Science of the Total Environment 536 (2015) 142–149

Contents lists available at ScienceDirect

Science of the Total Environment

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

The future of copper in China—A perspective based on analysis of copper flows and stocks

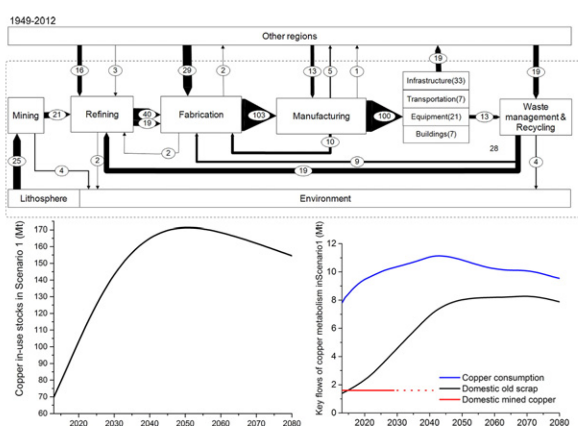
Ling Zhang [a], Zhijian Cai [a], Jiameng Yang [a], Zengwei Yuan [b,*], Yan Chen [a]

[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

- The highest peak of copper in-use stocks will be possibly achieved around 2045.
- Chinese copper industry will highly depend on imported copper until around 2020.
- Since 2060, the net import reliance will descend to 20% or lower.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 24 November 2014
Received in revised form 2 July 2015
Accepted 5 July 2015
Available online 21 July 2015

Editor: Simon Pollard

Keywords:
Copper
Substance flow analysis
Flows and stocks
Circular economy
Environmental management

ABSTRACT

This study attempts to speculate on the future of copper metabolism in China based on dynamic substance flow analysis. Based on tremendous growth of copper consumption over the past 63 years, China will depict a substantially increasing trend of copper in-use stocks for the next 30 years. The highest peak will be possibly achieved in 2050, with the maximum ranging between 163 Mt and 171 Mt. After that, total stocks are expected to slowly decline 147–154 Mt by the year 2080. Owing to the increasing demand of in-use stocks, China will continue to have a profound impact on global copper consumption with its high import dependence until around 2020, and the peak demand for imported copper are expected to approach 5.5 Mt/year. Thereafter, old scrap generated by domestic society will occupy an increasingly important role in copper supply. In around 2060, approximately 80% of copper resources could come from domestic recycling of old scrap, implying a major shift from primary production to secondary production. With regard to the effect of lifetime distribution uncertainties in different end-use sectors of copper stocks on the predict results, uncertainty evaluation was performed and found the model was relatively robust to these changes.

1. Introduction

China continues to enjoy a phase of rapid industrialization and urbanization, which generates a huge and continuous demand for basic

* Corresponding author.
E-mail address: yuanzw@nju.edu.cn (Z. Yuan).

http://dx.doi.org/10.1016/j.scitotenv.2015.07.021
0048-9697/

materials, such as steel, copper, aluminum, zinc, etc. For mineral resources in particular, which are nonrenewable, the severe pressure of resource shortage and related environmental pollution has gradually become an issue of national concern. As a major industrial metal, copper plays a fundamental role in the economic development of China. Meanwhile, total copper demand has been steadily on the rise since the 1980s with the rapid economic growth and societal development. The copper demand–supply gap for China has enlarged greatly in the last two decades (Zhang et al., 2012), accelerated by the insufficiency of copper ores (MLR, 2010). Therefore, it would is important to accurately forecast the copper utilization trend in China for strategic planning of the Chinese copper industry.

Forecasting the future trend of material flow and their corresponding stocks has attracted wide interest (Gerst, 2009), and corresponding methods have been gradually established. Particularly, studies analyzing future material cycles in the anthroposphere has led to the development of a stocks-driven model (Müller, 2006; Pauliuk et al., 2012; Hatayama et al., 2010; Pauliuk et al., 2013; Liu et al., 2013; Pauliuk and Müller, 2014), which has been detailed in a review of dynamic material flow analysis methods by Müller et al. (2014). In this model, the service provided by the in-use stocks is considered as the main driver of a material cycle. For the prospective copper use pattern of China, most future-oriented studies have made forecasts on copper demand or production by correlating the flows of copper consumption to external GDP projections (Zhang et al., 2012; Liu et al., 2010; Xu et al., 2010). However, copper consumption is easily affected by short-term oscillations, while the inertness and persistence of in-use stocks makes them suitable, robust long-term indicators of development. Under this circumstance, it would be well worth forecasting the copper utilization trend of China with a stocks-based model.

This article focuses on estimating futures of copper use for China. Since the future is based on history, analysis on a retrospective copper cycle is also within the context of this research. First, the evolution of copper flows and stocks from 1949 to 2012 were characterized and analyzed using dynamic substance flow analysis. Then the possible future trend of copper in-use stocks from 2013 to 2080 was extrapolated based on their historic patterns. By adopting a stocks-driven model, important flows within the copper cycle were then speculated. Key aspects were then proposed for maintaining the sustainable copper use. Finally by conducting a sensitivity analysis, the uncertainty of data used in the model was estimated.

2. Methodology

2.1. Accounting dynamic copper cycles

In order to speculate how copper flows and stocks have evolved in China, we define a six-life-stage model for analyzing copper metabolism within the anthroposphere, which consists of mining, refining, fabrication, manufacturing, use, waste management and recycling. In the mining stage, minerals such as copper sulfides are mined in two ways, surface mining and strip mining. Then, copper ore is crushed and ground to separate metal-bearing mineral from the gangue to produce concentrates and tailings. The concentrates are first fed into a smelter to produce blister copper (containing 98% copper) and slag; blister copper is further refined into high-purity copper (>99%), including refined copper and electrolyzed cathode copper (both called refined copper in the paper). Cathode copper then enters the fabrication process and is converted into semi-finished products such as wires and ingots. The manufacturing process encompasses production and assembly of more complex intermediate products, and final products which are often part of high-demand products such as automobiles and electronics. In this process, ‘prompt’ scraps are produced such as leftover materials and lathed scrap. They will get recycled internally or be returned to the refining process if impurities have been introduced. Some old scrap and copper wastes from domestic parts and imports also flow into the stage of manufacture and fabrication. Then, copper products enter the society use stage, which can be divided into four sectors, i.e., equipment, buildings, infrastructure, and transportation. These products will provide service for several decades, and are referred to as copper in-use stocks. Also, China is a net exporter in this stage, annually exporting various kinds of final products such as refrigerators, air conditioners, electric motors and generators, etc. On the other hand, an annual outflow of obsolete products are discarded and eventually become part of the waste management and recycling flow.

Fig. 1 describes the anthropogenic copper cycle in China. For calculation method of flows and stocks, see our previous research (Zhang et al., 2014). In this research, we further divide copper use into four categories (i) with specific product lifetimes: “Infrastructure” (such as electric power transmission and distribution, $i = 1$), “Transportation” (such as motor vehicles, $i = 2$), “Equipment” (such as household equipment, $i = 3$), and “Buildings” (such as residential buildings, $i = 4$). For the calculation of in-use stocks that are not detailed in Zhang et al. (2014), please see Zhang et al. (2015).

2.2. Forecasting future copper stocks and flows

A stocks-driven model is used to forecast future copper metabolism, which is based on the stocks-and-flows dynamics at the stage of society use. The details of the model used this research can be seen in Zhang et al. (2015). Based on the model, if the yearly amount of copper in-use stocks in the future are forecast first, then future inflows (domestic copper consumption) and outflows (copper scrap) of society can be calculated by determining the initial year of iteration.

For the prediction of copper in-use stocks, the stocks per capita and the population from 2013 to 2080 were extrapolated, respectively. Stocks futures forecast by Zhang et al. (2015) speculate on China's upper bound of copper in-use stocks. Based on the results, we modified the methods used to determine future trends of per capita stocks in the four major subsystems, i.e., electric power transmission and distribution (EPTD), household durables (HD), residential buildings (RB), and motor vehicles (MV), and then propose several scenarios for them, displayed in Fig. 2. The detailed assumptions for the scenarios as well as lifetime distributions for different end-use sectors can be found in this article's supplementary materials section. For population growth, medium variant projections from the United Nations Population Statistics Division are employed from 2013 to 2080 (United Nations, 2013).

Regarding per capita in-use stocks, the above considerations generated four scenarios for per capita in-use stocks, as shown in Table 1. Four scenarios for total in-use stocks will be further produced after combining population prediction, also called S_1, S_2, S_3 and S_4, respectively.

3. Results and discussions

3.1. Dynamic copper cycle from 1949 to 2012

Fig. 3 shows the cumulative copper cycle for China from 1949 to 2012. On the whole, approximately 25 Mt of copper was extracted from the lithosphere of China, and 53 Mt of copper was imported in the form of various copper-containing products to meet the huge domestic demand of 68 Mt. In total, around 10 Mt of copper waste was cumulatively generated in the form of tailings and slag and stored in waste reservoirs.

Further seen from the dynamic development of copper cycle (Fig. 4), all of the flows and stocks in the copper cycles have surged over the past six decades. It is also obvious that substantial increase of almost all flows and stocks occurred especially since the 2000s. This corroborates the boom in the Chinese economy in recent decade.

Fig. 4(a) approximately illustrates the evolution of main sectors of the Chinese copper industry, i.e. copper mining, copper smelting, and copper fabrication. The growth rate of these three sectors measured by the output has varied during the past 60 years. The ratio between