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Quantification and spatial characterization of in-use copper stocks in Shanghai

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ABSTRACT

Shanghai is the largest industrial and commercial city of China, where in-use stocks of metals are likely to be significant. The in-use stocks of copper in this city are thus established by an extensive "bottom-up" study. Spatial distribution of copper stocks within Shanghai has further been characterized for better understanding of copper utilization pattern of this city. For the year 2012, the results are a total stock of 914.6 Gg Cu, and 38.4–64.1 kg Cu per capita. Nearly 94% of copper stocks distribute in subcategories of electric power transmission and distribution, water transmission and distribution, buildings, and household durable. Features of spatial distribution show that three central districts of Jing An, Hong Kou and Huang Pu have the spatial density of more than 1 Gg/km^2. And Chong Ming county and Jin Shan District have the lowest spatial density of about 0.01 Gg/km^2. It has been found that the copper stock density within Shanghai is largely determined by population density and economic development level.

1. Introduction

The amount of metal in-use stocks for a region or country can reflect that region's standard of living under currently available technology, and therefore is an indicator of the amount of metal that less-developed regions may need to put in place to attain comparable material services. Furthermore, the knowledge of the magnitude of metal in-use stocks is useful in estimations of the amount of that kind of metal that will be available for future recycling (Mao and Graedel, 2009). For this purpose, academic research has been done on analyzing or estimating in-use stocks of a specific material, especially for a metal (copper, lead, zinc, etc.) (Ciacci et al., 2013; Gerst and Graedel, 2008; Gerst, 2009).

Copper is an indispensable metal for industrial and economic development. It is also one that is becoming more and more supply-limited material for China. China has been one of the largest and fast-growing copper consumers in the world since the year 2002 (Xu, 2008). In 2011, apparent consumption of the refined copper in China reached 7300 Gg. Driven by this huge consumption demand, Chinese copper industry has been blooming since the late 1990s, with refined copper production climbing to 5179 Gg in 2011 (China Nonferrous Metals Industry Yearbook Editorial Board, 2012). Nevertheless, due to the poor quality of copper ore in China (Zhu et al., 1999), a huge amount of copper containing products, such as copper concentrate, refined copper and copper scrap, has to be imported to meet the domestic demand. Also illustrated by 2011, a total of 3153 Gg copper was imported. On the other hand, copper incorporated in products in use have been considerably accumulating in recent 20 years, and these in-use stocks could be potential reservoirs of secondary copper resources in the future.

For this reason, quantitative assessment of existing copper stocks in various repositories can be a useful attempt to allow the waste management industry to identify which waste categories should be targeted for the most efficient increase in copper recovery. There are a few studies focusing on copper in-use stocks of China, notably copper in Nanjing City in 2009 (Zhang et al., 2012), and copper at the country level at a rough estimation (Terakado et al., 2009), etc. However, as one of the data support for sustainable utilization of copper resource, it is clear that the copper in-use stocks in China have yet to be well characterized. Such as, how much of the copper resource is present (mainly involved in magnitude of copper stocks)? What is the distribution pattern of copper in-use stocks at city scale (including various repositories and spatial distribution)? etc.

In this paper, Shanghai city was chosen as a geographical area for a detailed assessment of the copper in-use stocks. Shanghai is the largest industrial and commercial city of China, and also the famous international metropolis. It covers an area of 6340 square kilometers (km^2), and has a population of 23.8 million (Household registered population). In 2012, the Gross Domestic Product

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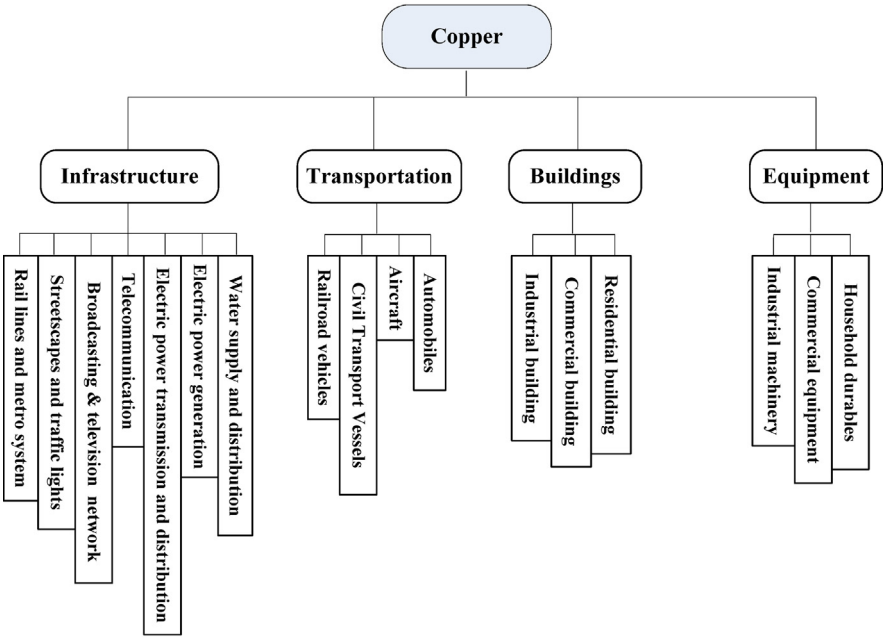

Fig. 1. Categories and subcategories of copper in-use stocks in Shanghai.

(GDP) and GDP per capita are about 329.5 billion US dollars ($) and 13,941$, respectively. The economic sectors in Shanghai are services by 60.4% of GDP, industry by 38.9% of GDP, and agriculture by 0.7% of GDP. It can be said that Shanghai is a developed economy with a high standard of living, where in-use stocks of metals are likely to be significant. Besides, much of the statistical data in this city is more available than other cities of China, which is essential for a detailed characterization of copper in-use stocks.

2. Analytical methodology

2.1. Calculation method

Two alternative methods are generally used to determine metal in-use stocks (Gerst and Graedel, 2008). The top-down method sums year-by-year the balance between the amount of metal entering use and the amount leaving use in the form of end-of-life products. Since direct data on metal discards are not generally available, the amount exiting use is determined by product lifetimes, usually represented by an appropriate distribution function. The geographical region considered in top-down calculations is usually a nation or larger region since metal production figures are usually available from national agencies. The bottom-up method of determining stocks in use relies on an inventory of all metal products within a bounded region, such as a city. Numbers of products and the content of the metal are determined. Proxy indicators are usually used to cover gaps in the data, as well as the impracticality of counting all individual metal-containing items. The bottom-up method has the advantage of showing where the metal is located.

The bottom-up method is facilitated by use of categories of copper-containing products, and the contents of copper in-use categories (also can be called reservoirs) are directly measured and counted one by one. In its simplest form, estimating in-use stocks via the bottom-up method is represented by

$$S_t = \sum_i N_{i,t} \times m_{i,t} \quad (1)$$

where S_t the is total in-use stocks of copper at time, $N_{i,t}$ is the quantity of final product i in use at time t, $m_{i,t}$ is the copper content of in-use final product i. It is worth mentioning that other calculation methods will also be used in a few cases if data of $N_{i,t}$ or $m_{i,t}$ is unavailable, such as calculating the amount of stocks directly on consumption information.

The categories used in the present study, listed in Fig. 1, were chosen to match as closely as possible the actual situation of China. The identified categories of copper in-use stocks are based on similar research (Rauch et al., 2007; Drakonakis et al., 2007; van Beers and Graedel, 2003), especially studies for China (Zhang et al., 2012), and supplemented by consultation with Chinese experts on copper fabrication sector. Chinese statistic database is also searched to make sure the structure of copper in-use stocks categories drawn reasonable and practical for Shanghai.

2.2. Data collection and calculation

To determine the amount of copper in-use stocks in the categories shown in Table 1, two kinds of data are needed: (1) the number of different copper containing products/service units existing in Shanghai; (2) the copper content per product/service unit.

The first kind of information is generally taken from official statistics (mostly from Shanghai Statistical Bureau, abbreviated as SSB in the following paragraphs) and published academic research. If these data is unavailable, estimation from industrial expert and engineer is the alternative data source. The second kind of information, copper intensity in these products is estimated based on kinds of sources and assumptions, like relevant research results, expert opinion, product observations and analyses, manufacturing standards, products specifications, etc. The following section briefly describes calculating method and data acquisition process, with all calculating formula and key parameters presented in Table 1.

2.2.1. Infrastructure

Infrastructure is one of the biggest categories of metal stocks. The systems with considerable amount of copper are water supply and distribution, electric power generation, electric power transmission and distribution, telecommunications, broadcast and television network, rail lines and urban rail transit system, and streetscapes and traffic lights.