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Optimization of urban industrial structure under the low-carbon goal and the water constraints: a case in Dalian, China

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A B S T R A C T

Rapid industrial development consumes a large amount of water and energy, which causes both urban water shortages and massive carbon emissions. Therefore, optimization of the urban industrial structure is urgently required to pursue the low-carbon goal under the constraints of water supply. In this paper, we chose Dalian city in China as a case study and divided its industrial sectors into three types according to their output value. Meanwhile, we used the LMDI (Logarithmic Mean Divisia Index) method to decompose the factors that impact industrial carbon emissions from energy consumption. Based on the ratio of the carbon emission effects, five scenarios were set respectively, and accounted for the carbon emissions and water consumption under different scenarios of industrial structure. The results indicated that the economic growth effect was the most significant factor that contributed to industrial carbon emissions, while industrial structure effect was the largest negative factor for increasing industrial carbon emissions. The results also indicated that the total carbon emissions under the HOV (high output-value)-preferred and water-conserved scenario will be lower by 8.5% in 2020 than the baseline scenario, while both its energy intensity and water intensity will meet the requirements of the constraints of the urban development planning.

1. Introduction

1.1. Overview of carbon emission and water consumption in industries

Rapid industrial development consumes enormous amounts of water and energy, which cause both urban water shortages and a large amount of carbon emissions (Carrillo and Frei, 2009). The industrial sectors (represents secondary industries in this research) are notably energy-intensive and account for 40% of the global energy use. Increased carbon emissions caused by energy consumption have resulted in serious environmental problems, including global warming (Wang et al., 2011; Zhang et al., 2015). Accelerating urbanization also brings the rise of the economic levels with increases in both water consumption and water pollution (Yue et al., 2014). Meanwhile, industrial water use efficiency exhibits an obvious gap between the developing countries and the highly developed countries (Wang et al., 2014a). The growing water shortage crisis restricts the sustainable development of the economy. Determining how to improve the industrial water consumption potential is similarly noteworthy.

As interdependent resources in industrial activity, energy and water consumption is traditionally planned separately. Facing increasing environmental pressures, such as global warming and water scarcity, it is both necessary and urgent that we consider the cooperative nature of energy and water consumption in social economic development plans, particularly in industrial plans.

Industrial sectors in China have consistently played a significant role in carbon emissions and in the enormous amount of water consumption of all economic activities. The development path of industrial sectors of high input and high consumption characters lead to rapid economic growth, as well as increasing carbon emissions, exhibiting a significant "high-carbon" characteristic (Ren et al., 2014). As the second-largest energy consumer in the world (Wang et al., 2014b), China made a positive commitment to the reduction of carbon emissions in 2009 and established the following goals China will commit to reduce its carbon dioxide emissions per unit of GDP, or carbon intensity, by 40%–45% of 2005 levels by 2020 (Zhang et al., 2014). In 2008, China's GDP per unit of energy use is approximately 38% lower than that of USA and 56% lower than that of Japan; consequently, energy efficiency in China

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should be more widely promoted (Wang et al., 2012). Transitioning to a low-carbon energy infrastructure is often an efficient approach to reduce the amounts of carbon emissions (Zhang and Xu, 2013; Yu et al., 2015).

The respective low energy efficiency is related not only to the level of equipment and other technical factors but also to the several factors, i.e., industrial structure, and energy structure. How to determine the effects that are responsible for changing the industrial carbon emissions and, finally, to decrease the energy intensity requires increasing attention.

1.2. Literature review

Few studies have investigated the relationship between energy and water consumption (Dale and Bilec, 2014). Meanwhile, energy and water use are interconnected, e.g., the distribution of water takes large amounts of energy, and the production of energy requires large amounts of water (King et al., 2008). Several findings indicated that energy-saving efforts in these industries will result in savings in water consumption and that cooperative water and energy conservation efforts help create policies that encourage simultaneous savings of both resources (Gu et al., 2014; Liu et al., 2007b).

To identify the effects that impact industrial carbon emissions from energy consumption, two primary methods are usually used for the decomposition of carbon emissions: structural decomposition analysis (SDA) (Xu et al., 2011; Tian et al., 2013) and index decomposition analysis (IDA) (Zha et al., 2010). The former method is always used in the input–output model, while the later method is more applicable for time-series modeling (Hoekstra and Van den Bergh, 2003). As one of the IDA methods, the Logarithmic Mean Divisia Index (LMDI) method was chosen in this research because this method can both eliminate residuals and save the data of 0 value problems, with a simple calculation process and intuitive decomposition results (Ang et al., 1998, 2005; Ang and Liu, 2007).

The LMDI method has been widely used in industrial carbon emission decomposition (Liu et al., 2007a; Zhao et al., 2010; Shao et al., 2014; Xu et al., 2014) and waste water emission decomposition (Geng et al., 2014). Many studies examined industrial carbon emissions at the national or provincial scales (Wang et al., 2005; Zhang et al., 2009; Su et al., 2014; Ouyang and Lin, 2015) and individual sector scale, such as cement industry (Xu et al., 2012; Wang et al., 2013b) and electricity generation (Malla, 2009; Zhang et al., 2013; Zhou et al. 2014). As a development of the method, a new three-level decomposition model to explore the driving forces based on provincial aggregated data (Wu et al., 2005; Chen and Yang, 2015). Some studies study large city in China, such as Beijing, Shanghai, Tianjin and Chongqing (Liu et al., 2012). Since the city is the basis of macroeconomic policy implementation, study at the urban scale with its all industrial sectors provide a more comprehensive picture to local decision-makers.

Studies using scenarios for future carbon emissions help to create proper pathways to realize local low-carbon development; research studies have been identified through the use of local low-carbon scenario creations (Wang et al., 2013a), including Kyoto (Gomi et al., 2010) and Bangkok (Phdungsilp, 2010) in foreign cities and Shanghai (Li et al., 2010) and Xiamen (Lin et al., 2010) in China. Scenario analysis helps provide information for policies on economic growth and energy and water efficiency improvement. Few studies attempted to integrate LMDI method with scenario analysis to forecast future carbon emissions (Xu et al., 2012; Jiao et al., 2013; Yan and Fang, 2015), but fails to combine the two methods closely.

In conclusion, the previous researches may have three shortcomings when it comes to urban scale. Firstly, lack of carbon emission decomposition of urban scale may neglect the changes of economy of the city, which leads to inconvenience in the summarizing and planning of industrial development on the macroscopic scale. Secondly, previous researches stayed just in driving forces analysis, instead of finding the guideline for industrial structure changes to reduce the carbon emissions. Last but not the least, integrated with low-carbon goal and energy intensity and water intensity, the scenario analysis will identify the best way of sustainable development of Dalian industrial sectors.

2. Methodology

To achieve low-carbon development under the pressure of limited water supply at the urban scale, this paper presents the development of an industrial optimal scenario choice model based on low-carbon goals and constraints of carbon emissions and water consumption.

2.1. Study area and data acquisition

Dalian, is a coastal city in China experiencing severe water shortage (Huang et al., 2015), its average annual water resources per capita is only 604 m^3, representing 25% and 6.75% of the national and the global averages, respectively. The economic development is incompatible with the region's water resources; the severe mismatch between water supply and water demand has already been restricting the social and economic development of Dalian (Nakayama et al., 2010). By the end of 2010, the industrial output value of Dalian accounted for 777.84 billion CNY (approximately 1USD = 6.1975CNY), with an average annual growth of 24.8%.

Based on the overall layout of the industrial pattern and relying on its basic development and comparative advantages, the industrial distribution of Dalian is sufficient alongside the regional area (Fig. 1). The municipal district (southern part) has a better economic foundation and more rapid development, where the main technology-intensive industries are located; in contrast, the other districts with less developed and of relatively small population have high concentrations of labor-intensive and capital-intensive industries.

To analyze the industrial carbon emissions under the water constraints of Dalian, we conducted research to obtain the information in the following table, (see Table 1).

We chose the time period of the years from 2005 to 2010. This period was chosen partly because the period corresponds to the high-growth period of the industrial economy of Dalian, with increases in both carbon emissions and water consumption. Meanwhile, the complete data of the above-scale industries from the *Statistical Yearbooks* for this period can be easily acquired, with a unified industry classification standard based on *National Economical Industry Classification (GB/T4754-2002)*. According to the *Statistical Yearbook*, industrial sectors are divided into 33 industries, with industrial enterprises of the main business income of over 5 million CNY as the statistical caliber, see Table 2.

In order to evaluate the economic development status of Dalian city, we divided the chosen industrial sectors into three types based on their proportion in the whole industrial output (Xu et al., 2013), including HOV, MOV and LOV. HOV refers to high output-value industry, whose output accounts for more than 3.5% of total output of industrial sectors, also represented as pillar industries; moderate output-value industry is denoted as MOV with its proportion of output from 1% to 3.5% of all; and the rest whose output accounts for less than 1% are low output-value industry, i.e. LOV. As for Dalian industries, HOV industries together account for more