driving factors of energy consumption for industrial wastewater treatment (wastewater-related energy). The results of driving force analysis illustrate that: From 2010 to 2018, the energy consumptions related to industrial wastewater in the BTH increase by 1.91, 1.50, and 1.11 times, respectively. The power consumption intensity and economic activity are the main drivers for the increase of industrial wastewater-related energy consumption. In contrast, the industrial structure is the main driver for its decrease. A significant increase in industrial wastewater-related energy consumption occurred between 2014 and 2018 (increased by 37.42 million kWh), while the decrease occurred from 2011 to 2014 (decreased by 11.02 million kWh). By identifying the critical driving factors of energy consumption change for wastewater treatment, this study aims to provide energy saving strategy to boost the synergies of energy-water nexus in industrial wastewater treatment.

**Keywords:** Wastewater treatment, LMDI, energy consumption, industrial structure, energy-water nexus

## 1. INTRODUCTION

Two decomposition methods, the index decomposition analysis (IDA) and structural decomposition analysis (SDA), are usually applied to study the contributions of driving factors to the total change in energy consumption and carbon emissions[1,2]. IDA has an advantage in analyzing the changes in energy consumption and carbon emissions in a specific department[3]. SDA has been widely used to distinguish production effects and final demand effects in multiple departments and evaluating direct and indirect effects by using input-output tables. Many studies have used these two methods to explore the driving forces of energy consumption and emissions [4,5].

LMDI, one of the most popular IDA approaches, has been widely used to analyze carbon emissions due to its superiority of the desirable characteristic of complete decomposition and aggregation consistency, ensuring the decomposition results without a residual term [6–8]. Although it is not capable of detecting synergies and other interactions between driving forces, the relative contribution of the various driving force behind change of various parameters over time can be quantified to design future policies and measures[8,9].

The complex interdependency between energy and water, termed as energy-water nexus, is creating opportunities to exacerbate or mitigate the energy and water risk[10]. Previous studies tended to focus on specific nexus questions or different aspects separately, while few studies addressed the influence of the nexus path on the entire system [11,12]. The synergy effects and co-benefits in industrial wastewater treatment system were also rarely investigated, which was particularly crucial for energy saving due to the wastewater treatment activities were energy intensive [13,14].

In this study, the temporal characteristics of energy-water nexus in the BTH region and its driving factors will be analyzed. A detailed introduction and formula of the methods used, the LMDI decomposition approach, are provided in Section 2. Then Section 3 illustrates the results including temporal variation of wastewater-related energy and its decomposition analysis.

## 2. METHODOLOGY

The factors affecting the change of industrial wastewater discharge in various provinces of China are decomposed into the discharge coefficient effect, technological progress effect, industrial structure effect, income effect, population mobility effect, and population effect by using LMDI. At the same time, the influence of industrial wastewater discharge intensity (wastewater discharge per unit industrial added value) on industrial wastewater discharge is analyzed[15–17]. The total amount of industrial wastewater discharge W can be expressed by Eq. (1):

$$W = \sum_i W_i = \sum_i \frac{W_i}{E_i} \times \frac{E_i}{V_i} \times \frac{V_i}{G_i} \times \frac{G_i}{P_i} \times \frac{P_i}{P} \times P \qquad (1)$$

where Wi is the industrial wastewater discharge of the region i, Ei is the industrial water consumption of the region i; Vi is the industrial added value of the region i; Gi is the gross domestic product of the region i; Pi is the population of the region i (ten thousand people); P is the total population.

Eq. (1) can be written as:

$$W = \sum_i SDC_i \times INT_i \times SV_i \times INC_i \times SP_i \times P \qquad (2)$$

where SDCi is industrial wastewater discharge and industrial water consumption in region i, that is, wastewater discharge coefficient; INTi is the intensity of industrial water use in region i; SVi is the proportion of industrial added value in the GDP of region i; INCi is the per capita GDP of region i; SPi is the proportion of the population of region i in the total population of the whole country.

When the time factor is introduced, Eq. (2) is changed into Eq. (3).

$$\dot{W} = \sum_i \dot{S}DC_i \times INT_i \times SV_i \times INC_i \times SP_i \times P + \sum_i SDC_i \times \dot{I}NT_i \times SV_i \times INC_i \times SP_i \times P$$
$$+ \sum_i SDC_i \times INT_i \times \dot{S}V_i \times INC_i \times SP_i \times P + \sum_i SDC_i \times INT_i \times SV_i \times \dot{I}NC_i \times SP_i \times P$$
$$+ \sum_i SDC_i \times INT_i \times SV_i \times INC_i \times \dot{S}P_i \times P + \sum_i SDC_i \times INT_i \times SV_i \times INC_i \times SP_i \times \dot{P}$$

(3)

## 3. RESULTS AND DISCUSSIONS

Figure 1 shows the industrial wastewater-related energy consumption during 2010-2018. During 2010-2018, the water-related energy increased by 1.91, 1.50, and 1.11 times in the BTH, respectively. In Beijing, the increasing speed is higher than that in Tianjin and Hebei. A significant increase in industrial wastewater-related energy consumption occurred between 2014 and 2018 (increased by 37.42 million kWh), while the decrease occurred from 2011 to 2014 (decreased by 11.02 million kWh). This is mainly due to the enhancement of industrial wastewater treatment in recent years. Tianjin has a significant decrease from 2012 to 2013 (decreased by 31.89 million kWh). Compared to Tianjin and Beijing, Hebei has a relatively high industrial wastewater capacity. This is mainly due to the dense population and high-developed heavy industry in Hebei.

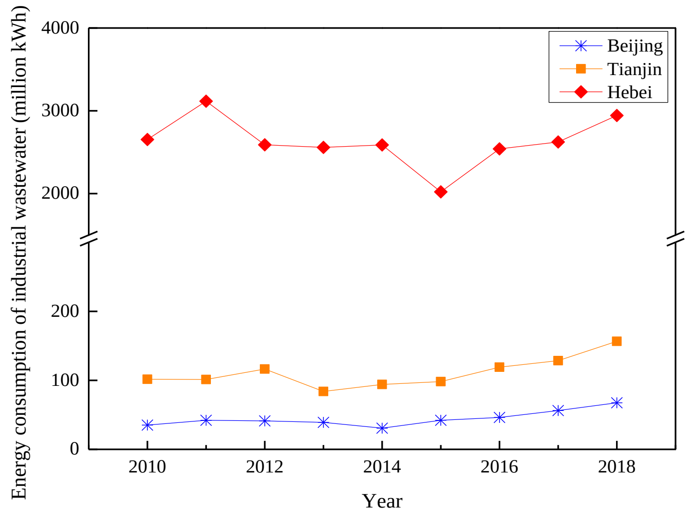

Figure 1 Industrial wastewater-related energy consumption in the BTH area

Figure 2 shows the drivers of Beijing's industrial wastewater-related energy consumption from 2010 to 2018. We decompose five driving factors to the change of industrial wastewater-related energy consumption, including (economic activity, population-scale, electricity consumption intensity, technology improvement, and industrial structure), which is represented by colored rectangles. The industrial wastewater-related energy consumption in Beijing decreased -13.0% from 2010 to 2014, and economic activity contributed the most increase (29.9%), while industrial structure contributed the most decrease (-86.5%) to the change of industrial wastewater-related energy consumption. Besides, the difference in electricity consumption intensity (-13.7%) and industrial structure (-10.2%) decreased while population-scale (8.6%) increased the industrial wastewater-related energy consumption.

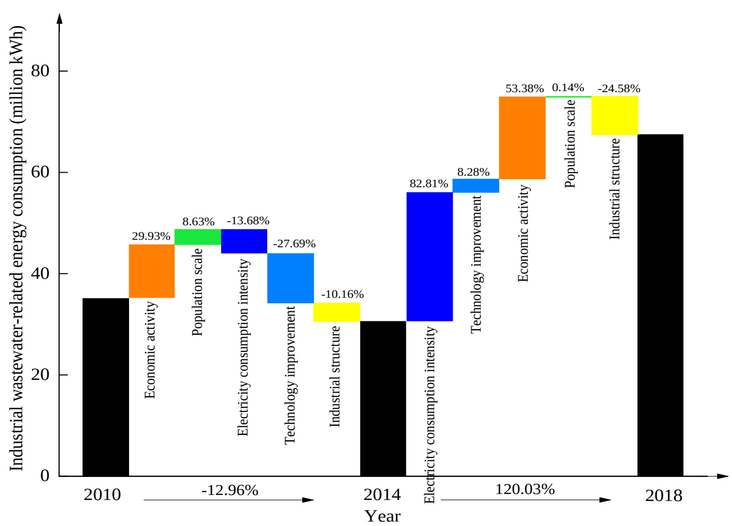

Figure 2 The industrial wastewater-related energy consumption

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**REFERENCE**

[1] Ang BW. LMDI decomposition approach: A guide for implementation. Energy Policy 2015;86:233–8. https://doi.org/10.1016/j.enpol.2015.07.007.

[2] Ma M, Yan R, Du Y, Ma X, Cai W, Xu P. A methodology to assess China's building energy savings at the national level: An IPAT–LMDI model approach. Journal of Cleaner Production 2017;143:784–93. https://doi.org/10.1016/j.jclepro.2016.12.046.

[3] Wang H, Ang BW, Su B. Assessing drivers of economy-wide energy use and emissions: IDA

[6] Feng L, Chen B, Hayat T, Alsaedi A, Ahmad B. The driving force of water footprint under the rapid urbanization process: a structural decomposition analysis for Zhangye city in China. Journal of Cleaner Production 2017;163:S322–8. https://doi.org/10.1016/j.jclepro.2015.09.047.

[7] Tan Z, Li L, Wang J, Wang J. Examining the driving forces for improving China's CO2 emission intensity using the decomposing method. Applied Energy 2011;88:4496–504. https://doi.org/10.1016/j.apenergy.2011.05.042.

[8] Moutinho V, Madaleno M, Inglesi-Lotz R, Dogan E. Factors affecting CO2 emissions in top countries on renewable energies: A LMDI decomposition application. Renewable and Sustainable Energy Reviews 2018;90:605–22. https://doi.org/10.1016/j.rser.2018.02.009.

[9] Zhao C, Chen B. Driving Force Analysis of the Agricultural Water Footprint in China Based on the LMDI Method. Environmental Science and Technology 2014;48:12723–31. https://doi.org/10.1021/es503513z.

[10] Williams J, Bouzarovski S, Swyngedouw E. Politicising the Nexus: Nexus Technologies, Urban Circulation, and the Coproduction of Water-Energy. Nexus Network Think Piece Series 2014:1–27.

[11] Wang S, Fath B, Chen B. Energy–water nexus under energy mix scenarios using input–output and

versus SDA. Energy Policy 2017;107:585–99. https://doi.org/10.1016/j.enpol.2017.05.034.

[4] Gao J, Li C, Zhao P, Zhang H, Mao G, Wang Y. Insights into water-energy cobenefits and trade-offs in water resource management. Journal of Cleaner Production 2019;213:1188–203. https://doi.org/10.1016/j.jclepro.2018.12.126.

[5] Wang S, Fath B, Chen B. Energy–water nexus under energy mix scenarios using input–output and ecological network analyses. Applied Energy 2019;233–234:827–39. https://doi.org/10.1016/j.apenergy.2018.10.056.
ecological network analyses. Applied Energy 2019;233–234:827–39. https://doi.org/10.1016/j.apenergy.2018.10.056.
[12] Wang S, Liu Y, Chen B. Multiregional input–output and ecological network analyses for regional energy–water nexus within China. Applied Energy 2018;227:353–64. https://doi.org/10.1016/j.apenergy.2017.11.093.

[13] Wang Z, Cui C, Peng S. Critical sectors and paths for climate change mitigation within supply chain networks. Journal of Environmental Management 2018;226:30–6. https://doi.org/10.1016/j.jenvman.2018.08.018.

[14] Calderón AJ, Guerra OJ, Papageorgiou LG, Reklaitis GV. Disclosing water-energy-economics nexus in shale gas development. Applied Energy 2018;225:710–31. https://doi.org/10.1016/j.apenergy.2018.05.001.

[15] Beijing Municipal Bureau of Statistics, 2011-2019. Beijing Statistical Yearbook. Beijing: China Statistics Press [in Chinese].

[16] Hebei Municipal Bureau of Statistics, 2011-20198. Hebei Statistical Yearbook. China Statistical Publishing House, Hebei. [in Chinese]

[17] Tianjin Municipal Bureau of Statistics, 2011-2019. Tianjin Statistical Yearbook. China Statistical Publishing House, Tianjin. [in Chinese]