Science of the Total Environment 478 (2014) 80–89

Contents lists available at ScienceDirect

Science of the Total Environment

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

Analysis of copper flows in China from 1975 to 2010

Ling Zhang [a], Jiameng Yang [a], Zhijian Cai [a], Zengwei Yuan [b,*]

[a] College of Economics and Management, Nanjing Forestry University, Nanjing 210037, PR China
[b] State Key Laboratory of Pollution Control and Resource Reuse, School of the Environment, Nanjing University, Nanjing 210023, PR China

HIGHLIGHTS

- An analytical framework is established for characterizing copper cycles in China.
- Copper flows of the specific years 1975, 1985, 1995, 2005 and 2010 are quantified.
- The utilization pattern of copper resource is illustrated.

ARTICLE INFO

Article history:
Received 8 November 2013
Received in revised form 16 January 2014
Accepted 19 January 2014
Available online 12 February 2014

Keywords:
Copper
Stocks and flows
Substance flow analysis
China

ABSTRACT

By applying substance flow analysis (SFA), the paper attempts to illustrate how copper utilization pattern has changed in the anthroposphere of China from 1975 to 2010. An analytical framework is firstly established and the detailed copper cycles of the specific years 1975, 1985, 1995, 2005 and 2010 are then characterized. Major conclusions include the following: (1) Chinese copper industry has made significant progress driven by large domestic copper demand since 1970s, especially after 1990s. Also the structure of copper industry has shifted from a basic industry to a processing industry. The share of secondary copper production in total refined copper has risen from 20% in 1975 to 38% in 2010; (2) the Chinese society has experienced a rapid copper accumulation since 1990s. The annual input flow to use stage jumped from only 334 Gg (that is 0.36 kg per capita copper consumption) in 1975 to 7916 Gg (5.90 kg per capita) in 2010; (3) a large amount of copper has to be imported to meet the huge demand, mainly involving in copper concentrate, refined copper and copper scrap. And the NIR (Net Import Ratio) of the three was 53.0%, 38.7% and 63.0% in 2010, respectively; (4) domestically produced copper scrap increased from 74.5 Gg in 1975 to 711.2 Gg in 2010. Comparing it with import scrap and domestic new scrap we found that at current stage the in-use stock is still too small to generate high quantities of copper scrap for domestic secondary copper production. (5) Major copper losses occurred through copper Mining, Refining and WM&R, with the Mining exhibited the lowest copper utilization efficiency (*CUE*) among the three processes, and may have the great potential for increasing copper utilization rate in China.

1. Introduction

Copper is a widely used fundamental material and is imperative for industrial and economic development. It is also one that may be potentially supply-limited, and one that in certain forms and concentrations is moderately biotoxic (e.g. Hall et al., 1998; Lander and Lindeström, 1999). Therefore, it is of interest to both resource economists and environmental scientists all over the world. As a direct result of its outstanding economic performance in recent years, China is now the biggest copper user in the world and is becoming the main driver of the overall global copper usage. Copper related industry plays an important role in Chinese industry system. Since the reform and opening up in 1978, copper industry has prospered with the expansion of industrial scale, shift of industrial structure and technological improvement. There are now 113 industrial sectors using copper containing products in China, accounting for 91% of the total 124 sectors (Xu, 2008). However, the copper industry has encountered increasing shortage of copper resources in recent years. For example, in 2007, the refined copper consumption was 4867 Gg, far more than domestic output of copper ore (i.e. 928 Gg). So 3890 Gg were imported in forms of copper concentrate, refined copper and scrap (China Non-ferrous Metals Industry Yearbook, 2008).

Under the circumstances, a series of policies have been put forward to regulate copper industry (NDRC, 2009). Meanwhile, many studies have been carried out to explore the development strategy of Chinese copper industry (Liu and Zhu, 2008; Gong and Zhou, 2005; Wang, 2005; Li, 2005), but most of them merely focuses on a single industrial sector among the whole industrial system, or the conclusions drawn were not based on a quantitative analysis for copper industry system (Jiang, 2007; Wang, 2007).

* Corresponding author. Tel.: +86 25 89680532.
E-mail address: yuanzw@nju.edu.cn (Z. Yuan).

0048-9697/$ – see front matter. Crown Copyright © 2014 Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.scitotenv.2014.01.070

Substance flow analysis (SFA) is an analytical tool which quantifies the pathways of a substance or a group of substances in, out and through that system (Brunner and Rechberger, 2004; Udo de Haes et al., 1997). It can provide relevant information for a region's overall management strategy of substance (Kral et al., 2013). Much SFA work has been conducted for kinds of substances at regional, national and global scales (Chen and Shi, 2012; Li et al., 2010). Specifically, a four-stage analysis framework (the Stocks and Flows, STAF) is put forward by the Center for Industrial Ecology at Yale University (Graedel, 2002). And the STAF framework is widely applied to investigate cycles of different metals (Graedel et al., 2005; Johnson et al., 2005, 2006; Mao et al., 2008; Wang et al., 2007; Spatari et al., 2005; Reck et al., 2008; Chen and Graedel, 2012; Lifset et al., 2012). After that, similar SFA framework was developed to examine the flows and stocks of a specific metal, such as aluminum (Chen et al., 2010; Chen and Shi, 2012). Additionally, there are also studies on substance flow analysis of a specific metal using different models (Cha et al., 2013). All of these have given useful guidance on resource utilization, environment and waste management. As for copper cycles in China, some SFA research has also been done in recent years. Graedel et al. (2004) have characterized the copper cycle of 1994 for several countries, including China. Chinese scholars, Yue and Lu have studied Chinese copper cycle of 2002 (Yue and Lu, 2005a, 2005b). Guo and colleagues have analyzed copper flows of China for 2004 (Guo and Song, 2008). Wang et al. (2008) have updated the work of Yue & Lu and Graedel et al on Chinese copper cycles, which compare Chinese copper cycle of 1994, 2000 and 2004. Zhang et al. has focused on the society use stage of copper cycle in China and estimated the amount and distribution of copper in-use stocks in Nanjing (Zhang et al., 2012). These studies show that the Chinese copper cycle illustrates a fully integrated, high-flow industrial economy since 1990s. And as a result, China has become more and more dependent on foreign supplies of copper ore, refined copper and copper scrap. However, all of the studies focus on Chinese copper cycles of recent decade, and long-term pattern cannot be observed, especially for years before 1990. Also, the cycle framework these researches adopted is relatively rough and hence detailed pattern cannot be observed.

By applying SFA, this paper provides a slightly modified framework for analyzing copper flows from the perspective of life cycle in China. Copper flows during 1975 to 2010 on national level are analyzed to investigate the evolution process of copper cycle. After quantifying copper cycles according to the framework, we analyze the change of copper flows during these decades to understand the utilization pattern of copper resource, including natural resources exploitation, recycling situation, and trade situation. Finally the paper ends by summarizing the conclusions that can be drawn. The results can reveal implications for further studies on resource policy, industrial development, and waste and environmental management. Besides, in consideration of China's important role in the world's copper industry, the analysis would be interesting to scholars, and other producers and users of the world copper market.

2. Methodology

2.1. Scope and system boundary

Considering the great expansion of copper production since the reform and opening up in 1970s in China, this paper is dedicated to examine the changes of flows in China from 1970s till now. For this purpose, it would be better to characterize copper cycles of each year during this period. However, this would require a huge amount of data which are difficult to acquire for China. Therefore, we quantify copper flows on a decade basis and characterize copper cycles for the specific years 1975, 1985, 1995, and 2005. The year 2010 was also chosen to show the copper cycle of the last several years. By examining the growth and structural changes of flows and stocks changes in these 5 typical years, an evolution process of copper cycle in China can be roughly observed.

The spatial boundary covers the geographical border area of mainland China, excluding Hong Kong, Taiwan and Macao.

2.2. Definition of life cycle process

As mentioned above, the Stocks and Flows (STAF) research project at Yale University has devised a SFA framework for analyzing the cycles of anthropogenic metals. In the framework, four life stages – production (P), fabrication and manufacturing (F&M), use (U), and waste management and recycling (WM&R) – are defined. In this work, we alter the STAF framework by differentiating the first two stages, that is, P and F&M. Specifically, (1) the P process is split into two sub-processes: Mining and Refining (the Refining process actually contains two sub-processes, i.e. smelting and refining, but we do not distinguish them in the study by using Refining to represent them). (2) F&M process is also differentiated to two sub-processes: Fabrication and Manufacturing. A slight-modified analytical framework is then established, as shown in Fig. 1, which consists of six life stages: Mining, Refining, Fabrication, Manufacturing, Use, and Waste Management & Recycling. The reason of splitting the production process is that the sub-process of mining generally represents copper mining industry while the copper smelting industry contains the sub-processes of “smelting” and “refining” (i.e. Refining process in this paper), so this division can help to show the flows of two industry sectors more clearly. Besides, these data are available in Chinese statistics system. F&M process is also subdivided because fabrication and manufacturing are relatively independent of each other in many of Chinese copper enterprises.

The flows entering and leaving these life processes can be classified into four categories: (1) the transformation flows that transform copper from one form to a different form (usually from one life process to the next life process), such as from refined copper (also called cathode) to copper alloy, and from copper alloy to copper semis; (2) import/export flows which link the Chinese anthroposphere and economies outside of the Chinese system boundary by exchanging copper-containing products; (3) loss flows which are mainly considered within three life processes, i.e., Mining, Refining, and WM&R. Loss flows in Fabrication and Manufacturing processes generally are recycled immediately and thus are excluded in the framework; (4) the recycling flows of copper scrap, including new scrap from Fabrication to Refining, Manufacturing to Fabrication, and old scrap from WM&R to Refining and Manufacturing stages. The details of symbols of flows/stocks in Fig. 1 can be seen in Table 1.

2.3. Calculation of copper flows and stocks

For the calculation of flows and stocks associated with each life process, the basic equations that govern the flow of materials adhere to mass conservation principles. Each process calculation uses a variation of the following equation to describe substance flows:

$$\Delta Stocks = \sum F_{input} - \sum F_{output}. \tag{1}$$

Eq. (1) expresses the net accumulation of copper within a defined process by adding all inputs and subtracting all outputs. F designates copper flows into and out of the process. The change in flow in a given time interval or the net accumulation or depletion of copper within the control volume is the change in stock ($\Delta Stocks$).

Eq. (1) is the most general expression for tracking substance flows in non-reacting systems. For the steady-state case where changes in stocks are negligible, Eq. (1) becomes,

$$\sum F_{input} = \sum F_{output}. \tag{2}$$