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Implications from substance flow analysis, supply chain and supplier' risk evaluation in iron and steel industry in Mainland China

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ABSTRACT

Supply risk evaluation is intended for adjusting industrial structure, and provides limited options to reduce supply risk. The links between supply chain and industrial structure deserve better understanding. In this way, the industrial activities can be managed to change industrial structure from supply risk. We took the anthropogenic iron in Mainland China into our case study. The comprehensive evaluation was modeled to tackle the problems of China's iron and steel industry. From the life cycle perspective, we found that extending iron and steel supply chain would digest the oversupply and reduce the excessive emission, the main problems affecting on the steel ratio for electric arc furnaces were steel scrap shortage and relatively high electrovalence, and Fe content of the social stock basically resided in construction industry which significantly influenced on the flow of steel products and steel and iron products. More attention should be paid to the factors of export price, resource allocation efficiency, financing capability and outdated capacity, strict inspection and prevention should be taken to these risks. A comprehensive picture of several customized risk reduction strategies was constructed for those problems. Of the strategies, China' risks of iron and steel industry could be reduced if the existing industrial structure were adjusted on the basis of the substance flow networks and global iron and steel industrial chains. Based on the result, recommendations were made in this paper, aiming to contribute important reference information for the industrial metabolism, resource management, and recycling of iron and steel industry in Mainland China. The proposed methodology, integrating suppliers' risk evaluation based on supply chain and substance flow analysis offers a quick and convenient examination on more comprehensive risk reduction alternatives. Further dedicated risk evaluation might be required to estimate the more precise risks for the iron and steel industries or other industries that were pre-identified as the outdated.

1. Introduction

Substance flow analysis (SFA) has gained prominence, as an increasing number of researchers across the world have embarked on the task of developing country and regional specific studies with broad ranging applications in many fields. Previous studies using SFA were conducted mainly to analyze flows of metals (lead, copper, zinc, aluminium, iron, nickel, cadmium, etc.) on a very large system boundary, such as at the local (Palmquist, 2004; Lindqvist and von Malmborg, 2004; Zhang et al., 2014), regional (Igarashi et al., 2007; Tabayashi et al., 2008; Lifset et al., 2012; Pauliuk et al.,2012; Cha et al., 2013; Huang et al., 2014; Wang et al., 2014), or global scale (Mao and Graedel, 2009; Elshkaki and Graedel, 2013). SFA has also been applied to some production processes, such as material and energy inputs into microchip manufacturing processes (You et al., 2001), the mass balance of waste water volume in a semiconductor factory (Williams et al., 2003), or material and energy flows in iron and steel manufacturing (Michael, 1999; Michaelis and Jackson, 2000a, 2000b; Yu et al., 2007; Zhang et al., 2013; Yellishetty and Mudd, 2014; Wang et al., 2015). Although several previous studies explored the steel cycle and created several models (Wang et al., 2007; Geyer et al., 2007; Lu and Yue, 2010; Park et al., 2011; Pauliuk et al., 2012; Yellishetty et al., 2014; Wang et al.,2014), their general modeling approach is an analytical method used to systematically assess the flow and stock of a material or substance through a given system (e.g. productive system, economic or social system) by the principle of mass balance (Huang et al., 2014), which should be clearly defined in space and time (Bringezu et al.,1997; Brunner and Rechberger, 2004; Hendriks

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et al., 2000). In-use material stocks are often the major cause of disconnection between system inflow and outflow in a given year, meaning that dynamic SFA models lead to more accurate prediction of future resource use and waste streams (Elshkaki et al., 2005). In recent years, some studies have applied dynamic material flow analysis to forecast production, recycling, and iron ore consumption in the Chinese steel cycle until 2100 by using steel services in terms of in-use stock per capita as driver of future development (Pauliuk et al., 2012). SFA of steel in Australia, Brazil, China and India has been aimed at providing better understanding of stocks and flows and to inform the policy making for achieving the industrial metabolism (Yellishetty and Mudd, 2014). Quantifying the Chinese steel flow from cradle to grave could assist Chinese iron and steel industry to understand its historical status and future options on production route transformation, capacity planning, scrap availability, resource and energy consumption (Wang et al., 2014). An enhanced dynamic modeling has been devised to explore stocks and flows of buildings in China and to quantify the related steel cycle (Wang et al., 2015). Almost all these studies outlined above took advantage of the quantity function of flows of metals to focus on the efficiency of substances or resources. However, supply chain and suppliers' risk evaluation were neglected, or at least not the first concern in these studies.

A supply chain is a system of organizations, people, activities, information, and resources involved in moving a product or service from supplier to customer. Supply chain activities involve the transformation of natural resources, raw materials, and components into a final product that is delivered to the end customer. In sophisticated supply chain systems, used products may re-enter the supply chain at any point where residual value is recyclable (Anna, 2006). A typical supply chain begins with the ecological, biological, and political regulation of natural resources, followed by the human extraction of raw material, and includes several production links before moving on to several layers of storage facilities of ever-decreasing size and increasingly remote geographical locations, and finally reaching the consumer. There are a variety of supply chain models, which address both the upstream and downstream sides. Supply Chain Roadmap is a method where an organization's supply chain strategy can be reviewed in an organized and systematic approach in order to assure alignment of the supply chain with the business strategy. The method is supported in the most important and recognized theories and practices about supply chain strategy and business strategy (Perez, 2013).

The current economic environment is full of competition and uncertainty, all kinds of uncertain factors contain risk in the integrated supply chain. As the upstream supply chain enterprises, suppliers are playing an important role. The suppliers' risk is one of the main sources of the supply chain risk, so it becomes the important issue in the current economic environment. Recently, as the awareness of the suppliers' risk is improving, the related researches are also carried out deeply. Some analyzed the source of the suppliers' risk from the perspective of the whole supply chain, the multilevel supplier risk index system is provided based on the theory, the suppliers' risk management is discussed, which pointed that the way to reduce the suppliers' risk is to strengthen the control of the supply chain's optimization (Sun, 2009; Wu et al., 2008; Liu and Liu,2012). According to supply chain structure division, the cooperation relationships between enterprise and supplier are divided into type A, type V and type T (Liu and Liu, 2012). A further study is done on type A. Based on the type A cooperation, the suppliers' risks contain the external risk effected by natural factors and market volatility factors and the internal risk effected by the change of internal factors in the dynamic cooperation systems. Because the influence of factors are random and fuzzy, it is usually inaccurate for suppliers' risk prediction. From this perspective, the method is used based on the likelihood of the fuzzy mathematics to study the suppliers' risk degree, which will make suppliers' risk evaluation more accurate. The general statistical samples can be seen as random set projection theory of single point, fuzzy sets can be manifested as random sets and random sets of fall shadow also conform to shadow of large number theory (Qin and Wei, 2008; Liu and Liu, 2012). Therefore, the fuzzy mathematics model is used to have a comprehensive supplier' risk evaluation and the effective risk prevention measures are put forward based on the theory which aims to provide references for enterprises' risk evaluation and prevention (Liu and Liu, 2012).

The main goal of our research is to construct a comprehensive picture of customized risk management strategies based on SFA, supply chain and supplier' risk evaluation. We'd like to enhance the methodology of supply risk evaluation in order to highlight the problems of iron circulation and the iron and steel industries of concern. The subsequent management measures can then focus on the structure of iron and steel industry, and examine the effects of the scenarios on supply risk reduction. The way to reduce the supply risk is to strengthen the control of the supply chain's optimization. We took iron and steel industry in 2011 in Mainland China as an example; the proposed methodology framework may also apply to other nations and regions.

2. Methodological and ideological options

Risk analysis and risk reduction can benefit from the model which enables comparison of scenarios with different risk management measures. Wu and Olson (2009) emphasized the benefit of risk modeling for risk control, especially the optimization of risk management. Our model combining SFA and risk evaluation has two advantages. First, the SFA screening of the most relevant factors enriched the domain of risk reduction solutions, e.g., changing an industrial structure. Second, we estimated the risk in the fuzzy model and supply chain which are end-point indicators, rather than the mid-point indicator which was used in most SFA studies. The factors of higher risk of supply can be identified.

The proposed methodology integrating suppliers' risk evaluation based on supply chain and SFA, for a case study of the iron and steel industry in mainland China the year 2011, is to offer quick examination on more comprehensive risk reduction alternatives. The integration of SFA to risk evaluation is implemented in the step of data collection and SFA framework formulation in following steps:

1. Identify the processes with iron input / outputs inputs/outputs and the goods containing iron.
2. Link the processes with the substance flows according to the supply chain or life cycle information.
3. Collect the data of goods flows with corresponding Fe contents.
4. Establish the substance flow models and flow charts.
5. Disaggregate the substance flow system into three main streams.
6. Do the suppliers' risk evaluation based on the Fuzzy model.

2.1. Substance flow analysis (SFA)

Following the general procedures of SFA (Van der Voe, 1996; Udo de Haes et al., 1997; Brunner and Rechberger, 2004; Geyer et al., 2007; Huang et al., 2014), we assume that the spatial boundary is Mainland China considering the annual flows in year 2011. The system boundaries are thus the geographical borders of Mainland China. By iron and steel we mean all economic iron and steel qualities, but data of all alloying elements are not contained in this study. The present study is therefore a substance flow analysis, which would only account for the Fe content of the material flows (Van der Voet, 2002; Graedel, 2002; Geyer et al., 2007).

We presented the static iron flow model in two forms. The first model is a production network which specifies several supply chains of iron related products. In principle, the flows associated with a process are categorized as import, export, interflow between processes, or emissions that return to the environment. The second model summarizes the overall iron flow from a life cycle perspective. All processes