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Assessing environmental implications associated with global copper demand and supply scenarios from 2010 to 2050

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ABSTRACT

Utilisation of resources is closely linked to population growth and economic and technological development. Hence, it is expected that global resource demand will increase substantially over the next decades. This resource challenge is currently partly addressed by the UNEP-IRP resource scenario activity, where metals, non-metallic minerals, and biomass resource availability and consumption scenarios are being developed. Advancements in the understanding of environmental impacts induced by anthropogenic activities indicate that large-scale exploitation of metal resources adversely affects the natural environment. Global copper demand is expected to grow significantly over the next decades, which is likely to result in increasing environmental stress and can be problematic for efforts to reduce the global environmental footprint. This research aims to estimate environmental implications of copper demand scenarios from present to mid-century by applying a life cycle sustainability analysis (LCSA) methodology. The results indicate that the environmental impacts related to global copper supply are expected to increase substantially between 2010 and 2050 – e.g., the carbon footprint is estimated to increase by 100% to 200%, depending on the scenario. This research discusses the main drivers of growing environmental implications of global copper supply scenarios and shows potential focus areas for mitigation policies.

1. Introduction

Growing world population, increasing global welfare, rising urbanisation rates, and technological development result in significant elevations of resource demand (UNEP, 2007). For some resources, demand rises faster than others. Copper (Cu) is such a resource – the global demand of refined copper has more than doubled between 1990 and 2015 (USGS, 1994, 2016). Copper is considered essential for various economic sectors, including electrical and communication wiring, infrastructure, electrical and electronic equipment, and transportation (Ayres et al., 2002; Mudd et al., 2012; Elshkaki et al., 2016). Since the drivers of copper demand are not expected to decrease over the next decades, it is expected that the demand for copper will increase significantly during this century (Kapur, 2005).

Production of raw materials poses environmental challenges in terms of resource depletion (e.g. copper ores), emissions and pollution (e.g. greenhouse gas emissions), and landscape impacts (e.g. conversion of natural habitat to metal mines). Metals are generally associated with high energy and material intensities, consequently resulting in high environmental impacts. Roughly 7–8% of global primary energy production is consumed by the metal sector (UNEP, 2013a). Rapidly increasing copper demands could be problematic for greenhouse gas (GHG) mitigation and for reducing other anthropogenic pressures on the environment.

Although the life cycle environmental impacts of copper production systems have been quantified in several studies (Krauss et al., 1999; Norgate and Rankin, 2000; Norgate, 2001; Ayres et al., 2002; Norgate and Lovel, 2006; Norgate et al., 2007; Classen et al., 2009; Norgate and Haque, 2010; Norgate and Jahanshahi, 2011; Northey et al., 2013), a quantification of the environmental impacts related to copper demand at global level is missing in current literature. Whereas some studies have addressed specific aspects of future copper supply (e.g., Harmsen et al., 2013), integrated explorations of future developments regarding copper demand and supply and the related environmental impacts are hardly available. Since copper is an important resource for many renewable energy technologies and since the production is expected to increase substantially over the next decades, this is an important gap in current literature, which we intend to address in this paper.

Here, we present a Life Cycle Sustainability Assessment (LCSA) methodology for assessing potential environmental implications related

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to global copper demand scenarios by combining a life cycle approach with metal demand scenarios for the period 2010–2050. We follow the methodology as outlined by van der Voet et al. (2018) and specify methodological choices and data below.

2. Methodology

The impacts related to copper demand depend on how the demand is supplied. Translating demand scenarios into supply scenarios includes, i.a., differentiating between copper production routes and technologies (e.g. primary and secondary production), specifying the amount of energy (influenced by energy efficiency, and ore grades), and type of energy (e.g. fossil or renewable) consumed during the extraction and production stages (Norgate and Rankin, 2000; Norgate and Haque, 2010; Norgate and Jahanshahi, 2010; Memary et al., 2012; Northey et al., 2013, 2014; UNEP, 2013b; Castro-Molinare et al., 2014; Kulczycka et al., 2016). As these variables change over time, the impacts related to copper production per unit will change accordingly (Mudd et al., 2013; Northey et al., 2013, 2014) – even if the total copper output would remain constant. Changing global supply quantity in combination with the changing global supply system (including the aforementioned variables) explain how environmental impacts might evolve on a decade timescale.

Life Cycle Assessment (LCA) is a tool widely used for quantifying and comparing environmental impacts of products and services (Finnveden et al., 2009). LCSA is a comprehensive framework originating from the field of LCA. In LCSA, the level of analysis of a traditional LCA is broadened by expanding spatial and temporal scales. The framework typically integrates models rather than being a model in itself (Guinée, 2016). Although we did not include these in this study, LCSAs may include social and economic impact assessments in concert with the environmental impacts with which the traditional LCA is concerned (Valdivia et al., 2011),

In the LCSA presented here, we use existing LCA methods and databases as a basis for calculating the current global average cradle-to-gate environmental impacts related to the production of refined copper (i.e., copper cathode). Subsequently, a temporal scale is added by including changing variables over time (e.g., production route ratios, amount of energy consumed during extraction and production processes, and types of energy consumed) to specify environmental impact scenarios of the per unit global average production of refined copper between 2010 and 2050. Finally, to upscale the average production model to the global level, the projected impacts per unit are multiplied with copper demand scenarios, whilst specifying various copper production routes, to quantify the environmental implications of the copper demand scenarios.

Environmental implications of copper demand scenarios are quantified by following three primary methodological steps. First, the current global average production system is modelled using LCA methods and databases to identify various distinct copper production routes and the related impacts per kg copper produced. Second, copper supply system scenarios are modelled from 2010 to mid-century based on projected developments in the supply system. Third, the copper supply system scenarios are aligned with the demand scenarios by specifying the supply ratios of distinct copper production technologies as part of the total demand scenarios and by linking specific supply system scenarios to the corresponding demand scenarios – i.e., linking IEA energy scenarios incorporated in the supply scenarios with the United Nations Environmental Programme-International Resource Panel (UNEP-IRP) LCSA copper demand scenarios. Once the supply system and demand scenarios align, the corresponding scenarios are multiplied to quantify environmental implications of the global UNEP-IRP copper demand scenarios.

2.1. Step 1: LCA of current global average copper production system

The scope in this study is the cradle-to-gate global average production system of refined copper, which can be supplied through two principal primary production technologies (i.e. pyrometallurgy or hydrometallurgy) or through secondary copper production (i.e. recycling of copper scrap) (Classen et al., 2009; Norgate and Jahanshahi, 2010; Elshkaki et al., 2016). A schematic representation of the pyrometallurgical, hydrometallurgical, and secondary copper production systems can be found in the Supplementary information (S1). Specific process data has been collected for the foreground system of pyrometallurgical, hydrometallurgical, and secondary copper production (i.e., copper recycling) from Ayres et al. (2002); Classen et al. (2009); Krauss et al. (1999); Norgate (2001); Norgate and Haque (2010); Norgate and Lovel (2006), and Norgate and Rankin, 2000). In short, pyrometallurgy refers to the metal extraction processes through smelting (i.e., high tempereature processes where chemical reactions take place). Hydrometallurgy refers to metal extraction processes involving leaching (i.e., applying aqueous solutions to extract metals from ores) (Ayres et al., 2002). Strictly speaking, secondary copper production falls under the category of pyrometallurgy. However, we adopted the terms pyrometallurgy to refer to primary pyrometallurgical copper production processes; hydrometallurgy to refer to primary hydrometallurgical copper production processes; and secondary copper production to refer to secondary (pyrometallurgical) copper production processes.

The Ecoinvent v2.2 database (Frischknecht et al., 2005) has been used for the life cycle inventory (LCI) background system. A detailed overview of all material and energy in- and outflows per production process of the LCI can be found in the Supplementary information (S2).

In the copper production stages, by-products such as Mo, Ag, Se, and Te, are generated (Ayres et al., 2002; Green, 2006; Classen et al., 2009; Mudd et al., 2013). This implies that not all environmental impacts of the copper production processes should be allocated to the production of 1 kg copper, but that part of the impacts should be allocated to the by-products. We applied economic allocation to these by-products, which is based upon the mass and economic value of copper material and the by-products.

For the LCIA, the CML2002 methodology and impact categories have been adopted (Guinée, 2016). Because of the importance of energy consumption for the magnitude of environmental impacts (Norgate and Haque, 2010; Kulczycka et al., 2016), the cumulative energy demand (CED) has been added as an indicator to quantify the total energy required for producing refined copper in each of the three copper production technologies.

In the LCIA, the environmental implications of each of the three global average copper production routes per kg refined copper produced are estimated. The results are presented in the Supplementary information (S3).

2.2. Step 2: copper production system scenarios

For including a temporal dimension into the model, the following variables that affect the environmental implications of copper production are considered: (1) developments in the background electricity supply mix, (2) ore grade degradation, and (3) energy efficiency improvements in the foreground system. Developments in the ratio of the different copper production routes are an important aspect as well, but this will be elaborated upon later in Section 2.3 when discussing the copper supply scenarios.

2.2.1. Background energy supply mix

To account for developments in the background energy supply mix from 2010 to mid-century, the International Energy Agency (IEA) World Energy Outlook (2012) energy scenarios have been adopted and incorporated into the LCA model (Verboon, 2016). This means that