Navigating the Future: Assessing Long-Term Global Copper Supply Sustainability Amidst Ambitious Energy Transition Goals

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Overview
As nations and industries pivot towards renewable energy sources, electric mobility, and green infrastructures, the demand for metals is expected to surge to unprecedented levels. This article relies on the theoretical modelling of metal markets in the long term to simulate the potential impacts of energy transitions policies on the price dynamics of copper on global markets. We use a framework based on the Cumulative Availability Curve (CAC) approach and incorporate demand-side factors such as the level of development and green transition goals. Results suggest that a) energy transition policies, especially those aiming for net-zero emissions, frontload the surge in demand for copper, yet b) over the next few decades the world demand for copper could also be driven by the unimpeded economic growth outside of energy transition considerations in major demographic regions, and c) around 2050, the world price of copper is expected to be quite comparable in both scenarios, and high by historical standards. In summary, this suggests that the sustainability of the demand for copper may be preserved although at a high price. Recycling and/or technological progress hold the potential to mitigate these sharp price increases.

Methods
This article relies on the theoretical modelling of metal markets in the long term in order to simulate the possible impacts of energy transition goals on the price dynamics of some metal commodities.

On the supply side, we build on the Cumulative Availability Curve (CAC) approach (Tilton et Lagos, 2007; Tilton et al. 2018): the CAC of an exhaustible natural resource is the graph of the function that relates a given price of this resource to the total world stock economically exploitable at this price. The CAC differs from the traditional supply curve in economics textbooks, which describes the flow of goods offered on the market for a given period (usually one year) as a function of price. The CAC corresponds not to a flow over a given period, but to a global stock available for the future. It shows the total quantity of natural resource recoverable in the economic sense of the term as a function of the price level. However, like the traditional supply curve, the Cumulative Availability Curve assumes that apart from price all other determinants of metal availability are fixed (including exploration and production costs, and technological level).

The CAC distinguishes the economic effects of three types of factors that influence the sustainability of global metal demand, namely:

1) Factors determining the shape of the CAC mainly reflect geological phenomena (ore content, depth, etc.) that affect future extraction costs.
2) Demand factors shifting the market equilibrium point are mainly linked to economic phenomena, such as global per capita growth, the level of industrial development of emerging countries, the metal intensity of low-carbon and digital transitions, and the effect of government policies in favour of metal recycling.
3) Mechanisms shifting the CAC to the right, such as technological progress which reduces the cost of metal extraction and production.

On the demand side, we determine the exogenous global demand levels for metals. These demands levels are driven by two main phenomena: i) the energy transition goals, and ii) the economic development of demographic powers.

Regarding the first aspect, we begin by defining energy transition scenarios, following the International Energy Agency's (IEA) nomenclature: Stated Policies Scenarios (STEPS), Sustainable Development Scenario (SDS), and Net Zero Emission by 2050 (NZE). We also consider a benchmark scenario that does not include any energy transition goals. Then each of these scenarios entail annual targets in the deployment of a wide range of clean energy technologies, among which low-carbon power generation technologies (solar photovoltaic panels, wind turbines, hydrogen electrolysers and fuel cells), electricity networks, electric vehicles, and battery storage. Finally, for each of the clean energy technologies, the overall mineral demand is derived using four main variables: clean energy deployment trends, sub-technology shares within each technology area, mineral intensity of each sub-technology, and mineral intensity improvements. Projected mineral demand levels are highly dependent on the stringency of climate policies reflected in the different scenarios as well as potential technology development pathways.

Regarding the second aspect, for countries in the process of industrial take-off (Lewis, 1954) the construction of infrastructures in the heavy industry, housing, transport and communications sectors implies a surge in the consumption of metal ores (in particular so-called structural metals iron, aluminium, and copper). It is therefore expected that demand for structural metals will be significantly sustained by large demographic powers (such as Indonesia, India, Pakistan, and the currently most rural Chinese provinces) that have not reached the Lewis point, *i.e* a wealth level estimated at $15,000 Gross Domestic Product (GDP) per capita (Vidal 2018). As a consequence, we assume increasing metal content of per capita GDP for developing countries until they reach the Lewis point, after which the metal content of per capital GDP is assumed to be decreasing (Malenbaum 1978, Bringezu et al. 2009, Jia et al. 2021).

From the Cumulative Availability Curve (linking market price of the metal commodity to supplied volumes) and the computed exogenous demand levels driven by energy transition and economic growth, we derive a sequence of price-quantity pairs for all annual periods on a 2020 to 2050 horizon. The demand adjustment to market price is computed using the US Bureau of Mines's lagged demand curve (MIDAS-II model), which matches demanded quantity to price while taking into account short-term and long-term price elasticities.

Finally, our theoretical model is calibrated for copper, a significant metal in the energy transition. Copper not only plays a crucial role in the transition to renewable energy but also provides reliable and readily available time series data over a satisfyingly long time interval.

For the calibration: GDP and population growth projections are derived from the OECD Economic Outlook, demand price-elasticities are taken from Fernandez (2018), data for copper consumption, production, reserves, and resources are USGS estimates, and 2020-2050 demand estimates are from the IEA's 2021 report The Role of Critical Minerals in Clean Energy Transitions.

Results

The results of the numerical calibration for copper highlight how this metal can be identified as a potential bottleneck in the context of the energy transition. The more ambitious the energy transition scenario is, the stronger the bottleneck on metal supply becomes. In a net-zero emission scenario long run equilibrium prices of copper may increase significantly — by around 60% in the next decade — reaching historical highs and persisting at elevated levels over a decade, which is significantly longer than observed in previous peak periods. The price peaks, primarily occurring around 2030, are caused by two key factors. Firstly, the surge in demand is front-loaded in the net-zero emissions scenario, where renewable energy production requires substantial metal inputs upfront for infrastructures like wind turbines and batteries. Secondly, the initial price boom triggers a supply response, mitigating market tightness after 2030.

Results also suggest a demand for copper primarily driven by unimpeded economic growth in major demographic regions globally. Unlike green energy production, which necessitates upfront metal usage, the continuous expansion of these economies itself becomes a driving force for copper demand across various industrial and infrastructural applications. Therefore, even in the absence of initiatives promoting sustainable energies the demand for copper remains significant due to the ongoing economic dynamism.

This highlights the necessity of considering not only factors associated with the energy transition but also the direct influence of economic growth on metal consumption.

Conclusions

The results bring about several policy implications. Given the uncertainty surrounding the energy transition there is a risk of delayed metal production investments without timely supply adjustments. A globally coordinated climate policy in order to signal gradual commitments could avert cost hikes in low-carbon technologies.

Expanding the model to incorporate secondary supply through improved recycling rates has the potential to alleviate the prevailing supply constraints and foster a more sustainable equilibrium. Acknowledging the potentially circular nature of metallic commodities by enhancing the efficiency of recycling processes would not only contribute to resource conservation but also serve as a strategic lever for easing the strain on primary metal production.

From the public decision maker's perspective, addressing the introduction of a tax fostering intergenerational equity in metal consumption could be a further extension to the model. Departing from the utilitarian framework of intertemporal utility maximisation, such a tax mechanism would serve as a dynamic instrument to potentially help smoothing the demand and supply curves over the horizon. In particular, the generated revenue could be strategically directed towards preventing demand destruction in the face of soaring metal prices, potentially hindering and delaying the green transition schedule.

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