Resources Policy 52 (2017) 235–244

Contents lists available at ScienceDirect

Resources Policy

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

Assessment of potential copper scrap in China and policy recommendation

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ARTICLE INFO

Keywords:
Substance flow analysis
Copper consumption
Copper scrap
Scrap recycling

ABSTRACT

This paper investigated dynamic behavior of China's potential copper scrap generation based on previous consumption. China has consumed refined copper up to 95 million ton (Mt) for economic development from 1949 to 2013, which is mainly concentrated in equipment (36%) and infrastructure (45%). During the period, only 16% of consumed copper (about 15.5Mt) transformed to scrap and others were still in in-use stocks. While from 2014 to 2022, generated scrap is almost 1.2 times (about 18.3Mt) as much as that before 2013, over 50% of which are from equipment. This is due to majority of refined copper is consumed during the past decade. Therefore China would face explosive increasing scrap generation in the next two or three decades for temporal delay of social economic system. The ratio of recycling efficiency rate (RER) increased all the time and it's high to 58% in 2013. Although recycling copper scrap can conserve energy and reduce emission, it accompanied by some issues for increasingly complex composition. To alleviate the problem of copper shortage and make full use of huge potential scrap resources, some policy recommendations are put forward for the Chinese government: (1) Adjust copper resource policy and pay more attention to copper recycling industry. (2) Develop copper recycling industries to accommodate explosively increasing scrap and enforce extended producer responsibilities to recycle equipment by the way of reusing, remanufacturing and recycling etc. (3) For environmental and social problems, gradually guide copper recycling industry optimization. Make full use of rural-urban surplus labor force to construct social recycling network and encourage copper recycling enterprises improve technology and optimize plant design to reach the level of cleaner production.

1. Introduction

Copper is widely used in many fields for its good properties as heat conductor, electricity conductor, corrosion resistance and antimicrobial Characteristics. (ICSG, 2016) The consumption of copper ranks the third after iron & steel and aluminum (Li, 2010). China, the second largest economy in the world, has consumed large amount of copper for its social and economic development. China has been the largest refined copper consumer since 2004 in the world (Zhou et al., 2014). Currently, there is large gap between domestic production and consumption in China. The net import reliance of copper ore is over 70% (Wen and Ji, 2013), which is a big risk for China. Copper in-use stock per capita in China is 36 kg in 2012 (Zhang et al., 2014a), far less than that of developed country. It's estimated that China would still need quantity of copper resources for social development in the future. How to solve the problem to sustain the future consumption demand is a big problem. The first one is to discover and exploit more copper resources on the earth's crust. The second one is to recycle the old scrap from the retired copper products. However, as Chinese government has more concerns on the environment and sustainable development, many new mines are constrained under current technology and circumstance. Recycling and utilizing copper scrap obey the energy saving and emission reduction policy promoted by the government. It saves energy consumption 91 GJ and reduces solid waste and SO_2 emission 420.5 t and 0.14 t respectively to utilize copper scrap per ton (Li et al., 2011). From 1949–2013, China has consumed almost 95Mt refined copper for social development. Only small portion of copper contained products is retired and majority is accumulated in in-use stock for temporal delay (Zhang et al., 2014b). These copper products accumulated in society composed huge amount of hidden resource, which may provide copper resources in the future. Scrap recycling industry will be concerns of Chinese government when facing serious environmental problem.

This paper used dynamic substance flow analysis (SFA) to draw the picture of copper transformation flows through social system. SFA is a systematic method to analyze the input and output transformation within a spatial and temporal boundary (Brunner and Rechberger, 2004). Industry Ecology of Yale University put forward four-stage stocks and flows (STAF) model (Graedel et al., 2002). Then based on substance flow analysis, some researches have been done at the stage of production (Gordon et al., 2002; Wang et al., 2015), use (Geyer et al.,

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http://dx.doi.org/10.1016/j.resourpol.2016.12.009
Received 1 August 2016; Received in revised form 8 December 2016; Accepted 8 December 2016

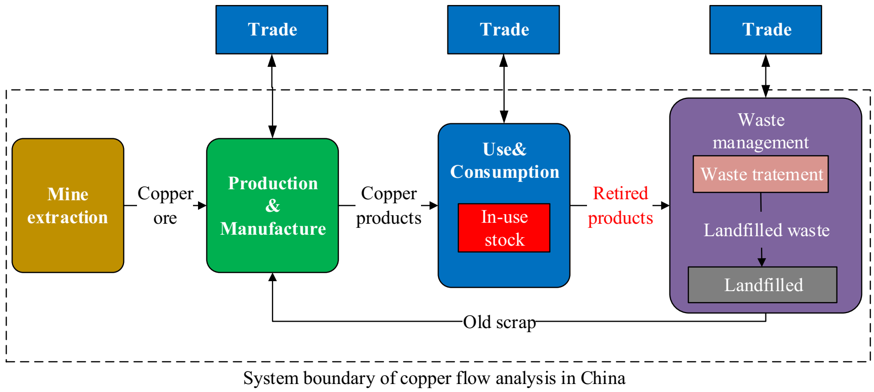

Fig. 1. Copper cycle from mine extraction to scrap recycling in China.

2007; Liu et al., 2013; Yue et al., 2016; Mao et al., 2009), waste management (Bertram et al., 2002; Melo, 1999; Davis et al., 2007) and all stages (Graedel et al., 2002; Chen et al., 2016; Tanimoto et al., 2010). Jaunky (2013) explored the relationship between copper consumption and economic development. In-use stock is one of the concerns among those researches. Many researches are on copper in-use stock (Glöser et al., 2013; Zeltner et al., 1999; Zhang et al., 2014a; Spatari et al., 2005), steel (Hirato et al., 2009; Yue et al., 2016; Davis et al., 2007; Park et al., 2011), lead (Mao et al., 2009), aluminum (Liu et al., 2013; Chen et al., 2012; McMillan et al., 2010; Buchner et al., 2015; Chen et al., 2012) and zinc (Beers et al., 2004; Yan et al., 2013). Besides, Müller et al. (2014) give an overview on calculating in-use stock method. Chen and Graedel (2015) put forward four ways to improve estimating in-use stocks. Yue et al. (2016) estimated iron in-use stocks in China using other ways as the average use life method and the fixed assets description method.

All these researches on in-use stocks contribute to knowing more about the metal accumulation in society, making the transformation from ore to metal products clearer. However, in-use stock in society is just like copper reserves in nature. In-use stock is just the potential resources and it is far from enough only knowing the quantity. The authorities would know the circumstance of scrap resources and make full use of these potential resources if knowing the transformation law from in-use stock to scrap flows. Melo (1999) analyzes the aluminum scrap generation in Germany, some research model steel scrap generation (Davis et al., 2007; Hirato et al., 2009). Wen and Ji (2013) analyzed future trends of Chinese copper resource using scenario analyses, stock-based prediction model and material flow analysis. Tilton and Lagos (2007) assessed the availability of copper in the long term. Gomez et al. (2007) explored copper scrap availability using an econometric mode. Elshkaki (2013) quantify future supply of platinum in secondary materials. Liu and Müller (2013) simulated global aluminum cycle using dynamic material flow analysis. Few researches are on copper scrap generation in China based on past consumption. Zhang have done a series of researches on copper in-use stock using Top-down and Bottom up way (Zhang et al., 2012, 2014ab; Zhang et al., 2015), which helps greatly on exploring the condition of copper scrap generation in the future. All copper products are actual consumption generally from official data (China Nonferrous Metals Industry Yearbook) and some researches (Zhang et al., 2015; Li et al., 2015; Cheng, 1994).

On the basis of those researches, this paper modeled copper metabolism by 2022 just based on refined copper consumption from 1949 to 2013. Through analysis, the goal of this paper is to explore the temporal delay laws from copper products to copper scrap through society. Then a series of problems concerned with copper metabolism would be discussed later. How much copper scrap will generate from in-use stock every year? How much copper is still temporally delayed in in-use stock? What's the condition of copper scrap recycling industry? When would majority previous consumed copper products get retired? This paper explored the transformation laws from copper products to scrap flows through society by solving these problems, which would help the government know more about these potential resources and make better decision. Then this paper provided corresponding policy recommendation for copper recycling industries and help Chinese government prepare in advance for embracing greatly increasing scrap generation.

2. Methodology

2.1. Scope and system boundaries

The scope of this paper is to quantify and analyze the scrap generation and recycling. To achieve the scope, this paper uses dynamic substance flow analysis (SFA) method. Substance flow analysis (SFA) can help trace the sources, the transformations, the pathways and the final sinks of a material (Brunner and Rechberger, 2004). The boundary of this study includes two parts: spatial boundary and temporal boundary. The spatial boundary is limited in the geographic border of mainland China. The temporal boundary is the period from 1949 to 2013. The aim of this paper is to estimate scrap generation based on refined copper consumption from 1949 to 2013.

The widely recognized anthropogenic copper cycle is based on four-stage copper cycle promoted by Yale University (Spatari et al., 2002; Graedel et al., 2002) as production, manufacture, use and waste management. Based on the emphasis of this study, this paper makes some adjustment and uses system dynamics (SD) method to have detailed analysis of copper scrap generation. Copper flow analysis in China is showed in Fig. 1. Copper lifecycle includes extraction from virgin ores, production of copper containing products, consumption, accumulation in social stock and scrap recycling. The whole copper lifecycle is a complicated system. For different copper end-use field, the lifetime of copper products is different. There is a temporal delay in society for different lifetime. So this paper uses SD method to present the simple transformation from inflows (refined copper) to copper in-use stock (inventory), and to outflows (scrap flows).

Based on SFA, the copper cycle from virgin ores extraction to scrap recycling is showed in Fig. 1. The emphasis of this paper is to explore the evolution from copper input flows to output flows through society. To have better analysis of transformation condition in society, this paper simplified Fig. 1 as Fig. 2 based on SD. The copper products consumption is simplified as refined copper consumption, not considering trade of copper semis and copper final products. Fig. 2 shows the transformation from copper products to copper scrap after the temporal delay of society. Society is the valve to regulate the transformation rate from copper products to copper scrap according to the residence lifetime model. P_i, P_t, P_e and P_b represent the rate of production as infrastructure, transportation, equipment, building in