DECARBONIZING THE COPPER SECTOR

Discussion Topics and Considerations for a 1.5°C-aligned Trajectory and Target-setting Methodology

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Acknowledgements

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Executive Summary

Copper production today is a small share (~0.2%) of global greenhouse gas (GHG) emissions. However, the sector also needs to expand production (including by doubling primary output by 2050) to support the overall energy transition as copper is a critical component for several key technologies including EVs, solar & wind power generation and transmission infrastructure. This expansion coupled with challenges (including eliminating diesel in large haul trucks or electrifying high temperature heat) to reduce emissions within the copper supply chain itself means that, without intervention, the sector could be >2% of global GHG emissions by 2050.

This report outlines the key issues to be addressed in the development of a copper specific 1.5°C-aligned target setting methodology (i.e., a sectoral decarbonization approach or SDA) similar to those that were recently developed in other sectors such as steel and aluminum. The SDA aim is to provide copper producing companies with a clear methodology to set emissions reduction goals that are in line with the 1.5°C target and which account for both the growth needed in copper production and the sector-specific challenges to decarbonization. Through stakeholder interviews and review of previous publications on copper trajectories, the following issues were identified to be addressed during the development of an SDA:

- Setting a consistent scope and system boundary — which needs to balance the goal of maximum coverage while also finding a sufficiently common endpoint to enable companies with varying levels of vertical integration to set targets.
- Considering different production routes within the target-setting method — large differences can exist in the emissions footprint and sources between the different routes (i.e., hydrometallurgical vs. pyrometallurgical) for copper production.
- Incorporating the impacts of recycled material — which will be a key lever to decarbonize the sector but cannot be the only focus given the needed near-term production growth.
- Accounting for co-products — given the large degree of flexibility in methodologies to account/allocate these emissions it will be necessary to ensure the trajectory/target-setting and accounting methods are aligned.
- Variance between regions and impacts of policy — which was highlighted as the main driver for the type and ambition level for company targets in some locations.
- Uncertainty on the decarbonization technology including on cost, availability, and time to implement — which is critical for setting the sector benchmark on pace of emissions reductions aligned to a 1.5°C scenario. Significant work has already been completed on this topic and will be leveraged into the target-setting method.

We plan to address each of these issues in an open and consultative approach to the development of a copper specific SDA following the release of this report.

Background

Copper production accounts for 0.2% of global anthropogenic greenhouse gas (GHG) emissions currently.[1] But, this share can increase significantly in the coming decades. Some estimates show that without intervention to reduce emissions, the copper cycle could contribute up to ~2.7% of the GHG emissions by 2050.[2] At the same time, copper plays a critical role in many of the technologies needed to decarbonize the global economy, including solar, wind power generation, electric vehicles, and electricity transmission. As a result, the copper sector faces the dual challenge of expanding production to meet the needs of the overall energy transition while at the same time reducing its own emissions in line with the global carbon budget.

To stay within a 1.5ºC-aligned carbon budget, the copper sector will need to substantially reduce its GHG emissions. However, current global integrated assessment models (such as the IEA's Net-Zero Emissions (NZE) scenario) used to understand the carbon budget for various sectors (e.g., power, steel, etc.) do not extend to copper.[3] Previous work has aimed to fill this gap either with a proportional approach or a bottom-up sectoral model based on inputs from global models.[4] However, copper producing companies still do not have an industry-approved 1.5ºC climate-aligned GHG reduction trajectory and/or target-setting methodology based on those trajectories that they can use to set their GHG emissions intensity targets.

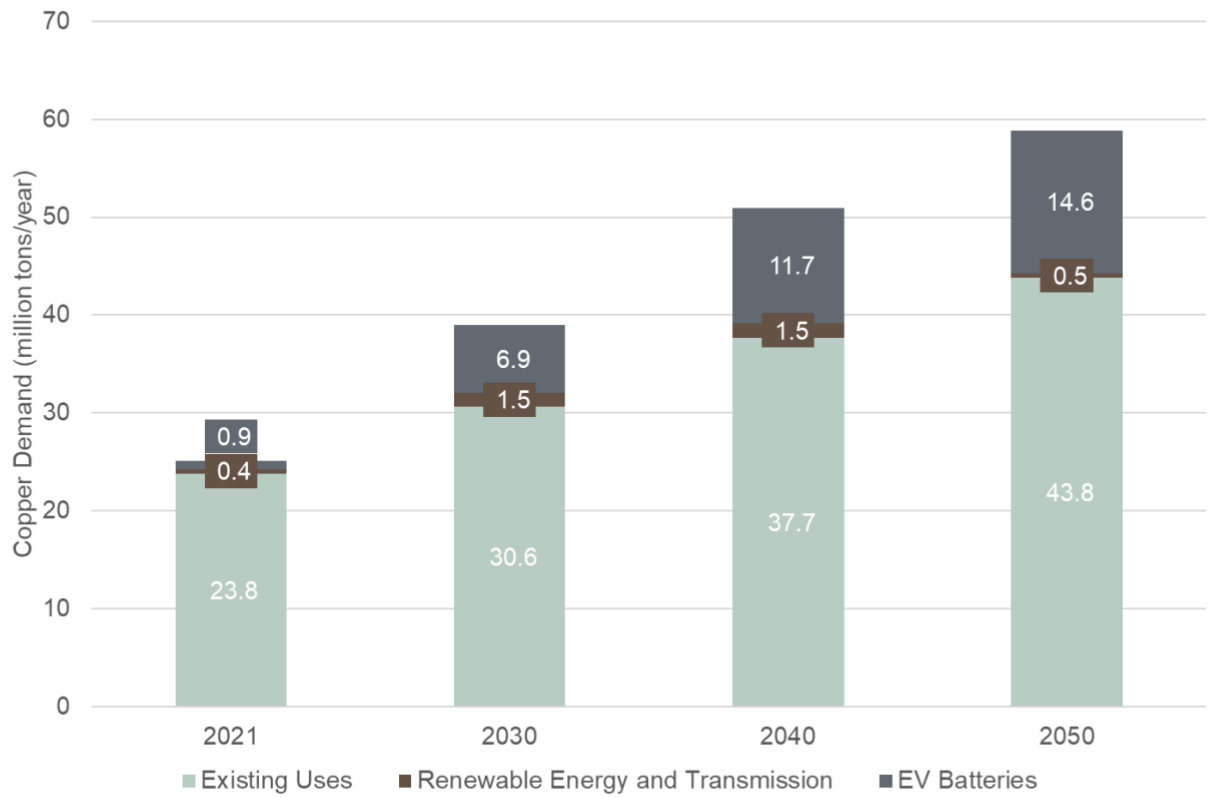
There are two key reasons for developing a copper-specific decarbonization trajectory and associated target-setting methodology (i.e., a sectoral decarbonization approach or SDA):

1. Growth — a copper-specific trajectory and methodology enables target setting on an intensity basis which allows for the production growth needed while simultaneously reducing production emissions.
2. Technology — decarbonization of copper production will need technology solutions (e.g., elimination of diesel from large haul trucks or electrification of high-temperature processes) that may have different cost profiles and development timelines than decarbonization technologies considered in global models.

Growth of the Copper Sector

Unlike some industrial materials and metals, the growth in the copper sector will not just be due to population growth and general trends in economic development. There will be a significant increase in copper demand from the deployment of technologies like renewable energy generation and electric vehicles that are crucial to the energy transition associated with a 1.5ºC climate-aligned future. Based on these scenarios, global copper demand is expected to be around 59 million tons in 2050 (more than double the demand in 2020).[5] Roughly 25% of this demand in 2050 is expected to come from installation of renewable power generation facilities (solar, wind, and others) and other low-carbon technologies (electric vehicle batteries and charging infrastructure, grid batteries, transmission infrastructure). Electric vehicle (EV) batteries represent a major portion of this new copper demand (see Exhibit 1). The 1.5°C climate-aligned copper SDA needs to reflect the increase in end-use demand as it will impact both the pace of decarbonization for the sector (e.g., via declining grades, locations of new supply, etc.) as well as the emissions intensity needed to stay within an overall sectoral carbon budget.

Exhibit 1 Increase in Copper Demand from Energy Transition Technologies



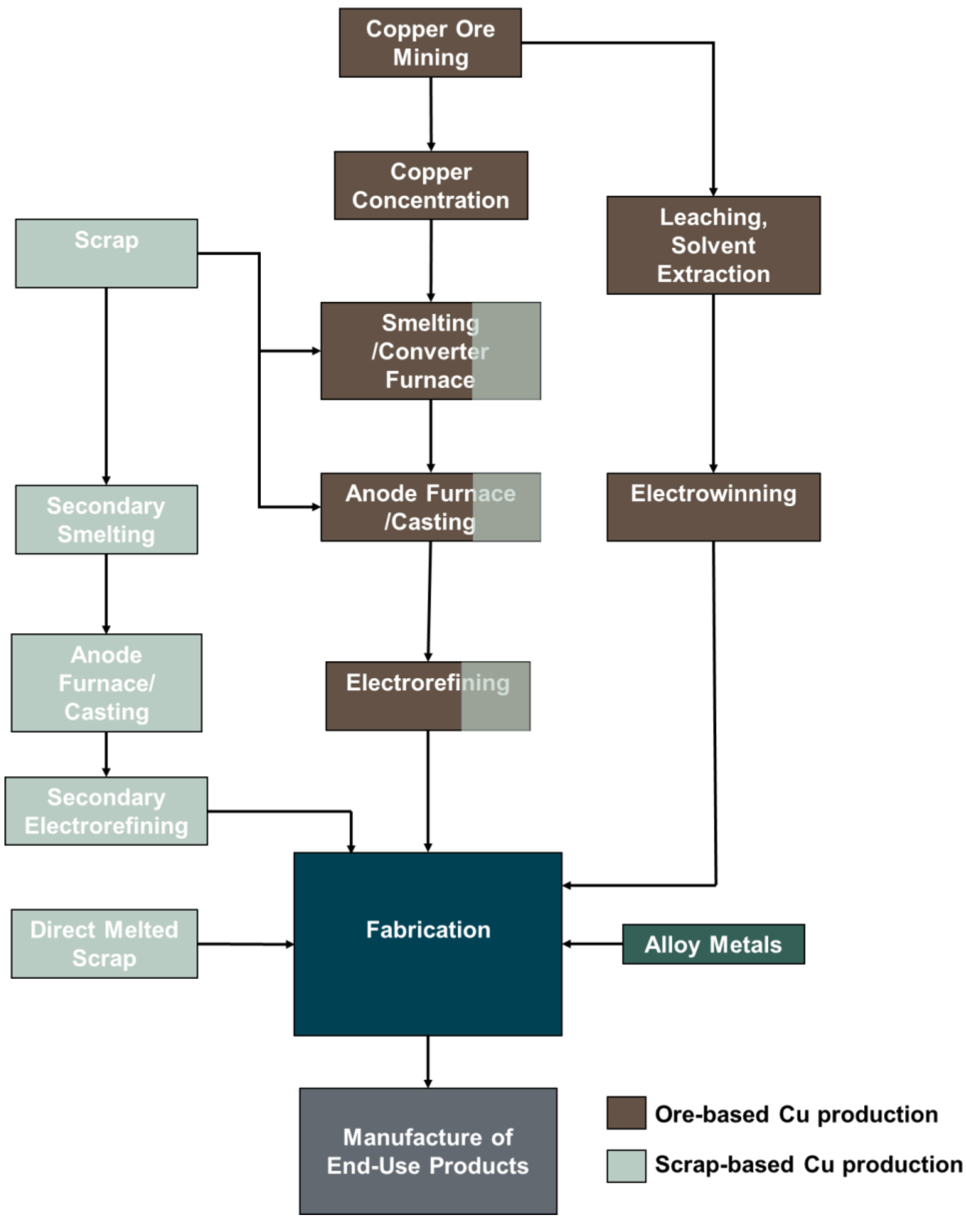
Data Source: *Net Zero Roadmap for Copper and Nickel Mining - Technical Report*, 2023.

Unique Decarbonization Challenges

The copper production value chain consists of several processes with various GHG emissions sources (see Exhibit 2). The mining and concentration processes together contribute 65%–80% of the total emissions from mine-to-copper cathode production. More than one-third of the total emissions come from the use of electricity at mine sites and at concentrate production facilities. The use of diesel at mine sites (for haulage trucks) is responsible for 15%–18% of the total emissions. Smelting and refining of copper cathodes are responsible for 20%–35% of the total emissions.[6]

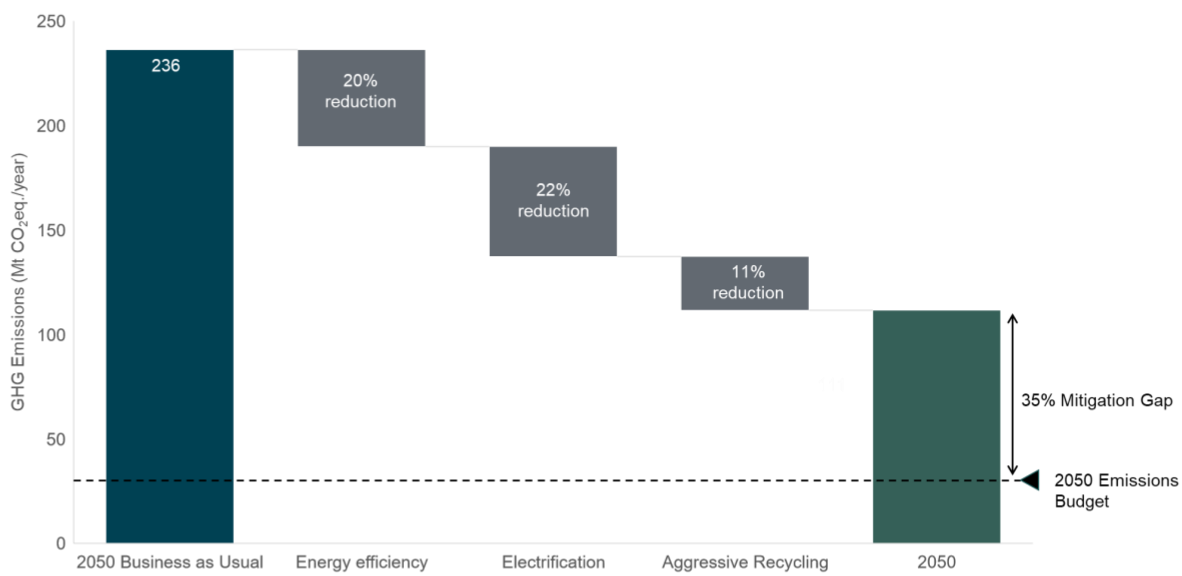
The diverse nature of the emissions sources along the copper value chain means that the decarbonization potential of various technologies targeting the each of the emissions sources is different. This decarbonization potential also varies with time as different technologies mature and become commercially available. For instance, decarbonized electricity (either from on-site/grid-based renewable electricity or power purchase agreements [PPAs]) is a key decarbonization lever already being deployed on mine sites. Whereas technologies to utilize hydrogen instead of natural gas for high temperature heat or electrify open-pit haul trucks are still in the pilot phase.[7] The copper sector may also have opportunities for decarbonization that are not reflected in global models such as mining-specific energy efficiency (which one estimate showed could contribute to 7%–12% of the emissions reduction needed for the sector[8]), for example via novel ore sorting technologies. The use of standard economy-wide GHG emissions intensity targets (e.g., 50% reduction by 2030 and 90% reduction by 2050) does not incorporate all these nuances.

Exhibit 2 Various Production Processes in the Copper Value Chain



The implementation of simple decarbonization strategies like energy efficiency improvements and electrification of process heat generation (for low, medium temperature processes) combined with aggressive recycling won't be sufficient to keep the copper sector emissions below the 1.5ºC climate-aligned emissions budget. In 2050, for instance, these strategies can only reduce sectoral emissions by 53% compared to the business-as-usual scenario. An additional 35% emissions reduction is needed to stay within the emissions budget. Therefore, relying on common economy-wide strategies for reducing GHG emissions is not enough to achieve the necessary emissions reduction in the copper sector. The appropriate decarbonization technologies should be implemented at the appropriate time to close the emissions reduction gap each decade. An SDA approach to setting GHG emissions reduction targets can serve as a strong driving force for such implementation.

Exhibit 3 GHG Reduction Potential of Various Decarbonization Strategies



Data Source: Watari et al., "Global Copper Cycles and Greenhouse Gas Emissions in a 1.5 °C World", 2022.

The rest of this document outlines the key considerations for developing a 1.5ºC climate-aligned sectoral decarbonization method that can be used for companies in the copper value chain to set emissions reduction targets.

Context

Given the needed sector growth and unique technology challenges, this report considers the development of a copper-specific SDA (i.e., a combination of a trajectory and target-setting methodology). The report is based on a review of existing work in copper roadmaps and analysis as well as interviews with experts and stakeholders throughout the copper supply chain including mine and smelter operators, semi-finished product fabricators as well as standard setters and civil society organizations. The aim was to identify the key issues that need to be addressed to develop a successful copper SDA. These were identified as:

- Setting a consistent scope and system boundary
- Considering different production routes within the target-setting method
- Incorporating the impacts of recycled material
- Accounting for co-products
- Variance between regions and impacts of policy
- Uncertainty regarding the decarbonization technology including on cost, availability, and time to implement

Each of these issues will be addressed through the SDA development process. The following provides details on each issue and some solutions that will be considered.

Scope and System Boundary

Given the fragmented nature of the copper value chain and varying levels of vertical integration at different sites and companies, there is a need for a consistent boundary against which the emissions of various copper companies are measured and benchmarked.

An SDA typically uses this consistent boundary to set the trajectory and the GHG intensity benchmark against which a company's progress is measured. Companies would then be required to set targets utilizing the fixed boundary which (depending on their level of vertical integration) may include Scope 1, 2, and 3 emissions. If companies also have significant emissions that fall outside the boundary it would usually be necessary to set separate targets (using a different methodology) for those emissions.

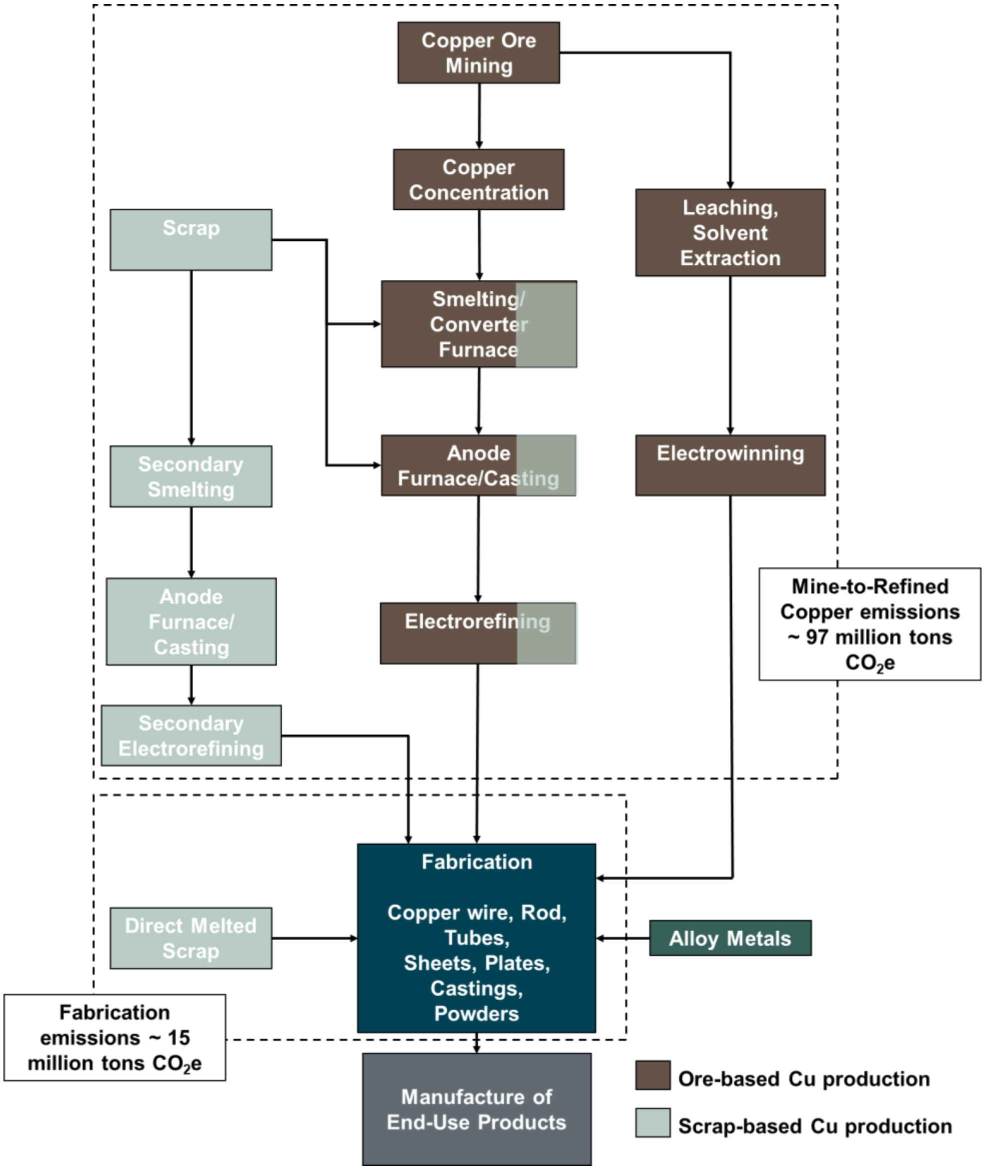
Copper ore mining and concentration can be responsible for up to 70% of the total GHG emissions from refined copper production.[9] Therefore, any GHG emissions reduction trajectory for the copper sector will need to include emissions from these upstream processes (i.e., a cradle-to-gate approach).

The selection of the endpoint for the boundary will need to balance between:

- Ensuring as much coverage of the sector's emissions as possible, and
- Finishing at a common point such that most companies can utilize it to set targets.

Based on this, the fixed boundary for the decarbonization trajectory and target setting could be from mining until either the production of refined copper cathodes or semi-finished copper products.

Exhibit 4 GHG Emissions from the Copper Value Chain



Data Source: *Copper—The Pathway to Net Zero*, 2023. Emissions data is for the year 2018.

A boundary to copper cathode would encompass almost 85% of the emissions from the copper industry (see Exhibit 4).[10] Copper cathodes are also the purest forms of copper that are bought and sold by companies. The production of copper cathodes is the last process after which pure copper is mixed with alloys and other materials in the fabrication process to be made into various end-use products. Therefore, copper cathode production can serve as a good metric against which the GHG emissions budget of the copper sector can be normalized. The main drawback of this approach is that it excludes the fabrication emissions (which are direct users of fossil fuels for high temperature heating processes) and excludes a key point of scrap re-processing.

Extending the boundary to include fabrication of semi-finished products avoids these issues at the expense of additional complexity. The fabrication of semi-finished products like copper wire, tubes, sheets, and castings accounts for almost 15 million tons of CO_2e emissions from the copper industry.[11] For specific products like copper sheet and tube, the fabrication process can represent almost 30% of the lifecycle GHG emissions with copper cathode contributing to almost 60% of the emissions.[12] Therefore, the fabrication emissions need to be explored while developing the copper SDA, specifically to consider:

1. Whether different types of copper semi-fabrication processes are sufficiently similar (in emissions and decarbonization technology profiles) to be considered as a single process/end-point within the SDA, and
2. If there is sufficient data on which to base a trajectory/target setting methodology at the semi-finished product level.

There is also an option to develop a hybrid approach which covers the full boundary (i.e., to semi-finished product) but also provides a trajectory/target-setting method to the cathode boundary. Companies could then choose which boundary is best suited given their assets. This approach has been suggested and used in other sectors.[13]

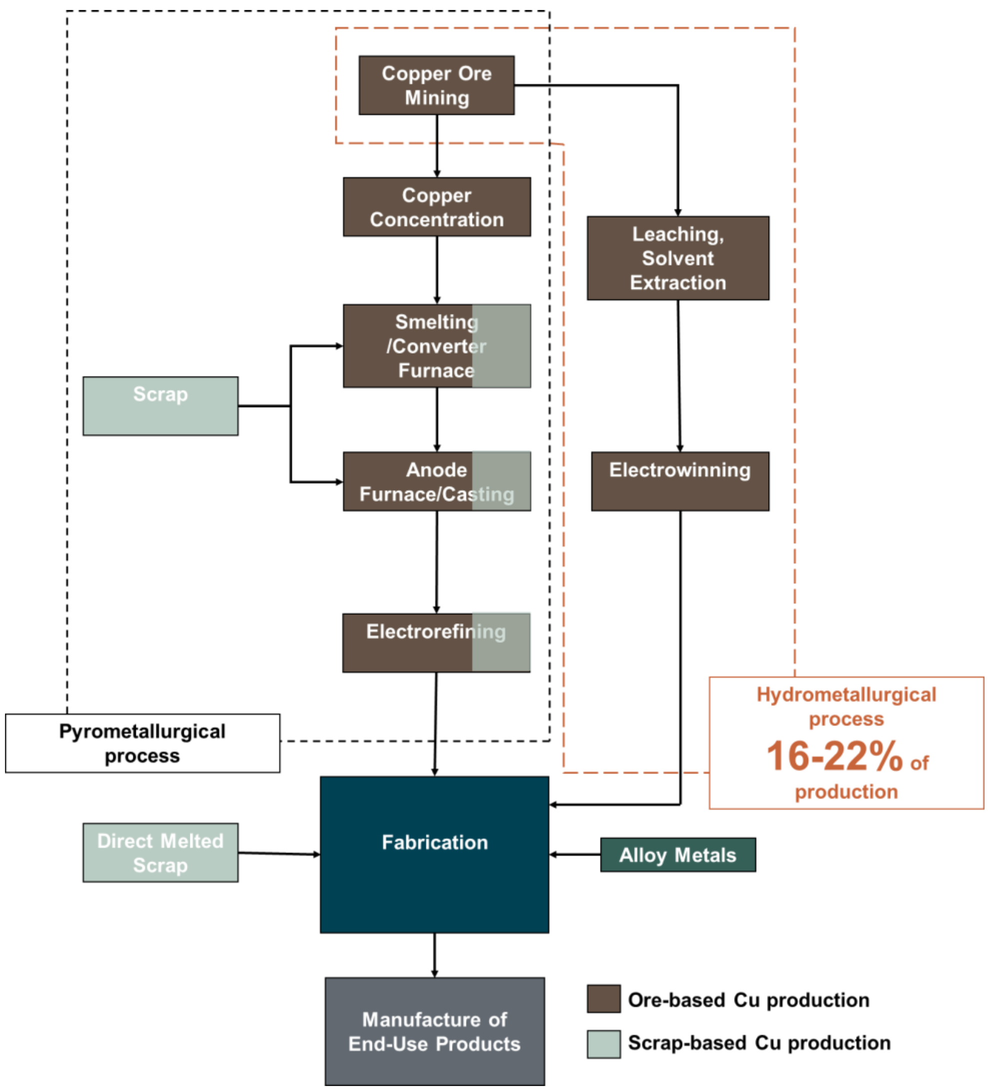
Production Route

The development of a sector-specific trajectory is typically based on a bottom-up assessment of individual production assets and the cost/barriers to implementation of decarbonization technologies within those assets between now and 2050.[14] In using the trajectory for target setting there is a need to consider how (if at all) the resulting industry-wide trajectory should be divided into its component parts. This will help in the development of the appropriate benchmarks against which individual companies/assets will set targets. As noted above, it can be divided by processes along the supply chain, however, there are other approaches that have been implemented in sectors such as steel.[15] The main benefit of this approach is that it helps the target-setting methodology to reflect the starting point more accurately and incorporate the decarbonization challenges faced by individual companies and assets. However, it also increases the complexity of the methodology and can lead to concerns about creating misaligned incentives (e.g., focus on emissions reductions within a divided portion of the trajectory instead of considering switching between the divided portions to an inherently lower emissions option).

For copper, one potential option would be to consider dividing the trajectory by production route for target setting purposes. Copper cathodes from ore are made either via a pyrometallurgical or hydrometallurgical process. The pyrometallurgical process involves smelting copper concentrate (made from crushing, grinding, and concentration of copper sulfide ore) in smelting/converter/anode furnaces to make copper anodes. These anodes then undergo electrolytic refining to form copper cathodes (see Exhibit 5). The hydrometallurgical process involves oxide ore leaching, solvent extraction, and electrowinning (also known as the SX-EW process) to make refined copper cathodes.

In 2020, around 16% of refined copper was produced through the SX-EW process.[16] The cradle-to-gate GHG emissions intensity of refined copper made using the pyrometallurgical process is 5.3 tCO_2e per ton of refined copper and that for the hydrometallurgical process is 7.3 tCO_2e/t of refined copper.[17] Other studies show smaller differences between the emissions intensities of both the processes.[18] Even in the case where the footprints of these production routes are similar (e.g., due to the emissions intensity of the electricity source and/or variances in the starting grade) the sources of the emissions are very different (i.e., much higher dependence on electricity for SX-EW). As a result of this different source profile, it is expected that the pace of expected decarbonization in line with a 1.5°C trajectory may also vary for each production route.

Exhibit 5 Different Production Routes for Copper Cathode



Considerations

1. During the development of the SDA for the copper sector, further analysis is necessary to consider if the emissions intensity and drivers for the pyrometallurgical and the hydrometallurgical processes are significantly different to warrant separate trajectories for target setting.
2. Understanding the pace of decarbonization and the different technological levers for decarbonization for the two processes should also be considered during the SDA development. This can also inform the decision regarding separate decarbonization trajectories. The degree to which it is possible to focus development of one pathway vs the other will also inform whether it is advisable to consider separate benchmarks.

Recycled Material

Another option for dividing the trajectory would be based on the metallic input, i.e., ore or scrap. This is similarly driven by considerations of differences in emissions intensity and decarbonization drivers between producing copper from either source. Given that ore and scrap are often mixed, this approach might involve setting targets based on a weighted (by input fraction) average of the two trajectories.[19]

Recycled copper gets added at various stages in the copper value chain (see Exhibit 2). Low- and medium-grade copper scrap can be mixed with concentrate at the start of the smelting process. This scrap can also be treated in a separate secondary smelting furnace. High-grade copper scrap can be mixed with blister copper before it is converted to copper anodes. This high-grade scrap can also be directly melted along with refined copper to produce semi-finished products like wire, rod, tube, sheet, plate, strip, castings, powder, or other shapes.[20]

Most projections estimate that copper scrap will account for 20%–25% of refined copper demand by 2050.[21] When direct melt scrap that is added to refined copper for making semi-finished goods is included, scrap will account for 40%–45% of total copper demand in 2050.[22] Therefore, ore-based copper will continue to be a significant source of copper supply in the coming decades. Hence, any decarbonization pathway for the copper sector should incentivize emissions reductions from the primary production of copper as well as the increased use of scrap.
Different metals sectors have different considerations when it comes to primary and recycled metal production. The Steel Science-Based Target-Setting Guidance developed by SBTi recommends the use of separate 1.5^{o}C climate-aligned pathways for 100% scrap-based steel production and 100% ore-based production when companies (that use a mix of ore and scrap input materials) want to set 1.5^{o}C climate-aligned GHG intensity targets.[23] For the aluminum sector, the 1.5^{o}C Aligned GHG Emissions Pathway developed by the Aluminium Stewardship Initiative (ASI) includes a recycling emissions intensity trajectory as part of the GHG pathways developed for entities with casthouse and semi-fabrication processes.[24] There is also an active discussion in the aluminium industry regarding embodied emissions of manufacturing

scrap. There needs to be a discussion around all these issues related to recycled copper, during the development of the SDA for the copper sector.

Considerations

1. While developing the SDA for copper, separate decarbonization trajectories for production of primary copper and recycled copper should be considered. Given the continued demand for ore-based copper in the coming decades, separate decarbonization trajectories can help to ensure that the appropriate decarbonization actions are incentivized.
2. If it is decided that separate decarbonization trajectories are necessary, then additional analysis is required to split the total copper sectoral carbon budget between the ore and recycled production routes. Since the decarbonization potential for recycled copper production — which essentially involves secondary smelting furnaces — is limited, the decarbonization trajectory for recycled copper production may be flat compared to the one for primary production. However, this needs to be explored in detail during the SDA development.
3. The copper SDA will need to include clear guidelines for companies on how to estimate the emission intensity of recycled copper production and/or determine targets based on the split trajectories.

Co-products

There are several co-products generated at various stages of the copper value chain such as sulfuric acid produced from sulfide ore smelting. Some of this sulfuric acid is used in electrolytic refining of copper. The remaining sulfuric acid is sold as a co-product for use in pharmaceutical, automotive, and other industries. The emissions from the sulfuric acid plant can be almost 5% of the “mine-to-cathode” emissions.[25] Similarly, zinc clinker, a product of slag generated during the smelting process can be used to extract metallic zinc. In addition to physical products some excess energy (in terms of heat, steam) generated during the smelting process may also be sold to the local energy grid. Various co-products are also produced outside the smelting process, for example, anode slimes generated during electrolytic refining is often further processed to make gold, silver ingots, platinum, and powdered palladium. The copper value chain, therefore, produces a mix of metallic and non-metallic co-products.

There are different ways to assign the impacts of the copper production process to the various co-products such as process subdivision, mass or economic allocation, and system expansion. For example, mining emissions might be allocated on a mass basis to various metallic end-products contained in the ore. In the smelting and the electrolytic refining process, which produces outputs of widely different economic value, emissions can be allocated to the outputs based on an economic allocation approach. The use of some of the co-products like sulfuric acid avoids the use of similar products that are manufactured with a different emissions profile which can be accounted for via a system expansion approach that can represent 5% to 10% of the “mine-to-copper cathode” emissions.[26] Given the wide variety of co-products generated during the copper production process, there should be a clear approach to accounting for the role of co-products and emissions credits in the copper SDA.

The copper SDA will mostly rely on other already established carbon accounting guidance either at the economy-wide level (e.g., the GHG protocol) or sector-specific (e.g., ICMM's Scope 3 guidance). However, the SDA may also require some additional specific guidelines to ensure the accounting matches how the trajectory was developed (e.g., inclusion or exclusion of credits).

Considerations

1. If emissions from co-products are included in the SDA there should be clear guidelines for emissions calculations associated with co-products including on the appropriate allocation methods used for co-products generated at different stages of the production.
2. It should be explicit whether the copper sector decarbonization trajectories include emissions credits from the use of co-products in other industries.
3. There should be clear guidelines on how reported emissions intensity values should include (or not) the emissions credits and what the resulting claims can be with respect to targets.

Regional and Policy Impacts

Copper mining and processing is highly concentrated in a few regions/countries. For example, Chile and Peru account for more than a third of global copper mining output while around half of all copper smelting occurs in China.[27] As a result, the decarbonization trajectory for the sector is highly dependent on regional specifics including:

- Cost and availability of existing fossil fuel energy sources (e.g., coal and diesel) compared with renewable resources (e.g., solar and wind).
- National level policy, which, given the level of concentration can have an outsized impact on the overall trajectory and/or be the main driver for certain company/asset actions to reduce emissions (e.g., Chile's Climate Change Framework Law).

Previous research has shown significant variation in policy between regions. For example, one assessment found that Chile has supporting policies covering renewable energy and storage, fuel switching and industrial decarbonization and mining specific technology applications whereas neighboring Peru was missing key policies across each of these areas including net-metering, best available techniques for mining, and green hydrogen policy.[28]

These regional and policy implications may impact both the trajectory and target-setting methodology. For example, significant changes in subsidies (either removal of fossil fuel subsidies or implementation of renewable energy subsidies) in a region/country responsible for a significant portion of copper production could shift the overall trajectory. This could impact the ability of companies/assets in other regions to utilize the trajectory to set ambitious yet achievable targets.

Considerations

1. The SDA development will consider both the need to update the sector-wide trajectory based on the latest policy developments in key copper producing/processing regions as well as the case for considering specific regions within the target-setting methodology given policy and resource/cost differences.

Decarbonization Technology Uncertainty

As outlined above, part of the reason to consider the development of a copper SDA is due to the specific technological challenges to decarbonize the copper industry. The topic of uncertainty on how these technologies will evolve was raised by several stakeholders as a key challenge to target setting. The emissions reductions in the copper sector depend on the level of maturity and the scale of adoption of the various decarbonization technologies available. Specifically:

- The pace of cost reductions for key underlying clean energy technologies (i.e., solar, wind, etc.) would dictate the timing for these technologies to be deployed.
- Ongoing innovation and technology development with respect to how clean energy technologies could be integrated into mine sites (e.g., novel in-haul charging solutions for large electric vehicles).
- Availability constraints even once technologies reach cost parity particularly in the context of technologies also needed for other sectors (e.g., battery availability for electric haul truck solutions).
- Potential for additional mining specific technology development/deployment (e.g., new leaching solutions, sorting technologies, etc.).

These uncertainties can have an impact both on the trajectory and the target-setting methodology.

Considerations

1. Significant work has already been completed in other roadmaps for the sector to consider some of these technology uncertainties and reflect these into the trajectories. The copper SDA process will review these efforts and make any additions necessary to reflect the latest developments. Further, the SDA development will consider how to ensure the target-setting methodology maintains sufficient flexibility to account for remaining sources of uncertainty.

Summary

Through a process of stakeholder interviews and review of existing copper roadmaps the following issues were identified as key requirements to be addressed as part of the development of a copper SDA:

- Setting a consistent scope and system boundary
- Considering different production routes within the target-setting method
- Incorporating the impacts of recycled material
- Accounting for co-products
- Variance between regions and impacts of policy
- Uncertainty regarding the decarbonization technology including on cost, availability, and time to implement

As outlined above, each of these issues will be considered via a multi-stakeholder process with the aim of developing an SDA (i.e., copper sector trajectory and associated target-setting methodology) that can enable copper-producing companies to set and track progress against a 1.5°C-aligned outcome.

Annex

Roadmaps Comparison

There have been a few copper sector decarbonization roadmaps developed over the years. The “Net Zero Roadmap for Copper and Nickel” released by the International Finance Corporation (IFC) adopted an economy-wide GHG reduction pathway to be applied to the copper sector. The International Copper Association (ICA) developed a Copper Net Zero Pathway based on a bottom-up techno-economic assessment of various decarbonization technologies and their scale of adoption across different time periods in the future. Watari et al. developed a copper sector emissions pathway until 2050 based on a 1.5^{o}C climate-aligned scenario. These roadmaps adopted different approaches to develop the copper sector decarbonization pathway. Exhibit 6 compares some key features of these roadmaps.

Exhibit 6 Key Features of Various Decarbonization Pathways Developed for the Copper Sector

Pathway Source	Published /funded by	Pathway objective	Modelling logic	Net-zero compliance mechanism	Model coverage	Geographical granularity
***Net Zero Roadmap for Copper and Nickel Mining - Technical Report*, 2023.**	International Finance Corporation (IFC)	Estimate the decarbonization potential of various low-carbon technology interventions like alternative fuel usage, equipment electrification, decarbonized electricity, energy efficiency. Impact of decarbonization technology (EVs, RE) deployment on copper demand.	GHG emissions abatement potential for various low-carbon technology interventions has been estimated based on various factors (technology readiness, cost competitiveness, scalability).	Assumed a 90% reduction in copper sector absolute emissions by 2050 compared to 2020 levels in line with a 1.5ºC climate trajectory for the entire economy. No specific 1.5ºC budget for the copper sector.	Medium — Only the copper and Nickel cycles are modelled. However, assumptions about future energy systems and future decarbonization technology deployment have been made for estimating future copper demand.	Global
***Copper—The Pathway to Net Zero*, 2023.**	International Copper Association (ICA)	Estimate the decarbonization potential of various strategies like alternative fuel usage, equipment electrification, decarbonized electricity, energy efficiency in the copper production process for the	The analysis estimates Scope 1 and 2 GHG emissions abatement potential through a bottom-up analysis drawing on information about copper production assets, reported mine development projects and country-by-country forecasts on the	No specific budget This target is based on current decarbonization technologies and analysis of their availability at scale, cost, and abatement potential. No explicit constraints on future carbon emissions from the copper sector i.e. future emissions in	Medium — Only the copper cycle is modelled. However, assumptions about future energy systems and future decarbonization technology deployment have been made for	Global. But regional level targets may be accessible upon request.

		years 2030, 2040, and 2050	evolution of grid emission factors.	2030 and 2040 might not be in line with a 1.5ºC budget.	estimating future copper demand.	
Watari et al., 2022	The University of Tokyo, University of Technology Sydney, and other Japanese research institutes/ Funded by Japanese Ministry of Education, Culture, Sports, Science and Technology	Impact of decarbonization technology (EVs, RE) deployment and a 1.5ºC emissions budget on the global copper cycle.	Used a stock-driven approach to estimate future copper cycle (accounting for expansion of copper used in decarbonization technologies). An optimization routine determined the copper supply which maximized the in-use stock available under a 1.5ºC emissions budget.	The emissions budget allocated to the copper cycle is determined based on the annual emissions mitigation rates in fossil fuels and industry to keep the global temperature rise below 1.5ºC relative to preindustrial level. It was assumed that the copper cycle contributes to emissions reduction pathways in proportion to other sectors.	Medium — Only the copper cycle is modelled. However, assumptions about future energy systems and future decarbonization technology deployment have been made.	Global

The future refined copper demand from all three studies is similar. The 2030 refined copper demand is ~38–39 million tons and the 2050 demand is ~57–59 million tons. Likewise, all the three studies estimate that 20%–25% of refined copper demand will be met by copper scrap. The rest will have to come from primary copper production. All three studies also agree that the copper sector GHG emissions need to reduce to 80%–90% of its emissions in 2020. The main difference is in the exact pathway to get to that reduction by 2050. The ICA and the Watari et al., studies serve as good starting points to develop a copper sector GHG reduction trajectory according to an SDA. The sectoral pathways in these studies can be modified based on the various considerations discussed in this report.

End Notes

[1] *Copper—The Pathway to Net Zero*, International Copper Association (ICA), 2023, https://copperalliance.org/wp-content/uploads/2023/03/ICA-GlobalDecar-202301-English-Final-singlepgs.pdf.

[2] Takuma Watari et al., "Global Copper Cycles and Greenhouse Gas Emissions in a 1.5 °C World", *Resources, Conservation and Recycling* 179, (April 2022): 106118, https://doi.org/10.1016/j.resconrec.2021.106118.

[3] Pauliuk, Stefan et al., "Industrial Ecology in Integrated Assessment Models", *Nature Climate Change* 7, (January 2017): 13–20, https://www.nature.com/articles/nclimate3148.

[4] Watari et al., "Global Copper Cycles and Greenhouse Gas Emissions in a 1.5 °C World", 2022; and *Copper—The Pathway to Net Zero*, 2023.

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