Resources, Conservation & Recycling 134 (2018) 228–238

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Material footprint of a fast-industrializing region in China, Part 1: Exploring the materialization process of Liaoning Province

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ARTICLE INFO

Keywords:
Material footprint
Raw material consumption
Material flow analysis
Input–output analysis
Structural decomposition analysis
China

ABSTRACT

Liaoning Province is one of the most important industrial bases in China that is confronting the challenges of resource restriction during the rapid industrialization and urbanization process. To explore the materialization process on an economy, previous studies have focused on the Material Footprint (MF), a consumption-based indicator of resource use, at the national level, but few results are available at the subdivision level, especially in rapidly developing China. In this study, a Structural Decomposition Analysis (SDA) was conducted of the MF of Liaoning to understand the key drivers behind the consumption of raw materials. The results show that Liaoning's MF more than tripled, with an average annual growth rate of 13.4%, rising from 534 Mt to 1880 Mt during 2002–2012. Among the four material categories, nonmetallic minerals dominated the MF by 55–77% and contributed 83.3% to the total increase. From a sectoral viewpoint, construction dominated the MF by 65–85% and accounted for 90.8% of growth. In addition, among the four categories of final demand, investment played a prominent role in the MF, which more than quadrupled from 414 Mt (77.5%) in 2002 to 1701 Mt (90.5%) in 2012. The SDA results show that per capita final demand level was the strongest contributor, and that production structure was another chief contributor. In contrast, the significant improvement in material intensity and final demand composition played an important role in dematerialization of Liaoning. Optimizing investment towards less material-intensive sectors and designing mandatory targets for non-energy resources should be given more importance.

1. Introduction

Over the last few decades, China has become the "workshop of the world", and has experienced the most rapid economic development, leading to a huge increase in resource and energy consumption (Geng et al., 2013). Depressingly, most of them are transferred into waste and emissions as by-products during the production and consumption processes. Thus, it is now widely accepted that resource and energy consumption need to be decoupled from economic growth (UNEP, 2011, 2014), and developing sustainable consumption and production patterns has been selected as one of the 2030 Sustainable Development Goals for both China and the United Nations (Ministry of Foreign Affairs of China, 2016; UN, 2015).

Recently, an increasing number of studies have included China in the global material flow comparison, indicating that China has become the largest consumer of natural resources (Dittrich et al., 2012; Krausmann et al., 2009; Schandl et al., 2016b; Schandl et al., 2010; Wiedmann et al., 2015). Moreover, other studies have selected China as the only focused country to explore more materialization details and policy implications (Chen and Shi, 2012; Lu et al., 2017; Wang et al., 2012; Wang et al., 2013; Xu and Zhang, 2007; Xu et al., 2008b), showing that China's rapid materialization process is closely related to its industrialization and urbanization.

Among these studies, the Economy-wide Material Flow Accounts

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https://doi.org/10.1016/j.resconrec.2018.03.015
Received 23 November 2017; Received in revised form 16 March 2018; Accepted 19 March 2018
0921-3449/

(EW-MFA) method is the most commonly used and widely accepted, as it quantifies material flows that cross economic and environmental systems (Bringezu and Moriguchi, 2002; Fischer-Kowalski et al., 2011). For methodological harmonization and international comparison, Eurostat published a series of compilation guidelines for EW-MFA (Eurostat, 2001, 2007, 2013). Following the EW-MFA method, researchers commonly monitor the materialization process using Domestic Material Consumption (DMC), which is the sum of the domestic extraction of natrural resources and total physical imports minus exports. However, DMC has been criticized for its two incoherent parts: the domestic extraction (DE) of natrural resources and physical imports/exports, which include not only natrural resources but also manufactured products, and consider merely the amount of resources directly used by an economy. Thus, DMC can be simply decreased by substituting domestically manufactured products with imported products, which misleads assessments of national resource productivity (Giljum et al., 2015; Schoer et al., 2012; Wiedmann et al., 2015). Moreover, DMC cannot be considered for some sub-systems of a country because of the lack of physical trade flow statistics among regions (Xu et al., 2008a).

These two weeknesses, however, have promoted the development of a new consumption-based material flow indicator, namely Raw Material Consumption (RMC), which quantifies the allocation of used raw material extraction to the final demand of an economy. It demonstrates material consumption in its Raw Material Equivalents (RME) (Schaffartzik et al., 2015), and by this method trade flows should include the upstream raw material requirements that were associated with their production. Theoretically, RMC is equal to Domestic Extraction (DE) plus the RME of imports minus the RME of exports. Compared to DMC, which reflects an apparent consumption, RMC can include the upstream raw materials related to imports and exports and thus provide a more scientific way to assess the real resource consumption of nations (Wiedmann et al., 2015).

It has been suggested that the term "Material Footprint" (MF) be used for this indicator because of its similarity to other footprint indicators (Hoekstra and Wiedmann, 2014). Due to its superiority to the DMC, a body of literature has emerged recently using the MF method to assess national resource use from the consumption side (Eisenmenger et al., 2016; Giljum et al., 2015; Hatfield-Dodds et al., 2017; Schandl et al., 2016a; Schoer et al., 2012; Wang et al., 2014; West et al., 2016; Wiedmann et al., 2015). However, few empirical studies have focused on sub-systems of China, considering that their development levels differ significantly.

Liaoning Province, one of the three northeastern provinces in China, is studied as a MF case in this article from 2002 to 2012. Liaoning is comprised of 148,000 km^2 and a population of about 44 million as reported at the end of 2016. Liaoning is regarded as one of China's most important industrial bases, covering a wide range of industries, such as machinery, metal refining, electronics, chemicals, construction materials, petroleum and coal. Liaoning is relatively rich in natural resources, having the most iron, magnesite, boron, and diamonds among all province-level subdivisions of China. However, these resources do not satisfy the rapid development in Liaoning, especially after implementation of a revitalization strategy for old industrial bases in northeast China (SCC, 2003). Since then, the share of secondary industries and the urban population rate in Liaoning Province had increased rapidly (Fig. 1). Such rapid industrialization and urbanization has resulted in the consumption of a large amount of resources, which has constrained sustainable development in this region. Hence, Liaoning Province provides an important example of the relationship between economic growth and resource consumption during its rapid transition.

This study first calculated the MF of four material groups (biomass, fossil fuels, metallic minerals, and nonmetallic minerals) for Liaoning Province based on the environmentally extended input-output (EEIO) model and then quantified contributions of five socioeconomic factors to the historical changes of the Liaoning's MF from the supply side during 2002–2012 (including material intensity, production structure, final demand composition, personal final demand level, and population), using a Structural Decomposition Analysis (SDA) (Dietzenbacher and Los, 1998; Su and Ang, 2012). This study aims to help policymakers understand how the rapid industrialization and urbanization transition influences the materialization process at the regional level, which will provide a valuable reference for other regions with similar developmental paths. To the best of our knowledge, this is the first comprehensive analytical study on the MF and its socioeconomic drivers for sub-systems in China, fulfilling the resource consumption gap in China's sub-regions. Another feature of this study is that our derived DE data for Liaoning Province, which were calculated following the 2013 Eurostat guidelines (Eurostat, 2013), include more than 200 types of resources at the most specific levels, providing a sound foundation for the MF calculation.

The following section presents the MF calculation and SDA method used to explore the socioeconomic driving forces of the MF, as well as how the data were prepared for this study. Then, we present our results on changes in Liaoning's MF, its sectoral contributions, and changes in developmental patterns during 2002–2012. Based on the results of this case study, we discuss policy implications towards future resource management. The final section includes a conclusion.

2. Method and data

2.1. MF calculation

We applied EEIO methods to calculate the MF. Among them, single-region input-output (SRIO) models (Liang et al., 2016; Miller and Blair, 2009; Muñoz et al., 2009; Ou et al., 2017; Tian et al., 2014b, 2017) and multi-region input-output (MRIO) (Kucukvar et al., 2017; Lenzen et al., 2012; Liang et al., 2014b; Peters et al., 2007; Wiedmann et al., 2011; Wood et al., 2014) are most commonly used. Compared with SRIO models, MRIO models have the advantage of estimating the RME of imports based on actual technology levels of the producing country or region, but require a large-scale when dealing with data and normally offer more aggregated sectoral information (Eisenmenger et al., 2016). In contrast, SRIO models provide more information on sectoral transactions, but estimate the RME of imports under a domestic technology assumption. A hybrid lifecycle assessment method has been developed to overcome this shortcoming (Kovanda and Weinzettel, 2013; Lenzen and Crawford, 2009; Weinzettel and Kovanda, 2011). It helps to calculate the RME of imports using lifecycle inventory data, but only applies a limited number of products (i.e., those imported products that are not produced in the observed economy or some), as a result of a shortage of lifecycle inventory data. Therefore, choosing a model largely depends on the aims of the specific study.

We chose the SRIO model for Liaoning Province. The main reason is that we wanted to explore how rapid industrialization and the urbanization transition has influenced the materialization process, and more sectoral information will help provide a better understanding of the intersectoral influence of MF based on the industrial structural changes inside Liaoning. Moreover, Liaoning Province has a broad range of industries, and most of its imported materials and commodities are produced within the province. This advantage of Liaoning facilitates estimating the RME of imports based on "native technology". In addition, the MRIO tables have not been compiled by the Chinese government, and only a few studies have constructed them with fewer than 30 sectors.

Under the SRIO model, the RME of the products included in each sector's final demand $\boldsymbol{y}$ can be calculated by (Hertwich, 2005; Wang et al., 2014):

$$e = F(1-A)^{-1}y = FLy \tag{1}$$

Where $\boldsymbol{e}$ is the RME of the products in vector $\boldsymbol{y}$; $\boldsymbol{F}$ is a row vector of