Environmental implications of future copper demand and supply in Europe

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Abstract

Copper is the third metal by production volume after iron and aluminium, but its wide use in modern technology can be affected by high vulnerability to supply restriction due to the anticipated mine production peak. Securing access to copper forms is of particular importance for countries highly depending on imports, notably many EU Member States. Recycling of post-consumer scrap can help to reduce Europe's reliance on natural reserves and to reduce the environmental impacts associated with primary copper production, but end-of-life management of copper scrap is far from perfect recycling performance. In this work, we combined material flow analysis, scenario analysis and life cycle assessment to explore the possible evolution of copper demand in the EU-28 to 2050 and discussed the potentials for energy savings and climate mitigation achievable under the creation of a circular economy in the EU-28.

1 Introduction

Copper is a major metal utilized in many traditional applications such as plumbing and infrastructure, but it is also essential component in emerging technologies including photovoltaics and wind turbines.

Despite modest copper deposits in the EU-28 and a strong import reliance of primary copper forms to meet the domestic demand, the European Commission has not included copper in the Critical Raw Materials list (EC, 2017). However, the decrease of ore grade and the anticipated mine production peak (Vieira et al., 2012; Northey et al., 2014), should the global copper demand keep growing at current rates, could result in limitations to access essential materials for the European copper industry.

Recycling of secondary copper sources, in particular post-consumer scrap (or old scrap) can help to reduce Europe's reliance on primary sources and to to move towards a closure of material flows in accordance with the Circular Economy (CE) approach (Ellen MacArthur Foundation, 2013).

Recycling of anthropogenic reserves has the further potential of avoiding the use of large amounts of energy, which would be required in primary metal production because recycling is often significantly less energy-intensive. However, despite a well-established industry network in the copper value chain, the EU-28 is still far from perfect recycling and margins for improvements are remarkable (Ciacci et al. 2017).

In this work, material flow analysis (MFA), scenario analysis and life cycle assessment (LCA) were combined to (i) explore the possible evolution of copper demand in the EU-28 to 2050, (ii) evaluate opportunities and barriers for improving recycling at end-of-life; and (iii) assess the potentials for energy savings and greenhouse gas (GHG) emissions reduction achievable under the creation of a circular economy in the EU-28.

This comprehensive approach merges complementary research drivers in the analysis of the metal-energy-climate change nexus to analyse (i) the potential impacts of copper recycling on future secondary metal supply to provide materials for traditional application segments and greener energy systems, and (ii) the potential for energy savings and carbon emissions reduction associated with recycling in the copper industry.

We expect that the results will be of novelty and timely to inform decision-makers addressing topics such as energy policies and climate change for enhancing the growth of an economy based on resource efficiency and recycling in the EU-28.

2 Materials and methods

a. Modeling future copper demand and supply in the EU-28

Efficient recovery of secondary resources requires quantitative estimates of total scrap generated at end-of-life and available for recycling. This pre-condition for sustainable management strategies is seldom available and builds upon characterisation of elemental cycles in modern society.

MFA is often the preferred technique to understand the anthropogenic metabolism of materials (Pauliuk and Müller, 2014) and was applied to analyse copper at different geographical levels (Bertram et al., 2002; Ruhrberg, 2006; Glöser et al., 2013; Soulier et al., 2018). Based on a systematic application of the principle of mass conservation, MFA quantifies flows and stocks of resources. Extending the analysis to a wide time span of investigation, MFA enables to simulate the annual generation of post-consumer scrap as function of historical demand (i.e., flow into use) and the useful lifetime of products in use.

In this work, MFA was applied to determine the copper cycle in the EU-28 from 1960 to 2014 (Ciacci et al., 2017). The comprehensive retrospective provided constituted the evidence-based information on which the future domestic demand for copper was built.

More in detail, regression analysis was applied to analyse the relation between historical copper demand in the EU-28 and a set of independent variables. Population, gross domestic product, the level of urbanisation, and time as a proxy for time-dependent variables (e.g., technology evolution) are often adduced as the main drivers of resource use (Roberts, 1996; Elshkaki et al., 2016; Elshkaki et al., 2018) and were used in this work as explanatory variables of annual copper inflow to use.

Copper demand was disaggreted by major application sector including building and infrastructure, transportation, industrial machinery, electrical and electronic products, consumer and general goods. The regression equation applied in the analysis is in the form:

$$Y(t) = \alpha_0 + \sum_{i=1}^{n} \alpha_i X_i(t) + \varepsilon(t)$$

Where $Y(t)$ is the copper flow into use at time t, n is the number of explanatory variables, $X_i(t)$ are the explanatory variables at time t, α_i are the regression model parameters and $\varepsilon(t)$ is the residual of the regression model. The choice for the best fitting regression equations is based on the statistical parameters describing the adequacy of the model and the significance of the explanatory variables. The confidence level was set at 95%.

Then, the domestic copper demand to 2050 was explored by applying a "business-as-usual" scenario (named Market First, MF) and a scenario that sets the United Nations Sustainable Development Goals (SDGs; UNEP, 2017) as a priority (Equitability First scenario, EF). The two scenarios are founded on the UNEP GEO-4 scenarios (UNEP, 2007) and a description of their storylines is reported elsewhere (Elshkaki et al., 2016). Each scenario models growth rates of the explanatory variables to 2050 according to its underlying dynamics and simulate a possible evolution of the copper demand in the region.

The estimated future copper demand informed the MFA model to simulate the generation of copper old scrap to 2050. Lastly, LCA was combined with copper cycle information to generate first-order estimates of energy savings and GHG emissions reduction associate with copper recycling.

b. Modeling environmental impacts from future primary and secondary copper production

Being interested in the potential environmental benefits that may derive from a closure of copper cycle in the EU-28, we discussed the results under a European-centric perspective. Thus, for both scenarios, copper old scrap was assumed to undergo recycling in the region fulfilling the principles of the CE.

The degree to which post-consumer copper can substitute for primary copper was explored for constant recycling conditions and for "optimal" end-of-life recycling. The former condition refers to the case in which the current end-of-life recycling rate (EoLRR) remains stable to 2050, while the latter one models a hypothetical improvement of EoLRR to near-perfect recycling, determined as 90% collection rate and 90% sorting and pre-processing rate.

Cumulative Energy Demand (CED) and Global Warming Potential (GWP) were selected as impact assessment indicators. According to the ISO guidelines (ISO, 2006), credit was given to recycling for offsetting the energy required to produce the same amount of copper input to fabricators from primary sources (i.e., assuming a 1:1 substitution rate for recycled and virgin material).

Energy inputs for primary copper production include primary and final energy demanded for drilling, blasting, hauling, crushing and beneficiation of virgin ores plus energy required for smelting and refining.

Energy associated to secondary production includes energy inputs for collecting and pre-processing (e.e., transport and pre-processing) of copper old scrap and was distinguished between inputs to fabricators for direct melting and to secondary refiners for cathodes production. Generally, direct melting is supplied with copper scrap of high quality, but it may require inputs of virgin copper for dilution purpose due to the presence of alloying elements in the scrap input.

The current primary production of copper in the EU-28 has almost reached the installed capacity and, based on the known domestic copper deposits, it was assumed to remain constant in the coming years. However, imports will continue to be dominant in the copper supply to the European industry. The ecoinvent processes "*Copper, primary, at refinery*" and "*Copper, secondary, at refinery*" (Classen et al., 2009) were used to compute the environmental implications from global and regional copper supply in 2015 and as a basis to model scenario transition to 2050.

For primary copper production, the future energy required was determined by ore grade declining, the metallurgical route followed (i.e., pyro- and hydrometallurgy), and worldwide implementation of best available techniques (BATs). More in detail, the relation between energy demand and ore grade declining as function of the anticipated cumulative copper production was defined by (Mudd et al., 2013) and previously applied to global copper demand evolution (Elshkaki et al., 2016).

In addition, according to several authors (Kulczycka, 2016; Norgate and Jahanshashi, 2011), between 10%-60% of current energy requirements could be saved through worldwide diffusion of BATs (e.g., flash-smelting). For the EU-28, margins for energy savings were quantified at 30% as more than 70% of domestic copper is produced in plants with best available smelting and refining technology (Kulczycka, 2016).

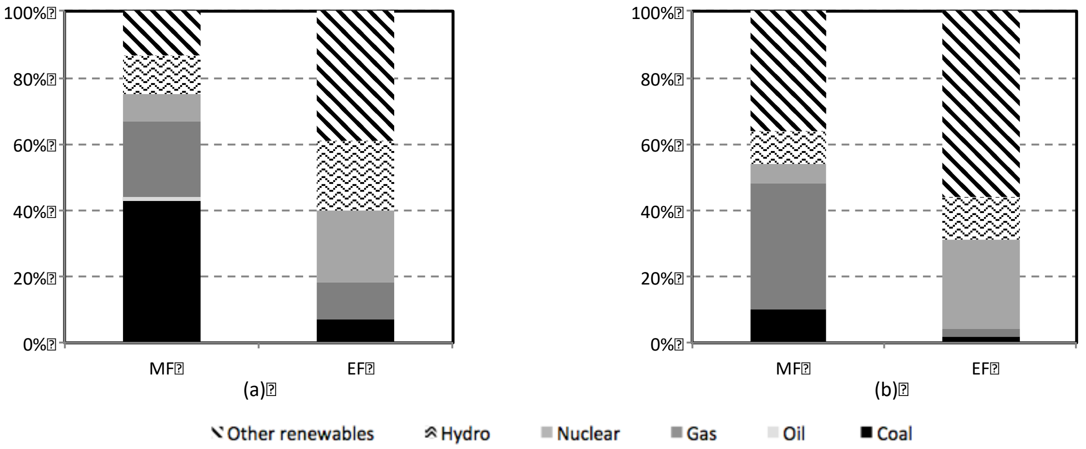

Figure 1: Electricity production mix for the world (a) and the EU-28 (b) in 2050 used in the model

For secondary copper production, it was assumed that the adoption of design for resource efficiency (e.g., design for disassembly, design for recycling) strategies offsets the additional energy requirements to improve old scrap recovery and achieve near perfect recycling. Thus, in first approximation, energy requirements for secondary copper production were assumed to remain constant to 2050.

Energy-related GHG emissions associated with primary and secondary copper production were distinguished between primary energy and final energy requirements. Carbon intensity values were set for primary energy sources (i.e., coal, heavy oil, natural gas, diesel, and blasting), while the carbon intensity associated to final energy was expressed as function of the electricity production mix in 2015 and 2050 (Figure 1). To this aim, the projections from the International Energy Agency (IEA, 2012) for the world and the EU-28, were applied to the copper scenarios. More specifically, the IEA Current Policies Scenario was set for MF, while the IEA 450 Scenario was considered for EF.

3 Results and discussion

Figure 2 displays the contemporary anthropogenic copper cycle in the EU-28. The results demonstrate that the EU Member States relies on imports of copper forms to meet the demand, with less than 20% of copper production being supplied from domestic reserves. Cumulative in-use stock amounts to 90 Tg Cu (or >200 kg Cu/capita), which almost doubles the known copper reserves in the region (~48 Tg Cu; USGS, 2017). Part of post-consumer scrap is recycled domestically, either sent to direct melting or secondary cathodes production. Part is net-exported, but the largest fraction of copper old scrap is not recovered and lost. (Ciacci et al., 2017)

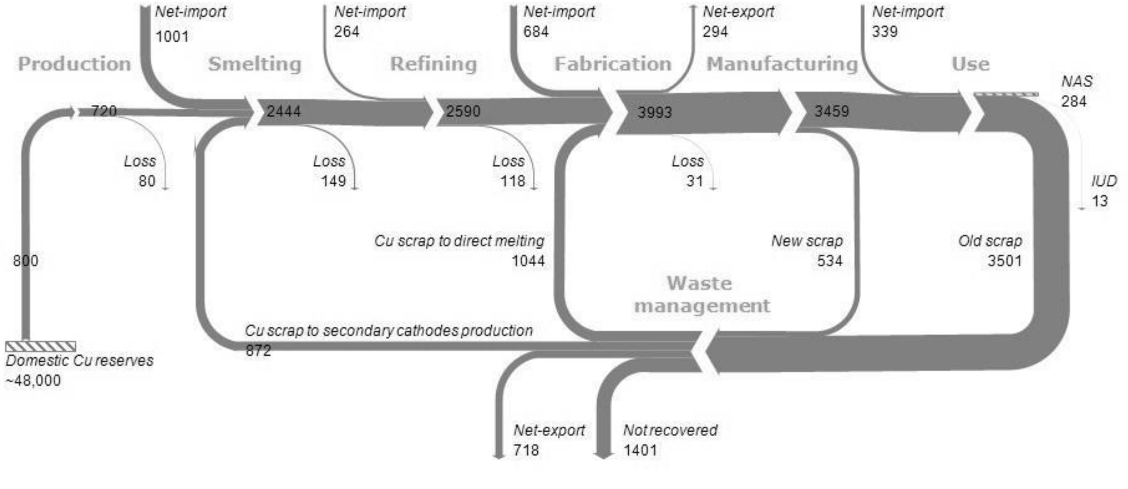

Figure 2: The anthropogenic copper cycle in the EU-28. NAS – Net addition to in-use stock; IUD – In-use dissipation. Values in Gg copper content. Reproduced from Ciacci et al. (2017)

The MFA model revealed that from 1960, the copper demand in the EU-28 has increased by about 1.6 times but, should the future follow the dynamics of a “business-as-usual” scenario (i.e., MF), the amount of copper demanded domestically will likely triple respect to current levels. This perspective implies severe constraints to a society based on secondary material sources.

As shown in Figure 3a, post-consumer scrap constituted about 50% of the copper demand in 2015. However, in case of a MF scenario, this ratio will likely decrease to less then 40% requiring more primary copper input at higher environmental costs due to the anticipated ore grade declining. Interesting to note, the increase in primary copper input would be also needed in case of "optimal" recycling.

In contrast, a world that would prioritise the SDGs will progressively result in a decrease of the copper demand to 2050. For instance, this positive situation could result from de-materialisation and decoupling strategies, which would lay the foundation for a circular economy in which the natural capital is preserved as secondary copper flows could even exceed the demand (Figure 3b).

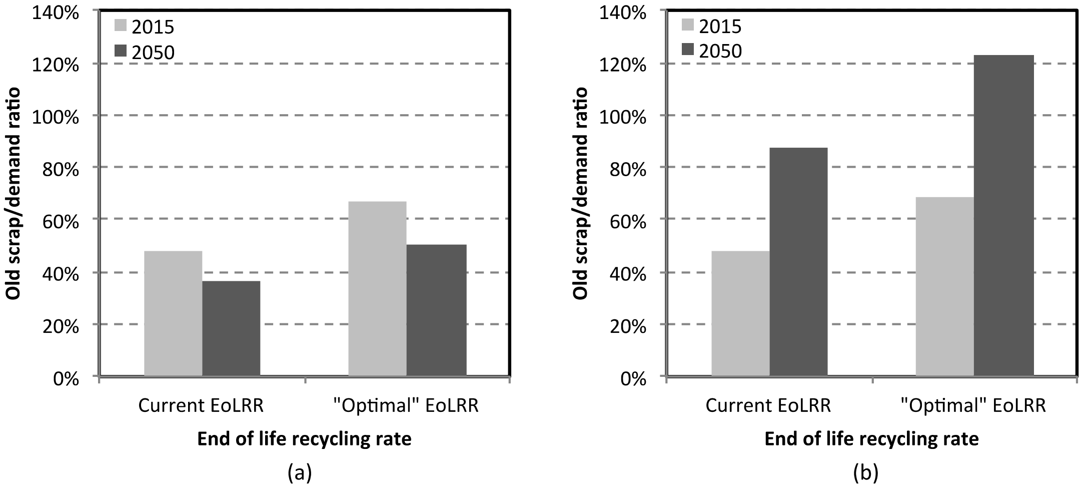

Figure 3: Recyled copper as fraction of total copper demand in the EU-28 in 2015 and 2050 for Market First (a) and Equitability First (b)

In terms of environmental implications, the results confirm that recycling can be significant in reducing primary material demand and the environmental impacts associated to virgin ore extraction and processing.

The greatest energy savings result for a EU-28 based on resource efficiency (e.g., enhanced recycling of post-consumer scrap, energy efficiency improvements in copper production, greater shares of renewable energy sources employed in electricity production), the effects of which are maximized in the EF scenario.

Interesting to note, in case of "optimal" EoLRR EF models surpluses of copper old scrap compared to the total demand, the recycling of which requires energy supplements. However, these energy increments are marginal compared to the energy savings offset from primary copper supply (Figure 4).

Potentials for reducing GHG emissions through recycling follow the same order. Putting the results in the context of the global climate challenge and assuming that each industrial sector must contribute proportionally to the 2°C target, we estimated that a world that follows the EF dynamics will likely fulfil the required reduction for GHG emissions at 50% below 2000 levels.

In contrast, the modest contribution of domestic recycling in light of the dramatic increase of future copper demand modelled by the MF scenario will determine an increase of 240-280% of the GHG emissions at 2000 levels.

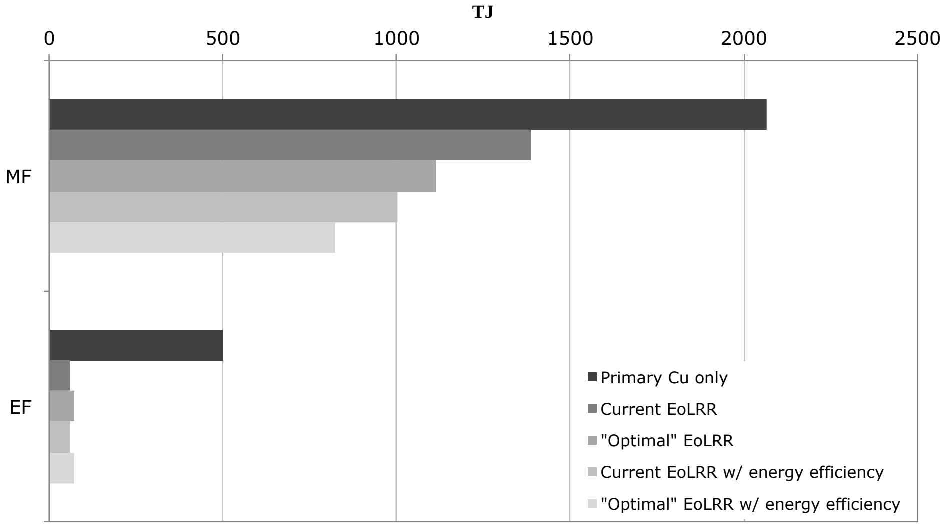

Figure 4: Energy requirements for copper supply to the EU-28 in 2050

4 Conclusions

The study constituted the first work integrating complementary life cycle thinking approaches such as MFA, LCA and scenario analysis to explore the future copper demand and supply from a Euro-centric perspective. The results can provide a foundation for complementary research lines including criticality assessments (EC, 2017), economic evaluations and environmental analysis (ICA, 2018) associated with the copper value chain.

Although the scenarios considered are not absolute predictions, but only a subset of the possible futures, the results demonstrated that secondary copper sources could cover a substantial part of the domestic demand if EoL recycling is adequately strenghtened.

However, the current recycling capability seems not enough to tackle the challenge of ensuring access to essential resources to the European copper industry while preserving the natural capital and mitigating climate change. Particularly, whether the world is expecting us is dominated by the current patterns of resource production and consumption.

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