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Improving resource utilization efficiency in China's mineral resource-based cities: A case study of Chengde, Hebei province

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ABSTRACT

China is facing serious shortage of mineral resources, while the resource utilization efficiency in China's mineral resource-based cities is low. This study applies a three-step material flow analysis (MFA) based analysis method to analyze and improve the resource utilization efficiency of Chengde, the second largest vanadium–titanium industrial base in China. Resource productivity and comprehensive utilization rate, are applied as two main indicators for mineral utilization efficiency analysis. The results show that compared with other resource-based cities in China, Chengde's resource utilization efficiency is low, suggesting that both the mining and manufacturing industries need to be strengthened. Based on these problems, eco-industrial chains are designed and positive effects are obtained. With the implementation of the design in the mining industry, by 2016, the comprehensive utilization rate of iron (Fe), vanadium (V), titanium (Ti), and phosphorus (P) will be increased by 16.22%, 75.72%, 1653.60%, and 387.56%, respectively. Likewise, the total comprehensive utilization rate and resource productivity will be increased by 23.99% and 9.85%, respectively.

1. Introduction

China is a major consumer of mineral resources, but its resource per capita is far below the world's average. Although China possesses a large amount of mineral resources, most of them are difficult to utilize due to low-grade. With the rapid development of economy, China's demand for mineral resources has exceeded its domestic supply and brought heavy burden on mineral resources (Ren et al., 2012). Most of China's mineral resources are of a low-grade quality and difficult to utilize. According to the report of the Ministry of Land and Resources (MLR) of China, 25 of the 45 main mineral resources, including iron, copper, alumina, will run short by 2020 (MLR of China, 2012). The shortage of mineral resources is becoming an obstacle for China's development.

Mineral resource-based cities are those whose development mainly depends on the exploitation of mineral resources, and mineral resource-based industries are the predominant part of their economic systems (Yu et al., 2008). Most of these cities are still at the stage of mining and producing primary mineral products (Cun et al., 2014). Besides, most of the tailings are treated by stockpiling, which leads to enormous waste of resources and serious environmental problems as well. Generally, resource utilization efficiency in these cities is far below that of other countries (Li et al., 2013), which further exacerbates the shortage of mineral resources.

Aiming at the problems mentioned above, the Chinese government has taken some measures to promote sustainable development in mineral resource-based cities. One of the major measures is to improve the resource utilization efficiency (Huang et al., 2012). Better resource utilization efficiency enables more economic benefits from a limited amount of resources with less natural resource consumption. Furthermore, it is the way to resolve conflicts between future development and heavy resource burdens. Improving resource utilization efficiency comprises two parts: one refers to improving the economic benefits of resources or resource productivity, and the other one is to improve the recovery rate of resource.

Besides this issue has triggered a lot of researchers to study. Especially in China, many researchers have published their papers on the development of mineral resource-based cities and evaluation of their resource utilization efficiency. So far, these studies can be categorized into two groups. One focuses on qualitative analysis to study the basic characteristics and countermeasure study of mineral resource-based cities and their sustainable development and show profound guiding significance (Hui, 2013a,b). And the other

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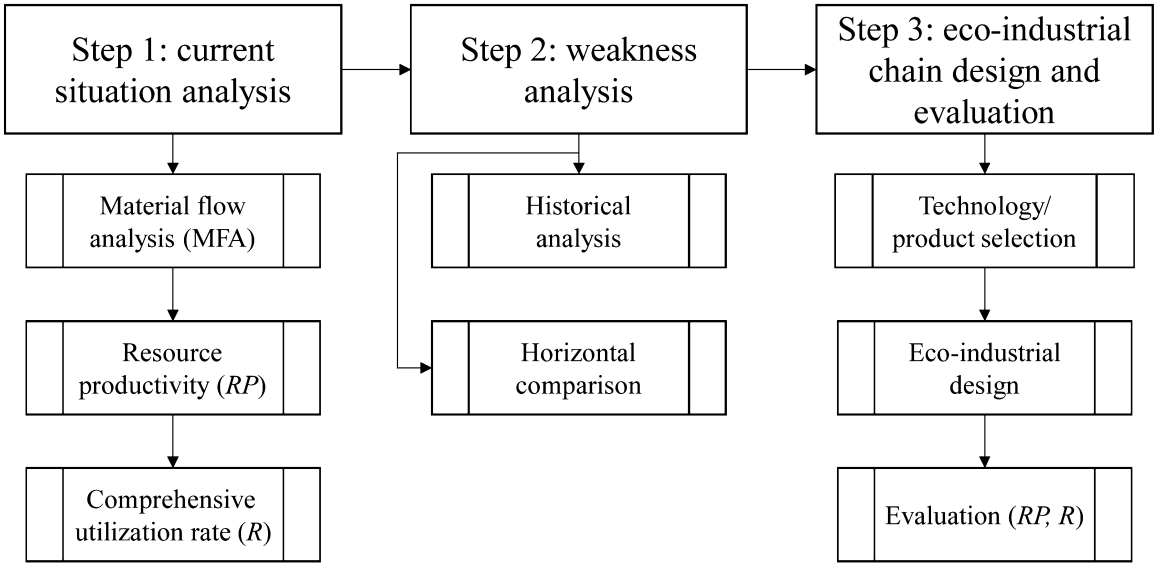

Fig. 1. MFA-based comprehensive analysis method for mineral resource-based cities.

one focuses on quantitative analysis to establish evaluation indicators systems and provide operational recommendations (Wang and Cote, 2011; Zhao et al., 2007).

At present, some statistical methods and data analysis methods are commonly applied in these studies, such as analytic hierarchy process (AHP), ecological footprint (Gao et al., 2008), material flow analysis (MFA) (Chiarawatchai et al., 2008; Huang et al., 2012; Qiu et al., 2009), emergy analysis (Qi et al., 2011; Koroneos et al., 2012), data envelopment analysis (DEA) (Tao, 2009; Yang and Wang, 2013). Among all these methods, MFA, as a useful tool in industrial ecology, is one of the most widely used. It is mainly applied to analyze the volume and structure of materials throughout the socioeconomic system, and to assess the metabolic performance in terms of sustainable development in a variety of systems, such as nation (Schandl and Schulz, 2000), city (Xu et al., 2004), and industrial park (Tian et al., 2012). Two indicators resource productivity (*RP*) and comprehensive utilization rate (*R*), which are derived from material flow analysis (MFA) (Gan et al., 2013), could be applied to resource utilization efficiency (Bringezu et al., 2004).

RP was defined as the ratio of economic output and its corresponding material input (Gan et al., 2013). As an integrated quantitative assessment of social economics, *RP* is extensively used in academia (Bleischwitz, 2010; Giljum et al., 2010), national statistical analysis (Eurostat, 2001), and policy management (AFG, 2002). Moreover, the Chinese government has applied *RP* as a key indicator to guide the future development, and the importance of improving *RP* of mineral resources is highlighted in China's 12th Five-Year Plan. Compared with the extensive applications in macro system, applications of *RP* in small systems such as industry or certain resources remain rare. The main obstacle is the statistical scope for GDP, which makes the data collection difficult (Kovanda et al., 2012).

Recovery rate or utilization rate is commonly applied in the industry for measurement and monitoring of the efficiency of recovery process. In China, comprehensive utilization rate (*R*), as the ratio of useful element output and its corresponding mineral resource input, is suggested by MLR of China to evaluate the total recovery rate of mineral resources. *R* is widely used by Chinese government and mineral companies, such as Panzhihua Steel and Hebei Steel.

The purpose of this paper is to offer a typical case study for other mineral resource-based cities in China to improve the resource utilization efficiency. This paper begins with the introduction of the method. Then, Chengde's industrial structure and current development status of vanadium–titanium magnetite are presented and regional MFA is applied to analyze Chengde's material input and output. Simultaneously, a time series analysis of *RP* and *R* and a comparison with Panzhihua are carried out to identify the weakness of Chengde's mineral resource-based industry and point out the development directions. Subsequently, eco-industrial chain design (EID) by choosing suitable technologies and products for Chengde is implemented. Finally, the performance of the design is evaluated by recalculating *RP* and *R*.

2. Method and data

2.1. Overview of the method

In order to improve resource utilization efficiency, a three-step MFA-based analysis method is applied throughout the case study (see Fig. 1). The method comprises three steps: current situation analysis, weakness analysis, eco-industrial chain design, and evaluation.

Step 1: Current situation analysis

Current situation analysis is used to get an overall understanding of the current resource utilization status. Regional MFA is applied to analyze the material input and output of the city. Then, the industrial structure and development of the mineral resource-based industry are analyzed. Finally, *RP* and *R* are calculated to evaluate the resource utilization efficiency.

Step 2: Weakness analysis

In this part, the weakness of the mineral resource-based industry is summarized by historical analysis and horizontal comparison. First, historical analysis is conducted to depict the development trend in terms of history by time series analysis of *RP* and *R*. The development potential and relationship with other industries are obtained at the same time. Second, a horizontal comparison with other mineral resource-based cities is conducted to find out the gaps and point out future development directions.

Step 3: Eco-industrial chain design and evaluation

Based on the results of step 2, EID for an upgraded development is conducted. Suitable technologies for both mining and manufacturing industries are collected to build eco-industrial chains. Then, *RP* and *R* are recalculated to evaluate the performance of the design.