Life cycle assessment of European copper mining: A case study from Sweden

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Abstract. The application of the life cycle assessment (LCA) methodology in the mining sector has the potential to evaluate the environmental sustainability of the primary production of metals. As part of a wider project on developing LCA models and methods for mining, life cycle inventory (LCI) data have been collected at two European copper-producing mine sites, Aitik (Sweden) and Cobre las Cruces (Spain). Results from Aitik, including their impact analysis, identify the use of diesel and explosives, the emission of sulfur dioxide, as well as nitrogen and other emissions in the upstream supply chain of explosives and electricity, as significant contributors to the environmental impact. These outputs have influence on the impact categories Climate Change, Photochemical Ozone Formation, Acidification, as well as Terrestrial and Marine Eutrophication. Due to the increasing incorporation of LCA into legislative demands on the mining sector, mining companies need to establish the necessary infrastructure and framework to be able to provide the required data in a fast, transparent and cost-efficient manner. For this reason, some recommendations to improve communication and data management within the companies have been established from the experience gained within this project.

1 Introduction

Life cycle assessment (LCA) is a useful methodology to address environmental sustainability in the industry and is expected to be increasingly incorporated into the European legislation concerning industrial processes, including those in the mining and exploration sector. In addition, individual companies can highly benefit from the incorporation of life cycle research, through its potential to identify bottlenecks affecting the efficiency and environmental impact of industrial process chains.

The application of LCA in the metal/mining sector is still incipient, since there are only a limited number of studies published in the literature. Moreover, there is a general lack of availability of life cycle inventory data, including the case of copper. There is a demand from the copper sector to verify the robustness of existing datasets (e.g. in commercial databases). In addition, the average global copper production datasets generated by the Copper Alliance (www.copperalliance.org) are not yet implemented into the available databases.

The focus of this life cycle impact assessment (LCIA) work is on the cradle-to-gate life cycle of copper, including the collection, analysis and interpretation of data from two active European mines: Aitik (Sweden) and Cobre las Cruces (Spain). The focus of this extended abstract is on the results of the Aitik case study.

Results will have important implications for the identification (and mitigation) of environmental hotspots of European copper production. This represents a crucial step towards the development of a sustainability profile of primary European metals production.

2 Background

2.1 The SUPRIM project

The project “Sustainable management of primary raw materials through a better approach in Life Cycle Sustainability Assessment” (SUPRIM)[1] aims to develop solutions and provide services to better address sustainability assessments in the raw materials sector. The main objectives of the SUPRIM project are:

- Development of a Life Cycle Impact Assessment (LCIA) method to address resource availability (‘depletion’) in sustainability assessment.
- Development of Life Cycle Inventory (LCI) datasets through case studies in collaboration with the industrial partners from the mining sector.
- Bringing the service to a broader audience, including the LCIA community, mining companies and their downstream users, policy makers and academia.

The aims of this project are to develop LCI datasets in collaboration with industrial partners from the mining sector and make environmental sustainability assessments of the cases using LCA, including the analysis of resource use – with the LCIA method developed within the project among the impact categories considered. In this framework, an analysis of the benefits of a product-oriented perspective in an

[1] More information at http://suprim.eitrawmaterials.eu/

environmental sustainability strategy of the mining sector has been published recently (Alvarenga et al. 2019.

2.2 Life cycle assessment (LCA)

The main purpose of LCA is to evaluate quantitatively the environmental impacts of a certain system or product. Its main strength is that it allows going from an inventory of the materials, emissions and other relevant flows within the boundaries of the system to the environmental impacts, revealing the environmental relevance of the different elements as well as the overall environmental performance. The LCA methodology is widely accepted and applied in science. Indeed, the methodology was standardised through the international standards ISO 14040 and ISO 14044 (ISO 2006a, b).

The LCA methodology is made up of four specific phases (goal and scope, inventory analysis, impact assessment and interpretation), as shown in Fig. 1. The workflow is commonly iterative, in order to ensure that all the phases in the study are consistent and coherent.

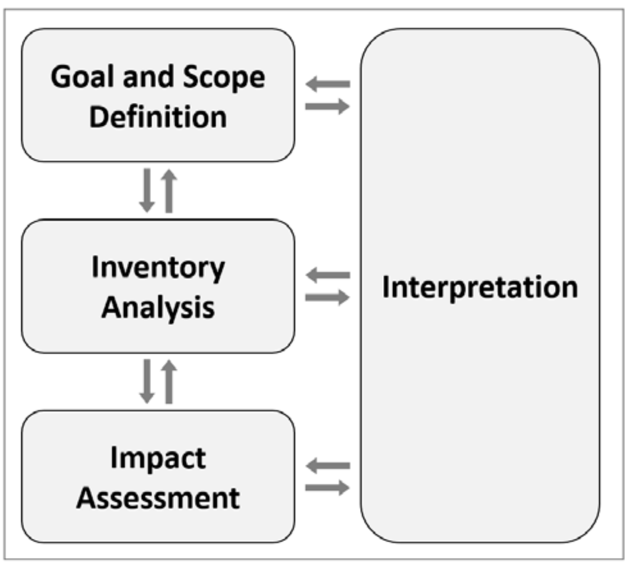

Figure 1. LCA framework. Adapted from ISO (2006a).

3 Methodology

3.1 Foreground data collection

The collection of the foreground LCI data (e.g. inputs and outputs of material, emissions to air, water and soil was conducted using different sources in the company Boliden Mineral AB, operating the Aitik mine. Whenever possible, data already available from reports or specific databases were utilised. The following data sources were used during the process:

- *External reports*: Environmental reports delivered to environmental agencies
- *Internal reports*: energy audits
- *Internal information (software) system*: Aaro data bank
- *Estimations*: for instance, estimation of emissions from work machineries, based on the parameter used in Aaro data bank
- *Direct correspondence* with staff from other sectors (e.g., Boliden Commercial)

The data were normalised to the production of 1 kg of copper cathode (functional unit). The data collection process took approximately 9 months. Boliden Mines acted as the central coordinator of data provision. This process required a substantial effort for the coordination and collaboration of the different internal contributors. More than 10 staff members were involved in the data collection, from four different departments/sub-companies (Boliden Mines, Boliden Commercial, Boliden Ronnskärsverken (Smelter), and Boliden Headquarters).

3.2 Software, background database, calculation method and impact category selection

To simulate the life cycle inventory regarding the environmental aspects, we used the database *ecoinvent* v3.3 and software *Simapro* v8.4.

The International Reference Life Cycle Data System (ILCD) Handbook, based on ISO 14040 and 14044 (ISO 2006a, b), was considered to conduct the LCA. This handbook is a guidance document, providing recommendations on models and characterisation factors to be used for impact assessment in applications such as LCA. This supports the analysis of emissions and resource consumption in a single integrated framework. The following impact categories have been selected to assess the environmental impacts of Aitik (and Cobre las Cruces):

- Climate Change
- Ozone Depletion
- Ionising Radiation
- Photochemical Ozone Formation
- Acidification
- Terrestrial Eutrophication
- Freshwater Eutrophication
- Marine Eutrophication

The characterisation factors were retrieved from the method "ILCD 2011 Midpoint+ v1.10" (European Commission 2012) for all impact categories except Climate Change. Regarding Climate Change, the characterisation factors were taken from "IPCC 2013 GWP 100a v1.03" (Joss et al. 2013; Myhre et al. 2013).

Some impact categories (e.g., human toxicity, ecotoxicity) were not included, since they lack a sufficiently robust LCIA model, as indicated in the Product Environmental Footprint guidelines by the European Commission (European Commission 2018).

4 Environmental assessment of copper production at Aitik

4.1 System boundaries

Processes for Aitik copper production have been divided into three sub-systems, for each of which LCI data (inputs and outputs) have been collected. These systems are the Aitik mine, the Aitik concentrator and the smelter. An important characteristic of copper production at Aitik is that the smelter processes take place at geographically separate (ca. 410 km distant) facilities (Rönnskär, Skellefteå, Sweden). This smelter receives copper concentrate from several mines, as well as other metal concentrates (lead, zinc) and secondary material (scrap). As a result, the smelter produces, apart from copper cathode, various metals, metal sulfates or clinkers, as well as sulphuric acid, sulphuric dioxide and iron sand. This made economic allocation procedures necessary in this study. A flowchart of the processes and the system boundaries for Aitik copper production is provided in Fig. 2.

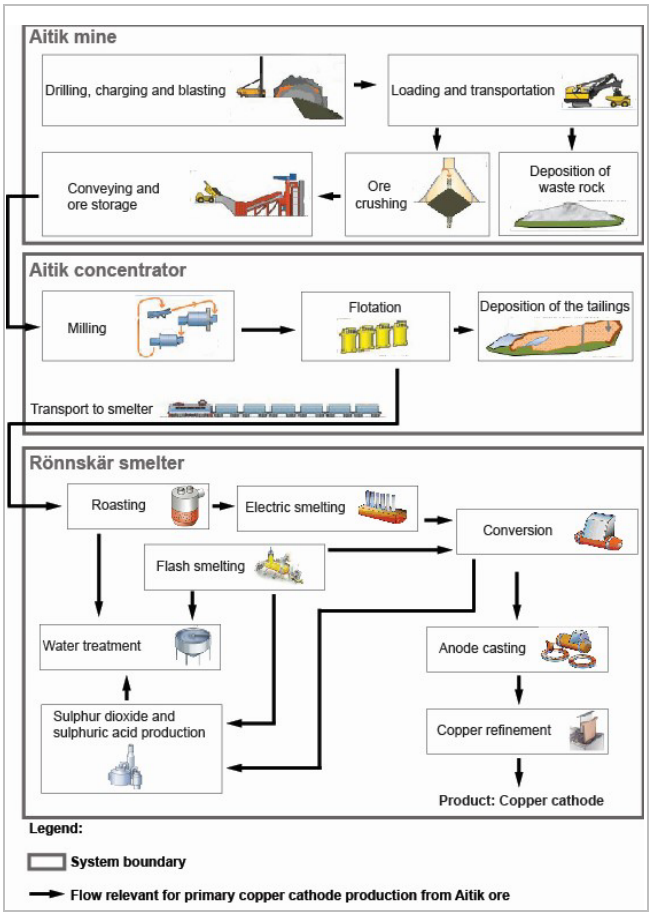

Figure 2. System boundaries for the Aitik LCIA case study, incl. the Rönnskär smelter (only primary-copper-relevant processes).

4.2 Environmental hotspots

Regarding the case study focused on Aitik Copper Concentrate, Fig. 3 shows the profile of the copper produced for the eight environmental impact categories considered. The relevant hotspots have been identified to support the industry on the management of environmental sustainability to reduce the footprint profile of copper production.

The main hotspots identified in the Aitik case are the following:

- Diesel and Explosives, at mine and concentrator, for climate change.
- Sulphur dioxide emissions at the smelter, affecting acidification and photochemical ozone formation.
- Nitrogen emissions to water, at mine and concentrator, for marine eutrophication.
- To a minor extent, NO_x, NH_3, and SO_x emissions at the supply chain of electricity (at smelter, mine and concentrator) and explosives (at mine and concentrator), affecting a few impact categories (photochemical ozone formation, acidification, terrestrial and marine eutrophication).
- Electricity use in general, due to emissions in its supply chain affecting ozone layer depletion, ionizing radiation and freshwater eutrophication.

It is important to highlight that these results are referring solely to primary copper produced from Aitik copper concentrate.

As pointed out, diesel and explosives were the main hotspots identified in many impact categories. Compared with LCIA results obtained from the Cobre las Cruces copper production (part of the SUPRIM project, but not shown here), a correlation is apparent between deposit copper ore grade (<0.2 wt.% at Aitik, ca. 5 wt.% at Cobre las Cruces) and tonnage of explosives used in the mining process.

5 Suggestions for future LCA work in the mining sector

5.1 Structured communication and organization

One of the main issues regarding the data collection in this study was communication between LCA practitioners and industrial partners. Boliden Mineral AB, similar to many other mining companies, holds a complex structure that includes different, relatively independent departments and sub-companies (Boliden Mines, Boliden Smelter, Boliden Commercial, etc.), each conducting their own functions.

In order to improve these communication issues in future projects that involve LCI data collection processes, the definition of a key person of contact is advised. This contact person should be staff in a more central role and department in the organization, which may facilitate communication with the different departments.

Overall, the key message is that an optimal and efficient organization of the data collection is important to save efforts and resources along the development of an LCA study.

5.2 Comprehensive data management strategy

Another important point that might be crucial for the improvement of the efficiency of future LCI's is the adaptation of the data available at the mining company to the LCI requirements. This step requires substantial efforts due to the requirements to format certain data flows according to the requirements for LCI (e.g. allocations at the smelter).

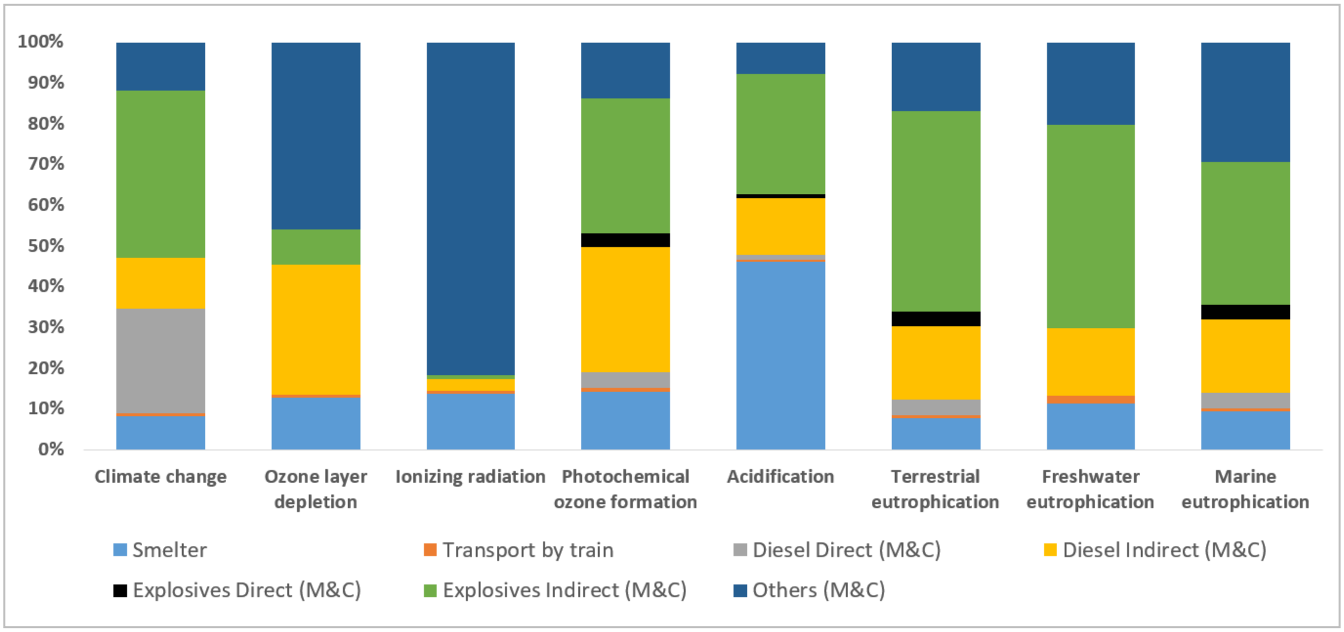

Figure 3. Contribution of the different elements of the system to the environmental impacts of copper production in the Aitik case study. Abbreviations: M&C = Mine and concentrator.

An efficient LCI data collection will be possible only if the data needed in the LCI are linked with the data already available in the organization (e.g. data generated due to the legislation compliance). Thus, it is crucial to create awareness for this and employ existing tools that already collect data for LCA purposes. Such data may be already available in the allocated format, i.e., as emissions allocated to certain product systems of interest.

Therefore, we suggest that the data already collected for other purposes (such as environmental reports) could be structured and formatted for a life cycle study prior to the data collection work. This could be done through a more comprehensive data management strategy.

Acknowledgements

This study has been made possible through funding by EIT RawMaterials (SUPRIM Project number 16121). Workshop discussions with expert staff at the project partners Leiden University, Euromines, Boliden Mineral AB and Cobre las Cruces S.A. have aided to improve the approach to and the results of the work.

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