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# The global environmental footprint of metal commodities

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## 1. Introduction

The environmental burden generated by the production of metal raw materials has become a societal concern, particularly in the context of increasing demand driven by energy transition pathways. Many studies have recently investigated the environmental impacts caused by the production of metal raw materials through life cycle assessment (LCA), however they often exhibited a limited scope, with a tendency to focus on small-scale case studies covering a limited share of the global production (e.g. focusing on a single raw material, process chain or production site). Thus far, only Nuss and Eckelman [1] have comprehensively assessed the environmental impacts of metal raw materials supply at a global scale by providing LCA results for 63 different metal substances modelled according to the global market. It is, however, noteworthy that the underlying data of the latter study, such as life cycle inventories (LCIs) and market information, date back to 2000 – 2010. Therefore, these studies may not represent the environmental impacts of the current mining and refining industry, given its evolution in the last decades (e.g. new deposits in exploitation, new or updated production processes, decreasing ore grades, etc.). This study seeks to provide an up-to-date overview of the global environmental footprint of metal commodities using LCA, considering 62 different substances (including 61 metal elements and graphite<sup>1</sup>). More specifically, the objectives of this study are: i) develop market-representative global LCA models for each of the 62 substances, and ii) provide an in-depth investigation of the main environmental hotspots of the mining and metal industry at both global supply and process levels. As a showcase of the considered approach, the tungsten case study is hereafter detailed.

## 2. Materials and Methods

The development of global LCA models follows a stepwise approach, divided into three main steps:

i) **Market analysis**, to generate a comprehensive overview of the main commodities and production routes associated with each substance, distinguishing producing countries, co-/by-production patterns and global recycling input rates.

ii) **LCI data review and analysis**, considering existing data in the literature and ecoinvent database. The LCI datasets are scrutinized both in terms of market coverage (i.e. commodity and associated production route)

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<sup>1</sup> Although graphite is not a metal, it is here included in the 'metal' list for the sake of conciseness in the writing.

and data quality and representativeness through the implementation of the Pedigree approach (as also implemented in the ecoinvent database). As a result, a selection of the most relevant LCI datasets (with respect to the global market and in terms of Pedigree scores) is performed.

iii) **LCA modelling**, using the selected LCI datasets as foreground data, while the background system is modelled based on ecoinvent data. The global (i.e. market) models are then developed through integrating the different LCI datasets as functions of the market shares they respectively account for. Cases of co-/by-productions of metal products are addressed using subdivision and economic allocation (based on averaged market prices), while other types of co-/by-products (e.g. chemicals) are addressed through system expansion/substitution (using ecoinvent data for modelling alternative production routes).

### 3. Results and discussion: showcasing the approach with the case of tungsten

The tungsten (W) market analysis identified tungsten carbide (WC) as the main W commodity, accounting for about 60% of the global W production; with ferrotungsten, W metal and chemicals (to a lower extent) representing the remaining production. China was identified as the main W-producing country, both at the mining and refining stages. Finally, the analysis also showed an important contribution (about 35%) of secondary production routes (i.e. recycling of new and old scraps) to the global W production [2].

The literature review for W revealed the availability of eight distinct LCI datasets covering different production routes. The in-depth analysis of these inventories eventually led to the selection of three datasets (out of the eight) considered both suitable in terms of market coverage, quality and representativeness. Among these three LCI datasets, two cover W mining and WC production, in China [3] and North America [4], respectively; the last dataset represents the recycling of hardmetal scrap into ammonium paratungstate (APT) [5], an intermediate in the production chain of several W commodities.

Given that no LCI data regarding W commodities other than WC were found to be available, the global LCA model developed for W focuses on the primary production of the latter commodity. Table 1 details the LCI datasets underlying the developed WC model, which builds on the reviewed literature data, complemented with ecoinvent data for covering the remaining share of WC production.

LCI data sources	Modelled primary production routes	Market shares
Ma et al., 2017 [3]	W mining and WC production in China	85.6%
Furberg et al., 2019 [4]	W mining and WC production in North America	4.4%
ecoinvent v3.7.1 cut-off	W mining and WC production in the 'rest-of-the-world'	10.0%

*Table 1: Data considered for the global (primary) WC model*

The carbon footprint of the global primary production of WC is calculated (using SimaPro v9.4) to amount to 73.3 kg CO<sub>2</sub>-eq/kg WC. The impact is dominated by the Chinese WC production route, in particular due to the electricity consumption in the whole process, and the use of nitrogen in the refining step. Regarding the recycling route, the APT recycling induces 5.2 kg CO<sub>2</sub>-eq/kg APT, primarily due to the use of heat in the oxidation step, and of electricity and ammonium hydroxide in the solvent extraction/APT crystallization steps.

### 4. Conclusions and perspectives

Building on existing literature and ecoinvent LCI data, a preliminary model representing the global primary production of WC was developed, covering a large share of the current W market, which then enabled a first assessment of the global environmental impacts of W. Similar models are currently under development for the 61 other substances under study, following the same approach as that implemented for W. However, several challenges remain to be addressed to improve these global LCA models, e.g. regarding the integration of recycling routes for which detailed market information is relatively limited (as in the W case).

### 5. References

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