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Estimating global copper demand until 2100 with regression and stock dynamics

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ABSTRACT

Future global copper demand is expected to keep rising due to copper's indispensable role in modern technologies. Unfortunately, increasing copper extraction and decreasing ore grades intensify energy use and generate higher environmental impact. A potential solution would be reaching a circular economy of copper, in which secondary production provides a large part of the demand. A necessary first step in this direction is to understand future copper demand. In this study, we estimated the copper demand until 2100 under different scenarios with regression and stock dynamics methods. For the stock dynamics method, a strong growth of copper demand is found in the scenarios with a high share of renewable energy, in which a much higher copper intensity for the electricity system and the transport sector is seen. The regression predicts a wider range of copper demand depending on the scenario. The regression method requires less data but lacks the ability to incorporate the expected decoupling of material use and GDP when the stock saturates, limiting its applicability for long-term estimations. Under all considered scenarios, the projected increase in demand for copper results in the exhaustion of the identified copper resources, unless high end-of-life recovery rates are achieved. These results highlight the urgency for a transition towards the circular economy of copper.

1. Introduction

Resource scarcity is one the main challenges facing human society in this century. Improving living standards, together with a world population that is expected to reach 9 billion in the year 2050 and could pass the 10 billion mark before the end of the century (UNDESA, 2015), are expected to push the demand for resources into unchartered waters.

One of these resources is copper, a ubiquitous metal in modern society. Copper demand has been growing rapidly all through the 20th century with no signs showing that it will be slowing down anytime soon. It is used in a broad range of applications, mainly because of its unique electricity conducting properties, which also makes it difficult to substitute. It will become even more crucial for the society in the future, given the expected increase of copper-intensive low carbon energy and electrification of transport technologies.

The rapidly rising demand may cause future supply problems and may contribute to environmental issues. For example, declining ore grades result in higher energy requirements for the same amount of copper extraction (Memary et al., 2012; UNEP, 2013a), thus increasing greenhouse gas emissions.

Circular economy has been proposed as an answer to tackle the challenges brought by the increasing resource demand (European Commission, 2015). Closing the material loop would help avoid resource supply problems, and would also reduce environmental impact by cutting the need for mining and energy use: secondary copper production requires only 20% of the energy used for primary copper production (International Copper Study Group, 2013).

A prerequisite for a circular economy of copper is an understanding of societal copper metabolism: the inflows and outflows, and the accumulated stocks. This provides essential information on the potential for closing the loop. There has been significant research in stocks, flows, and environmental impacts of metals (Daigo et al., 2009; Graedel et al., 2002; Kral et al., 2014; Lifset et al., 2002; UNEP, 2013a, 2013b, 2011, 2010; Wen et al., 2015). In addition, other research has suggested that around 85% of the copper that has been produced since the beginning of the 20th century is still in use (Wen et al., 2015), highlighting the

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Table 1
Socio-economic, population and technology development for each of the five Shared Socio-economic Pathway scenarios. Modified from O'Neill et al. (2014).

SSP scenario	Economy and social equality	Population	Technology
SSP1	High sustainable development with low inequalities. Fast technological innovation and change towards environmentally friendly and lower carbon intensive industries and energy sources.	Moderate population growth.	Fast technological innovation towards low carbon energy sources and industries.
SSP2	Intermediate between SSP 1 and 3.		
SSP3	Moderate economic growth and high inequalities.	Fast population growth.	Slow change in the energy sector, leading to high emissions.
SSP4	Heterogeneous development due to isolated economies. High social inequalities.	Intermediate population growth.	Heterogeneous technological development. Fast change towards low emitting technologies in key regions, but less development in lower emission regions.
SSP5	High economic growth and social equality.	Low population growth.	Carbon based fuel technologies, leading to high emissions.

potential of urban mining and copper recycling in general. But even if all the copper were to be recovered, it would not be enough, given that the copper demand is still growing, and it is only possible to reach a circular economy of a resource when the demand stabilizes. In this context, understanding how the copper demand will develop in the future is one of the central factors that will determine how and when a circular economy of copper can be achieved.

This paper explores how copper demand might develop until the year 2100 under different socio-economic and technology scenarios. Two methods are adopted to study this question, a top-down method, based on a regression model, and a bottom-up method, based on a stock dynamics model. Several studies have applied both a top-down and bottom-up approach in finding a demand or stock of copper, and give future prospects of the two (Auping et al., 2012; Elshkaki and Graedel, 2013; Zhang et al., 2015). Our aim, besides estimating copper demand, is to point out the differences in prospects between the two approaches in the long term. Moreover, a comparison of the results from the two methods provides an insight of the factors that are important in determining copper demand.

2. Methods

We employ two methods to answer our research question. The top-down method establishes the relationship between copper demand and general development variables such as GDP and population. The future trend can be extrapolated from the estimated relationship on the basis of empirical data from the past, similar to the approach employed by Halada (Halada et al., 2008). The advantages of this method include its transparency, its small number of assumptions, and most importantly its limited data requirement. Because of the lack of specificity in available inflow data in many cases, the regression method is less useful for regional estimations (Müller et al., 2014).

Bottom-up methods are usually applied in small-scale case studies, to estimate the stock dynamics of metals, and assess the environmental impact of the flows (Bergbäck et al., 2001). Here we have used such an approach in order to estimate future demands. The bottom-up method yields more detailed results than the top-down approach, i.e. results that can be related to the level of individual applications, but it also requires more data and assumptions.

The copper in-use stock estimation conducted by Zhang et al. (2015) uses both top-down and bottom-up analysis from 1952 to 2012 and looked into the historical events leading to societal changes corresponding to the stock development. Zhang et al. (2015) conducted top-down, bottom-up, and spatial distribution to strengthen its retrospective results regarding the copper stock in the past 60 years. Zhang et al. (2015) also used a bottom-up method to estimate future copper stock until 2050. The total in-use stock in Zhang et al. (2015) study peaks at 2030 and declines towards 2050. For this paper, we aim to point out the differences (or similarities) between the methods in a long term prospective estimation.

2.1. Scenarios for demand

In terms of the estimation for future demand, both methods need assumptions on how the society will develop. In this paper, we use the Shared Socio-economic Pathways (SSPs) scenarios (O'Neill et al., 2014), which explore how population and GDP, among other variables will develop in five different future social pathways. The SSPs consist of a narrative storyline and quantified measures of development, and describe feasible alternative development paths for the society and the planet during the 21 st century (O'Neill et al., 2014). The SSPs were developed in order to help climate research and policy makers in assessing the effects of climate change mitigation and adaptation measures for the research framework developed by van Vuuren et al. (2014). These scenarios were made based on two axis: the level of radiative forcing on the climate system and a variety of different possible global development trajectories (van Vuuren et al., 2014). Descriptions of the five scenarios can be found in Table 1. Both the bottom-up and top-down analysis use the scenarios in Table 1.

2.2. Stock dynamics method

The stock dynamics method starts from the stock of applications, and calculates demand as a derivative. The actual in-use-stock of the copper-containing products is the essential variable, and not the production. Demand is then calculated based on two considerations: (1) replacing the products discarded from the stock, and (2) allowing for net stock increase as a result of population and welfare growth.

The first step of the stock dynamics method is to establish the categories of products that contain copper. Next step is to collect data on the copper content and the quantities of these categories of products to determine the past and present stock of copper in use. Then, the future stock is calculated based on the assumptions of population and welfare growth as well as stock dynamics and stock saturation. Hereafter, steps are explained in more detail. Note that not all categories have had their copper demand calculated with this stock dynamics method. Describing the method as 'bottom-up' would be more correct, and so we mostly refer to it as such.

Besides the demand-side analysis, we performed an estimation of the secondary production of copper to provide further understanding of the role that secondary supply could play under the demand scenarios and potential depletion. The secondary production is derived using the same dataset of the demand estimation, although the estimation method is relatively less sophisticated, such comparison gives some information on whether the society would be able come close to circle the economy. Under the circular economy framework, we wish to explore to what extent mining from the societal stock could relieve the pressure exerted on natural reserve.

2.2.1. Category definition

We use the categories of copper applications as have been defined by Joseph and Kundig (1999) based on the weight percentage share per