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Metal Mining's Environmental Pressures: A Review and Updated Estimates on CO_2 Emissions, Water Use, and Land Requirements

Michael Tost [1,*], Benjamin Bayer [1], Michael Hitch [2], Stephan Lutter [3], Peter Moser [1] and Susanne Feiel [1]

[1] Mining Engineering and Mineral Economics, Montanuniversitaet Leoben, 8700 Leoben, Austria; benjamin.bayer@stud.unileoben.ac.at (B.B.); peter.moser@unileoben.ac.at (P.M.); susanne.feiel@unileoben.ac.at (S.F.)
[2] School of Science, Department of Geology, Tallinn University of Technology, 19086 Tallinn, Estonia; michael.hitch@ttu.ee
[3] Institute for Ecological Economics, Vienna University of Economics and Business (WU), 1020 Wien, Austria; stephan.lutter@wu.ac.at
* Correspondence: michael.tost@unileoben.ac.at; Tel.: +43-664-452-9872

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Abstract: The significant increase in metal mining and the inevitability of the continuation of this trend suggests that environmental pressures, as well as related impacts, have become an issue of global relevance. Yet the scale of the impact remains, to a large extent, unknown. This paper examines the mining sector's demands on CO_2 emissions, water use, as well as demands on land use focusing on four principal metals: iron, aluminium (i.e., bauxite ore), copper, and gold. These materials represent a large proportion of all metallic materials mined in terms of crude tonnage and economic value. This paper examines how the main providers of mining data, the United Nations, government sources of some main metal producing and consuming countries, the scientific literature, and company reports report environmental pressures in these three areas. The authors conclude that, in the global context, the pressure brought about by metal mining is relatively low. The data on this subject are still very limited and there are significant gaps in consistency on criteria such as boundary descriptions, input parameter definitions, and allocation method descriptions as well as a lack of commodity and/or site specific reporting of environmental data at a company level.

Keywords: mining; gold; bauxite; copper; iron ore; environmental pressure; CO_2; water; land use

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1. Introduction

The environmental impact of metal mining has been an issue for centuries (e.g., [1–3]), maybe even millennia. For most of this time however, these impacts have been mainly local such as deforestation (e.g., in Saxony/Germany), water pollution (e.g., Rio Tinto/Spain), and soil contamination (e.g., in Bleiberg/Austria).

Today, largely due to the "great acceleration" of economic growth after World War II [4] and ever-increasing globalization of trade, global metal mining is increasing significantly (e.g., [5,6] (p. 10)) and environmental pressures such as land and water use, as well as related environmental (and social) impacts have become an issue of worldwide relevance. There is an expectation that this trend will continue in alignment with society's increasing demand for raw materials. Yet the question remains: how big is this issue?

To answer this question, the authors focus on four metals–iron, aluminium (i.e., bauxite ore), copper, and gold. Iron, aluminium, and copper represent over 96 percent of all metals mined globally in terms of bulk tonnage [7], and together with gold they possess over 68% of industrial value [8]. In addition, the extraction technologies can be considered representative, making the results indicative for metal mining as a whole. To evaluate environmental pressures, the authors focus on data for three categories considered highly relevant to mining, admittedly by the industry itself (e.g., [9–12]), including climate change (i.e., CO_2 emissions), water use, and land use. To assess responses, the authors look at the main providers of mining data, the United Nations (UN), government sources of some main metal producing and consuming countries, the scientific literature, and company reports.

The main providers, i.e., US Geological Survey (USGS) [13], British Geological Survey [14], World Mining Data (WMD) [7], and S&P [15], of mining data often do not include environmental data in their publications. Their annual reports and S&P's database focus on production and economic data only, which, the authors would argue, means that aggregated environmental data are not yet considered as material mining data for public disclosure.

The same can be said for UN and independent government sources: the International Resource Panel (IRP) has produced various reports looking into the material flows of metals [6] and their environmental impacts, including data for water consumption and greenhouse gas emissions [16] (pp. 101–105)—based on scientific literature further discussed below, but the IRP also acknowledges that further research is required:

> "Important knowledge is still missing in the linkages that exist between different types of resources: metals, energy, water, and maybe others. This refers both to the resources needed in the chain of the metals (e.g., energy for refining) and to the fact that metals are in some cases mined as a by-product of other materials (mostly other metals, but sometimes other materials, e.g. mercury production from natural gas). In scenario explorations for the future, this is essential knowledge. It requires an interdisciplinary approach and the cooperation of researchers from different fields to build up this type of knowledge." [16] (p. 21).

The United States Geological Survey's (USGS) webpage, makes reference to material flows and that "understanding the whole system of material flow, from source to ultimate disposition, can help us better manage the use of natural resources and protect the environment" [17], but none of the studies listed include current or timely environmental data as described above. The European Union's Raw Material Information System (EU RMIS) also includes a section on environmental and social sustainability, listing "water", "air emissions and climate change", and "land and biodiversity" as areas, but they do not include specific environmental data required for meaningful analysis [18]. Other government websites, such as the Australian Bureau of Statistics [19], Natural Resources Canada [20], the Chinese National Bureau of Statistics [21], or Statistics South Africa [22] all focus on economic indicators such as production, sales, and gross value added or employment and not environmental impact in our focus areas.

At the company level, in response to conflicts and increasing societal pressure, the majority of mining companies have committed themselves to sustainability [23] and the reporting of environmental data has become relevant, either through legal requirements such as the European Union's (EU) non-financial reporting directive [24], voluntary industry iniatives such as the International Council for Mining & Metals' (ICMM) requirement for its member companies to annually publish reports in accordance with the Global Reporting Initiative (GRI) [25] or pressure from customers/consumers and/or financiers for companies to respond to initiatives such as the CDP [26] or the Dow Jones Sustainability Index [27]. However, such reporting is not mandated yet for all mining companies, as it is either not legally required or only required above a certain size, as is the case with [24] and hence segmented environmental data is not consistenly available.

Given that data are not readily available on a commodity and/or mine site specific level from the sources described above, the authors focus efforts on a review of scientific literature and company data as described in Section 2, with the main aim to compile data on the environmental pressures brought about by mining for four metals (iron, aluminium, copper, and gold), focusing on CO_2 emissions, water use, and land use. For each metal, an estimated range (minimum, average, and maximum) for the year 2016 and a comparison with company data is shown in Section 3. Section 4 discusses the key results and proposes a way forward.

2. Materials and Methods

The base of the data compilation is a literature review of existing scientific studies. In order to check for the comparability of the data stemming from different sources and to select useful publications a set of criteria is applied:

- Boundary descriptions

The authors consider this as the main criterion. A data sample should include only production sites at the same position in the value chain. Looking at mining, the production steps (i.e., mining, concentration, purification, refining) are different depending on the metal in focus. Even for one metal, processes applied at a site differ greatly, e.g., in copper production with pyro-metallurgical or hydro-metallurgical routes [28] (p. 120), [29] (p. 24ff). Publications that separate process steps are rare, because companies report for a production site and not for a production step. The majority of the studies listed in Table 1 consider the shipment of (concentrated) iron ore and bauxite from the mine as the boundary. For copper and gold, the boundary includes purification and refining, but it does not differ between underground or open pit mining and production routes. This study uses the same definitions, but also presents estimates for downstream steel and aluminium production processes for CO_2 and water use to allow for 'mine to metal' comparisons for all four metals.

- Input parameter definitions

A clear definition of the parameters considered is needed. This is the case for CO_2 with the GHG Protocol [30], but not for water data ([31,32]). In this study, we consider data for water withdrawal and consumption.

- Allocation method

In the case of companies/mines that produce more than one commodity; input/output measurements alone do not provide enough information to attribute e.g., water consumption or CO_2 emissions to a single commodity. A description of the subsystems (processes) would be necessary. To overcome this problem, volume flows are attributed to a commodity by allocation, e.g., based on revenues achieved from the commodities [33] (p. 68). Reporting companies as well as authors of publications should describe their allocation methods, otherwise they are not considered in this study.

- Purpose of the publication

The purpose of the publication can influence the result because of sample bias, boundaries, allocation method, input parameters, and other parameters connected to the intent. The result may be good for a specific purpose, but may not be usable in the context of this study, which the authors check against the first three criteria.

Table 1 contains a basic description of the publications analyzed and if they were considered in the analysis. It gives an overview of the purpose of the respective publication, the allocation method, type of data, boundaries, if input parameter definitions exist and, based on these, our decision for consideration and inclusion in the data summaries shown in the results section below.

Table 1. Studies analysed for this paper.

Name	Purpose	Allocation Method	Type of Data	Boundary	Definitions (Water/CO_2/Land)	Considered (Yes/No)
Gold Mining in Australia: Linking Historical Trends and Environmental and Resource Sustainability [34]	Assess the development of production and environmental data of gold mining in Australia	None. By-products not considered.	Company reports	Au: Mine to Metal (MtM)	Yes/Yes (scope 1)/-(not applicable)	Yes (Water only)
Global Trends in Gold Mining: Towards Quantifying Environmental and Resource Sustainability [35]	Assess the sustainability of global gold production in the context of reporting, declining grades, increasing efficiency, etc.	No information provided	Company reports	Au: MtM	Yes/unclear (?)/-	Yes (Water only)
Sustainability Reporting and Water Resources: a Preliminary Assessment of Embodied Water and Sustainable Mining [36]	The data have been grouped into principal ore type to better assess the effect on grade, scale, and sector	No information provided	Company data	Bauxite (B): Ore Product (OP), Cu: MtM, Au: MtM	Yes/-/-	No (recycled water is included)
Water Use in Metal Production: A Life Cycle Perspective [37]	Estimate water consumption for several commodities	Unknown	LCA	B: OP, Cu: MtM, Au: MtM	?/-/-	No
Quantifying, Reducing, and Improving Mine Water Use [33]	Estimate global water withdrawals of the metals mining sector	Economic	Company data	B: OP, Cu: MtM, Au: MtM, Fe: OP	Yes/-/-	Yes
Energy and Greenhouse Gas Impacts of Mining and Mineral Processing Operations [38]	Assist the Australian minerals industry in identifying potential areas of improvement of their environmental performance	None. All mines in LCA produced only one product	LCA	B: OP, Cu: Mine to Concentrate (MtC), Fe: MtC	-/Yes/-	Yes (not Cu due to boundary difference)
Using Life Cycle Assessment to Evaluate Some Environmental Impacts of Gold Production [39]	Compare refractory to non-refractory ore. Identify impacts of various production steps.	Mass and economic for comparison	LCA	Au: MtM	Yes/Yes/-	Yes
Using Sustainability Reporting to Assess the Environmental Footprint of Copper Mining [28]	Show opportunities and limits of reported data for creating environmental footprints	Economic	Company reports	Cu: MtM	Yes/Yes/-	Yes
Assessing the Environmental Impact of Metal Production Processes [40]	Show various impacts	None. All mines in LCA produced only one product	LCA	Cu: MtM	-/Yes/-	Yes
Good Practices and the Efficient Use of Water in the Mining Industry [41]	Show the freshwater consumption of Chilean copper mines. Compare concentrators with hydro-metallurgy. Show development	No information provided	Company data	Cu: MtM	Yes/-/-	Yes

Table 1. *Cont.*

Name	Purpose	Allocation Method	Type of Data	Boundary	Definitions (Water/CO_2/Land)	Considered (Yes/No)
Global Area Disturbed and Pressures on Biodiversity by Large-Scale Metal Mining [29]	Estimate the specific direct land use for Au, Cu, Ag, Bauxite, and iron ore mining	Economic	USGS satellite images plus random sample of mines	B: OP, Cu: MtC, Au: MtC, Fe: MtC	-/-/Yes	Yes (boundary difference not material)
Unearthing the Carbon Footprint [42]	Unknown	Unknown	Value for base metal ores	Comparable to [38], but actually unknown	-/?/-	No
Quantifizierung der Umwelteinwirkung des Bauxitbergbaus [43]	Quantification of land use for bauxite mining	None	Company data and modelling	B: OP	-/-/Yes	Yes
A Global Environmental Impact Assessment for Bauxite Mining—Land Use and Soil Erosion [44]	Quantification of land use for bauxite mining	None	Company data and modelling	B: OP	-/-/Yes	Yes
Flächeninanspruchnahme des Kupferbergbaus [45]	Quantification of land use for copper mining	None	Company data and modelling	Cu: MtC	-/-/Yes	Yes (boundary difference not material)
Entwicklung eines Betriebsübergreifenden Resourcenmanagementsystems [46]	Quantification of land use for copper mining	None	Company data and modelling	Cu: MtC	-/-/Yes	Yes (boundary difference not material)

For the calculations of the specific environmental pressures and the comparison of results, this study applies the averages from the literature considered and also provides the minimum and maximum numbers to show the range identified in the literature. Since the values are from different years, the authors then update all pressures to 2016 by using the production data from WMD [7]. In the cases where no data on gross ore extraction but only data on net metal content are reported, estimations were required, in order to transform all reported net metal content values into equivalents of gross ores. For these estimations of ore grades, the data from the UN IRP Global Material Flows Database [47] is used. In the evaluation, the assumption is that the average mined ore grade did not change and that the specific environmental pressure (e.g., due to process changes or efficiency gains) remained relatively constant. The authors are aware of the errors implied by these assumptions, but data availability does not allow for a more accurate estimation.

For comparison, the environmental data publicly reported for 2016 by the top five mining companies listed in Table 2, who represent between 19% and 68% of mine production for the four focus metals, is analyzed. Since most of these companies produce multiple commodities and do not report their data broken down to the commodity level (in some cases the organization of companies is based on commodity and therefore the data might be reported), an additional survey is used to ask for their commodity specific data. Finally, the authors extrapolate these data, based on production share, to the overall 2016 production of each metal, allowing for an approximate comparison of the results from literature with actual data reported by companies.

Table 2. List of companies and their share of production for each commodity.

Copper (2016)	**Units**		**Gold (2016)**	**Units**	
Codelco	1.827	Mt	Barrick	5.52	Moz
Freeport-McMoRan	1.696	Mt	Newmont	4.9	Moz
Glencore	1.288	Mt	Anglo Gold Ashanti	3.63	Moz
BHP	1.113	Mt	Goldcorp	2.87	Moz
Southern Copper	0.9	Mt	Kinross	2.79	Moz
Share of WMD	**33.4**	%	**Share of WMD**	**19.1**	%
Bauxite (2015)	**Units**		**Iron ore (2015)**	**Units**	
Rio Tinto	44	Mt	Vale	345.9	Mt
Alcoa	38	Mt	Rio Tinto	327.6	Mt
Chalco	18	Mt	BHP	227	Mt
CBG	15.2	Mt	FMG	169.4	Mt
Hydro	10.1	Mt			
Share of WMD	**43.2**	%	**Share of WMD**	**68.0**	%

Sources: https://www.statista.com/statistics/274260/market-share-of-major-copper-producing-companies/; http://www.mining.com/update-worlds-top-10-gold-producers/; https://www.alcircle.com/news/bauxite/detail/26315/top-five-bauxite-mining-companies-in-the-world; https://news.steel-360.com/worlds-top-iron-ore-producers-h1-2016/; Company reports, WMD [7]; all links accessed 12 June 2018.

3. Results

Overall, the authors find 16 publications of which 13 are considered in this study, which means that the number of publications investigating the environmental pressures of mining for iron, bauxite, copper, and gold is limited to between one and five per commodity.

The variation in the results from the different publications is within a factor of three for the specific environmental pressure of a commodity, even after considering the selection criteria. In some cases, the variation of data for mine sites can be within a factor of 100, as in [28], with a range of 9.8 to 1046.9 m^3/t Cu of water consumption. This is due to different mine types and processing routes. The detailed results for CO_2, water, and land are described below.

The company survey the authors wanted to use to get more reliable data for comparison had a very poor response rate. Of the companies listed in Table 2, only one—Rio Tinto—sent back data as requested. Four companies said that they do not disclose any additional data other than what they disclose in company reports or to initiatives such as the CDP or sustainability rating organizations and the remaining companies did not respond at all. Therefore, the comparison of company data with literature data is very limited, and we are only able to compare specific factors rather than overall values for 2016. Given these limitations, the numbers are shown below, but the results are not discussed any further since they show some large variations, which might be explained by variations in the selection criteria listed above and which are not analysed at this stage, given the very limited company data. We also do not show the company names in the tables.

3.1. CO_2 Emissions

Literature on CO_2 emissions is closely linked to literature on energy consumption. Declining ore grades and the increasing geologic and metallurgical complexity of orebodies are leading to increased energy demands [38] (p. 266), that might ultimately be offset by the development of more energy efficient technology [48] (p. 2). Reporting methods/definitions [49], [30], emission factors [28] (p. 125), allocation methods, and the minor significance compared to the downstream processes (i.e., aluminium or steel making) [38] (p. 266) are further key factors in this discussion.

Table 3 shows the literature data for all four commodities. Estimations for CO_2 emissions of copper and gold show a similar variation to water below. It is notable that all values from life cycle analysis are higher than results from studies based on company reports. Tables 4 and 5 show the data (average of studies, minimum and maximum) updated to 2016 and the available company data for comparison.

The estimations in Table 4 show that copper and gold (with both calculation routes delivering similar results) cause the highest emissions, followed by iron ore and bauxite, which causes by far the lowest emissions of the four commodities.

The authors estimate that the average of the literature values updated to 2016 is 190.5 Mt of CO_2 emissions for the mining of bauxite, copper, gold, and iron ore based on commodity produced. For ore based values combined with the global ore processed, the result is very similar at 189.8 Mt respectively. The minimum and maximum values from literature lead to a range of 149.6 Mt to 233 Mt.

Table 3. Summary of literature values for CO_2 emissions of bauxite, copper, gold, and iron ore mining.

	Max.	**Min.**	**Average**	**Units**	**Source**
Bauxite					
Ore	–	–	4.9	kg CO_2/t	[38]
Copper					
Metal	8.5	0.9	2.6	kg CO_2/kg	[28]
	–	–	3.3	kg CO_2/kg	[40]
	–	–	6.2	kg CO_2/kg	[40]
Gold					
Ore	–	–	61.7	kg CO_2/t	[39]
	–	–	77.2	kg CO_2/t	[39]
Metal	–	–	26,840	kg CO_2/kg	[39]
	–	–	17,560	kg CO_2/kg	[39]
	–	–	19,520	kg CO_2/kg	[39]
	–	–	29,820	kg CO_2/kg	[39]
Iron Ore					
Ore	–	–	11.9	kg CO_2/t	[38]

Table 4. Global CO_2 emissions of bauxite, copper, gold, and iron ore mining in 2016.

	Result of the Literature Review			CO_2 emissions 2016 [Mt]
Bauxite				
Ore	Average	4.9	kg CO_2/t	1.4
Copper				
Metal	Average	3.7	kg CO_2/kg	75
	Max.	4.8	kg CO_2/kg	97
	Min.	2.6	kg CO_2/kg	53
Gold				
Ore	Average	69.5	kg CO_2/t	74.6
	Max.	77.2	kg CO_2/t	82.9
	Min.	61.7	kg CO_2/t	66.3
Metal	Average	23,435	kg CO_2/kg	75.3
	Max.	29,820	kg CO_2/kg	95.8
	Min.	17,560	kg CO_2/kg	56.4
Iron Ore				
Ore	Average	11.9	kg CO_2/t	38.8

Table 5. CO_2 data from company sustainability reports and comparison to literature average values.

Commodity	Specific CO_2 Emissions	Units	Average of Literature Values
Bauxite	10	kg CO_2/t	4.9
Copper	2.46	kg CO_2/kg Cu	3.7
Copper	8.8	kg CO_2/kg Cu	
Gold	23,300	kg CO_2/kg Au	23,435
Iron Ore	10.39	kg CO_2/t	11.9
Iron Ore	9.3	kg CO_2/t	
Iron Ore	13	kg CO_2/t	

Global CO_2 emissions from fossil fuels and industry for 2016 are estimated at about 36 Gt [50,51], which means that the mining of bauxite, copper, gold, and iron ore contributes approximately between 0.4 and 0.7 percent to these CO_2 emissions. Considering only fossil fuel combustion, the International Energy Agency (IEA) estimates CO_2 emissions at 32 Gt [52], of which 36 percent can be attributed to industry (p. 12). Using this as a baseline, mining of these four metals contributes between 1.3 and 2 percent of all industrial emissions.

The picture changes completely in consideration of the downstream, highly energy intensive processes for iron ore/steel and bauxite/aluminium, where emissions for 2016 were about 3.1 Gt [53] (p. 4) and 1 Gt [54].

3.2. Water Withdrawals

Based on the reasons discussed above, i.e., different definitions regarding water withdrawals and consumption, the literature does not show as much coherence about mine water use as would be desirable. Gunson [33] is the most comprehensive publication dealing with water withdrawals of the mining industry and he describes this problem of coherence much in the same way.

Table 6 shows the literature data for all four commodities. For bauxite and iron ore, little data is available. For copper production, some publications distinguish pyro-metallurgical production from concentrate and hydro-metallurgical production without previous concentration. The publications show that hydro-metallurgical production consumes significantly less water. Tables 7 and 8 show the data (average of studies, minimum and maximum) updated to 2016 and the available company data for comparison.

Table 6. Summary of literature values for water use of bauxite, copper, gold, and iron ore mining.

	Bauxite				
	Max	**Min**	**Average**	**Units**	**Source**
Ore	1.154	0.022	0.404	m^3/t	[33]
	Copper				
Ore	3.065	0	0.521	m^3/t	[33]
	0.432	0.1	0.22	m^3/t	[33]
	1.4	0.92	1.16	m^3/t	[41]
Metal	1046.9	9.8	70.4	m^3/t	[28]
	402.61	0.013	88.03	m^3/t	[33]
	96.18	27.77	48.01	m^3/t	[33]
	Gold				
Ore	1.72	0.67	0.88	m^3/t	[34]
	2.87	0.72	1.42	m^3/t	[35]
	10.9	0.003	0.745	m^3/t	[33]
Metal	666,000	224,000	325,000	m^3/t	[34]
	1,783,000	224,000	691,000	m^3/t	[35]
	–	–	259,290	m^3/t	[39]
	–	–	288,140	m^3/t	[39]
	4,742,000	610	400,000	m^3/t	[33]
	Iron Ore				
Ore	3	0.094	0.598	m^3/t	[33]

Table 7. Global water withdrawals of bauxite, copper, gold, and iron ore mining in 2016.

	Bauxite			
	Result of the Literature Review			**Withdrawals 2016 (Mm^3)**
Ore	Average	0.404	m^3/t	115
	Copper			
Ore	Average	0.765	m^3/t	1730
	Max.	1.16	m^3/t	2630
	Min.	0.371	m^3/t	840
Metal	Average	69.21	m^3/t	1413
	Max.	70.4	m^3/t	1440
	Min.	68.02	m^3/t	1389
	Gold			
Ore	Average	1.015	m^3/t	1090
	Max.	1.42	m^3/t	1530
	Min.	0.745	m^3/t	800
Metal	Average	422,428.75	m^3/t	1358
	Max.	691,000	m^3/t	2221
	Min.	273,715	m^3/t	880
	Iron Ore			
Ore	Average	0.598	m^3/t	1950

Table 8. Water data from company sustainability reports and comparison to literature average values.

Commodity	Specific Withdrawals	Units	Average of Literature Values
Bauxite	0.604	m^3/t	0.404
Copper	245	m^3/t	69.21
Gold	0.379	m^3/t	1.015
Iron Ore	1.047	m^3/t	0.598
Iron Ore	1.410	m^3/t	

As Table 7 shows, iron ore causes the largest water withdrawals, followed by copper and gold (with some variation in the calculation routes) and once again bauxite with the lowest water withdrawals.

The sum of the global water withdrawals we estimated from the minimum and maximum values from literature for bauxite, copper, gold, and iron ore mining in 2016 is between 3705 and 6225 Mm^3, with an average of about 4850 Mm^3.

To put these numbers into a global context: The Food and Agriculture Organization of the United Nations (FAO) estimates the global water withdrawal for 2010 as almost 4000 Gm^3, with industrial withdrawals accounting for about 19 percent [55]. Assuming the same growth rate as in the years 1900–2010 of about 31 Gm^3 per year for the years 2010–2016, bauxite, copper, gold, and iron ore mining is in a range of 0.09 and 0.15 percent of global water withdrawals and 0.46 and 0.78 percent of industrial withdrawals.

Same as for CO_2 emissions, this changes significantly if downstream water withdrawals for steelmaking (estimated at 45.8 Gm^3 based on [56] (p. 4)) and aluminium production (estimated at 1.3 Gm^3 based on [54] (appendix A)) are considered.

3.3. Land Use

According to S&P Global Market Intelligence there are over 36,000 mining properties in the world [15]. Estimates for the global area disturbed by mining range from 0.3 [57] to 1 [58] percent of terrestrial land surface. The estimations have in common that they are vague. Either the basis for the estimation is unclear as in the case of Norse et al. [59], suggesting a global area disturbed by mining of 0.5 to 1.0 Mkm^2, or data was only available for some countries and the global estimate is an extrapolation [57].

A key publication on the subject is by Murguia [29], who based his study on mine sites visible on satellite images. Table 9 shows the specific values from literature for land use for each commodity analyzed in this paper. The data is complemented by older studies on direct land use for copper and bauxite.

Table 9. Summary of literature values for land use of bauxite, copper, gold, and iron ore mining.

Bauxite					
	Max	**Min**	**Average**	**Units**	**Source**
Ore	–	–	7.98	ha/Mt	[29]
	–	–	21	ha/Mt	[43]
	–	–	13	ha/Mt	[44]
	–	–	16	ha/Mt	International Aluminium Institute, 2009, cited in [29]
Copper					
Ore	–	–	4.5	ha/Mt	[29]
	–	–	2.3	ha/Mt	[45]
	–	–	2	ha/Mt	[46]
Gold					
Ore	**Max**	**Min**	**Average**	**Units**	**Source**
	–	–	6.7	ha/Mt	[29]
Iron Ore					
Ore	**Max**	**Min**	**Average**	**Units**	**Source**
	–	–	4.25	ha/Mt	[29]

Tables 10 and 11 show the data (average of studies, minimum and maximum) updated to 2016 and the available company data for comparison.

Table 10. Newly disturbed global land use for bauxite, copper, gold, and iron ore mining in 2016.

Bauxite				
	Result of the Literature Review			**Land Use 2016 (km^2)**
Ore	Average	14.5	ha/Mt	41.3
	Max.	21.0	ha/Mt	59.8
	Min.	7.98	ha/Mt	22.7
Copper				
Ore	Average	2.9	ha/Mt	66
	Max.	4.5	ha/Mt	100
	Min.	2	ha/Mt	45
Gold				
Ore	Average	6.7	ha/Mt	72
Iron Ore				
Ore	Average	4.25	ha/Mt	139

Table 11. Land data from company sustainability reports and comparison to literature average values.

Commodity	Specific Land Use	Units	Average of Literature Values
Bauxite	23	ha/Mt	14.5
Bauxite	33.2	ha/Mt	
Bauxite	107.6	ha/Mt	
Iron Ore	11.86	ha/Mt	4.25

To sum up, 318 km^2 have been newly disturbed by mining of bauxite, copper, gold, and iron ore in 2016 using the average values from literature, with a range of 278 km^2 to 370 km^2 using minimum and maximum values. Since the area is very small, we did not put this in a global context.

Murguia also calculated the cumulative net area disturbed for these four commodities in 2011 as 11,485 km^2 [29] (p. 163) and looked into the types of land disturbed as a proxy for the impact on biodiversity.

4. Discussion

In this paper, the authors analysed three categories of environmental pressures—CO_2-emissions, water use, and land use—related to global mining of bauxite, copper, iron ore, and gold-making results indicative for metal mining. The available numbers show that in absolute terms and on the global level the overall dimension of the pressures put on the environment—about 190 Mt of CO_2 emissions, 4850 Mm^3 of water use and 318 km^2 of newly disturbed land in 2016—are comparably low However, this must not be seen as a charter to not taking mining activities into environmental considerations. These remain relevant, especially as the local impacts are increasing, and will do so even more in the future, as demand for metals increases and accessibility declines. These numbers change of course significantly for CO_2 emissions and water use in the case of iron ore and bauxite when including the production of steel and aluminium in the analysis.

The data review reveal that, to carry out such environmental analyses, available data are still very limited, and there are significant gaps in comparability of different sources, especially related to the identified boundary conditions (including type of mine and process routes), input parameter definitions, and the applied allocation methodology. Hence, further work is needed to align these assessments with the identified criteria. Another key limitation is the lack of detailed reporting of environmental data at the company level, a concern which Mudd [36] and Northey et al. [28] raised in their studies and which has not changed since. Similar to (economic) production data, where this is largely already the case, environmental data would need to be reported consistently, at the commodity and at the site, ideally even process, level. This would allow for further comparison of process routes and technologies, but also for better modelling of future environmental pressures from increased metal demand, as well as better policy making related to metal mining, for example in areas such as mining's role in achieving the Sustainable Development Goals (SDGs), the circular economy, responsible supply chain management, and trade agreements or the transition of our energy system towards a low carbon footprint.

Suggesting a way forward to overcome these limitations, organizations like GRI, ICMM, and the commodity specific associations should collaborate to define (and standardize) the criteria mentioned above and update standards for companies to report at the site level. Data providers such as WMD, USGS, or S&P should then think about broadening their services to include environmental (and social) data in their products.

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