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A CRITICAL ENVIRONMENTAL ANALYSIS OF STRATEGIC MATERIALS TOWARDS ENERGY TRANSITION

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ABSTRACT

Global consumption of materials is rising rapidly leading to an increase in environmental impacts associated with the supply chain. Similar issues also affect a set of materials strategic for the transition towards a sustainable energy production and distribution system: i.e. materials employed in renewable energy (wind turbines and photovoltaic panels), energy storage, electrolysers, electricity distribution networks and electric vehicle charging infrastructure. The analysis identifies, maps and defines a priority hierarchy for the environmental risks generated along the life-cycle of strategic raw materials. Standard construction material such as iron, steel and concrete showed the lowest environmental risks whereas platinum and iridium presented by far the highest impacts (respectively about 24.100 and 14.700 kg CO_2 eq, 354.000 and 216.000 MJ, and 140 and 83 m^3 of water for 1 kg of raw material). Recycled materials have shown to enable the lowering of the environmental risk associated with some raw material production processes (i.e. copper, lead, aluminium, nickel, manganese), whereas specific materials (i.e. platinum, iridium, indium, dysprosium) and related applications will need to be monitored to guarantee a sustainable transition towards renewable energies.

1. INTRODUCTION

Global consumption of materials is rising rapidly leading to an increase in environmental impacts, including habitat destruction, biodiversity loss, overly stressed fisheries and desertification, and contributing to greenhouse gas emissions (OECD, 2019). Failure to find more productive and sustainable ways to extract, use and manage materials, and change the relationship between material consumption and growth, has grave implications for economy and society.

The global energy transition could drive one of the most substantial increases in critical raw material (CRM) demand in history. CRMs are defined as raw materials that are economically and strategically important to an economy but carry high risk associated with their supply due to various factors such as insufficient production capacity, geopolitical concerns, and market price dynamics (Ferro & Bonollo, 2019). Low-carbon technologies typically have high and diverse mineral resource requirements compared to conventional counterparts (IEA, 2021), e.g copper, silicon and silver for solar PV. There is currently no shortage of these mineral resources, but recent price rises for cobalt, copper, lithium and nickel highlight how supply could struggle to keep pace with world's climate ambitions. According to a World Bank report, meeting Paris Agreement targets will require 3 billion metric tons of materials worldwide for low-carbon technology, representing more than 1000% growth in demand for key CRMs by 2050 (Hund et al., 2020).

This study aims at identifying, mapping and defining a priority for the environmental risks generated along the life-cycle of strategic raw materials, from mineral extraction, to first transformation phases and raw material production process.

2. MATERIALS AND METHODS

A set of 21 primary and/or recycled raw materials have been analysed according to the Life Cycle Assessment (LCA) methodology. LCA is a technique to make more informed decisions through a better understanding of the human health and environmental impacts of products, processes, and activities (Magrassi et al., 2019; Pederzoli et al., 2022). This can include an evaluation of the potential environmental impacts linked to the air, water, and soil emissions, and material and energy consumption of a production process, and possible alternative scenarios. LCA, performed according to ISO 14040-44 standards (ISO, 2021a, 2021b), is increasingly adopted for the appraisal of products, as the methodology accounts for environmental impacts and resource use over their entire life cycles

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(Magrassi et al., 2019; Strazza et al., 2016). Depletion, scarcity and criticality of raw materials are key issues under discussion both in the LCA community and in the wider resource debate.

Materials reported in Table 1 are the strategic ones identified for the transition towards a sustainable energy production and distribution system. They have been listed according to the following categories: base metals, precious metals, technology metals, rare-earth-oxides (REOs), and other materials. Such materials are employed in renewable energy production systems (wind turbines and photovoltaic panels), energy storage, electrolysers, electricity distribution networks and electric vehicle charging infrastructure.

The above-described materials and production processes of primary materials – divided into the mining, refining and production steps – have been analysed through LCA. The functional unit applied is 1 kg of raw material. If possible, also recycling processes for the production of secondary materials have been assessed.

All materials have been assessed on a global scale, considering the market share available in the database. Final distribution of the material is neglected whereas transportation of intermediate and auxiliary materials is considered.

The mining step considers the extraction processes for the mineral resource: open-pit mining, also known as opencast mining, and underground mining are mainly considered. This step does not consider any pre-treatment of the resource and is mainly characterised by diesel and blasting consumption for the mining activity.

The refining step considers all the pre-treatment process needed before the production step. Ore concentration may be done by froth concentration, gravity concentration, magnetic separation, and/or crushing and milling. Treatment of tailings and residues from the concentration activities is assessed in this phase.

The production step considers the final process for obtaining the considered material. Such step mainly involve pyrometallurgical and hydrometallurgical processes.

Most data have been obtained using the Ecoinvent database v.3.5 (Wernet et al., 2016) and modelled using the software SimaPro v.9.3.0. Instead, different literature sources have been considered for the assessment of dysprosium (Zapp et al., 2018), vanadium (Weber et al., 2018) and the allocation of process impact among platinum and iridium (Nuss & Eckelman, 2014).

The main environmental impacts assessed along the life-cycle of all the materials, in terms of resources depletion,

TABLE 1: List of materials and applications.

Materials		Wind turbines	PV panels	Batteries	Electrolysers	Distribution networks	Charging stations
Base metals	Copper	X	X	X	X	X	X
	Lead					X	X
	Aluminium		X			X	X
	Nickel	X		X	X		
Precious metals	Platinum				X		
	Iridium				X		
Technology metals	Indium		X			X	
	Lithium			X	X	X	
	Cobalt			X	X		
	Silicon		X			X	X
	Manganese			X			
	Vanadium			X			
	Titanium				X		
Rare-earth-oxides (REOs)	Neodymium	X					
	Dysprosium	X					
	Praseodymium	X					
Other materials	Iron	X	X			X	X
	Steel	X	X			X	X
	Concrete	X	X			X	
	Graphite			X			
	Phosphorous			X		X	

waste generated, emission of greenhouse gases and recycling related impacts, are summarised in Table 2, complemented by reference to characterisation methods and sources.

LCA examines a product's life cycle and identifies where the main environmental impacts arise. Table 3 presents the main environmental impacts associated to each process.

TABLE 2: Environmental indicators (characterisation methods).

Environmental impacts	Impact description	Characterisation method	Unit	Source
Material extracted from the quarry	Total quantity of material extracted from the quarry per unit of material produced. Inventory of mineral ore extracted.	Life Cycle Inventory (LCI)	kg	(Wernet et al., 2016)
Release of hazardous waste materials into the environment	Release of hazardous waste materials into the environment (extraction phase). Inventory of hazardous waste.	Environmental Design of Industrial Products (EDIP), 2003	kg	(Wernet et al., 2016)
Quantity of waste/scrap generated	Quantity of waste / scrap generated per unit of material produced. Inventory of total waste.	Environmental Design of Industrial Products (EDIP), 2003	kg	(Wernet et al., 2016)
Hazardous chemicals	Use of hazardous chemicals in the process. Number of hazardous chemicals applied. Secondary material process impacts included.	Life Cycle Inventory (LCI)	n°	(EC, 2006; Wernet et al., 2016)
Water use	Water consumption per unit of material produced. Inventory of total water consumption. Secondary material process impacts are included.	Life Cycle Inventory (LCI)	kg	(Wernet et al., 2016)
Energy use	Energy consumption per unit of material produced. Inventory of primary energy consumption in terms of both non-renewable (fossil, nuclear, biomass) and renewable (biomass, wind, solar, geothermal, hydro) energy. The method is based on higher heating values (HHV). Secondary material process impacts are included.	Cumulative Energy Demand (CED)	MJ	(Wernet et al., 2016)
Emissions of greenhouse gases	Greenhouse gas emissions per unit of material produced, expressed as Global Warming Potential (GWP). GWP is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given time period, relative to the emissions of 1 ton of carbon dioxide (CO_2). The larger the GWP, the more a given gas warms the Earth compared to CO_2 over that time period. The time period used here for GWPs is 100 years. Secondary material process impacts are included.	Global Warming Potential (GWP) – IPCC, 2013	kg CO_2 eq	(Wernet et al., 2016)
Current recycling rate of end-of-life material	Current recycling rate of the material at its end-of-life (EoL-RR). EoL-RR captures the amount of materials recovered at end-of-life compared to the overall waste quantities generated (output perspective). It provides information about the performance of the collection and recycling to recover materials at end-of-life.	Bibliography	%	(EC, 2020b, 2020a; Eurometaux, n.d.)
Rate of use of recycled material	Rate of use of recycled material. This rate accounts the percentage of recycled materials as a contribution to the total inputs of new raw material (input perspective), i.e. recycled content.	Bibliography	%	(EC, 2020b, 2020a)

TABLE 3: Environmental indicators (hotspots).

Environmental impacts	Mining	Refining	Production
Material extracted from the quarry	The quantity of ore extracted is related solely to the mining phase.	No mineral ore extraction assessed.	No mineral ore extraction assessed.
Release of hazardous waste materials into the environment	Generally not relevant.	Generally not relevant.	Mainly related to slag or spent solvent deriving from the production process.
Quantity of waste/scrap generated	Generation of overburden material from the mining activities.	Generation of tailings during the concentration processes of mineral ore.	Residual tailings or inert waste.
Water resource consumption	Direct water consumption is predominant in the life cycle assessment of the materials. The water demand of the three different stages varies considerably according to each industrial process.		
Energy consumption	Diesel consumption in mining machinery.	Direct electricity consumption in machinery.	Direct electricity or heat consumption in the production process.
Emissions of greenhouse gases	Emissions from the diesel burned in the mining machinery and from the production of blasting.	Indirect emissions deriving from the electricity consumption and the production of auxiliary materials.	Indirect emissions deriving from the electricity consumption or direct emission from heat consumption.

3. RESULTS AND DISCUSSION

Environmental indicators listed in Table 2 have been calculated for 1 kg of each material. After assessing the environmental impacts for each of 21 key raw materials, in order to define a priority for the environmental risks generated along the life-cycle, specific results of each material have been analysed and combined to obtain a comprehensive level of environmental impact.

An actual subdivision of the results among mining, refining and production steps was not possible for dysprosium and for the water use of platinum and iridium production.

Final results are reported in Tables 4-5 and Figures 1-3.

As the database uncertainty may affect the results both in terms of the quantitative assessment of the impact categories and especially in terms of the qualitative assessment of the risk hierarchy, a Monte Carlo analysis was operated for each of the raw material in order to identify the variation range of such environmental impacts. A 95% probability range has been calculated according to the derived mean and standard deviation: coherently, the 2,5-percentile (minimum expected value) was set at 2 times the standard deviation below the mean value, whereas the 97,5-percentile (maximum expected value) was set 2 times the standard deviation above the mean value. Results are reported in Figures 4-6, where the minimum and maximum values are shown in green and red colour respectively. No lower boundary is shown for water use (Figure 6) as the standard deviation would have set it below 0: a null water consumption can thus be set as the minimum expected value. Analysing the graphs and the variation coefficients (standard deviation over mean value) of the different materials and impact categories, it is possible to assess how data uncertainty does not represent a critical issue in terms of GHG emissions and energy use. For the former impact category, the qualitative comparison of the raw materials is not affected by uncertainties and variation coefficients range between 5,1% (aluminium) and 15,5% (graphite), whereas for the latter variation coefficients range between 5,6% (aluminium) and 17,1% (graphite). On the other side, water use seems to be strongly affected by data uncertainty with variation coefficients all above 800%. Despite the strong influence on the quantitative assessment, still the uncertainty should not consistently affect the qualitative comparison of raw materials and the resulting risk hierarchy.

Potential reductions in environmental impacts are expected with the use of secondary raw materials. Results reported in Table 4 show negligible recycling rate and recycled content for most of the materials. Moreover, reliable LCA data on recycling processes were not found for all the recycled materials. Thus, environmental results for recycled materials were assessed only for 8 different secondary raw materials (Table 6): copper, lead, aluminium, nickel,

TABLE 4: Environmental indicators (results) of primary raw materials.

Materials	Material extracted from the quarry [kg]	Hazardous waste [kg]	Total waste [kg]	Hazardous chemicals [n°]	GHG emissions [kg CO_2 eq]	Energy use [MJ]	Water use [m³]	Recycling rate [%]	Recycled material [%]
Copper	191,85	1,40	190,83	2	4,70	69,22	0,08	70%	33%
Lead	7,96	0,35	6,86	6	1,90	19,85	0,02	95%	80%
Aluminium	3,83	1,66	1,68	1	16,72	186,22	0,08	90%	37%
Nickel	56,22	0,00	55,06	3	10,00	140,19	0,12	68%	34%
Platinum	138.540,99	3.854,43	119.419,01	2	24.098,04	353.893,39	140,24	50%	25%
Iridium	85.128,65	1.826,13	73.546,73	2	14.732,51	215.934,28	83,20	25%	14%
Indium	388,02	0,14	314,46	1	207,14	2.528,58	1,99	1%	0%
Lithium	25,53	0,00	39,06	3	41,90	581,94	0,60	0%	1%
Cobalt	101,22	0,00	99,90	2	9,02	117,52	0,15	68%	22%
Silicon	2,92	0,00	0,03	1	10,61	152,61	0,13	0%	0%
Manganese	16,43	1,88	15,86	1	3,13	55,22	0,03	37%	9%
Vanadium	16,85	1,63	2,22	4	18,78	318,84	0,16	1%	1%
Titanium	4,66	0,00	3,66	4	28,31	412,16	0,26	95%	19%
Neodymium	38,73	6,26	45,79	4	21,88	573,94	0,33	1%	0%
Dysprosium	3.990,50	1,75	1,75	5	318,60	3.941,89	N/A	1%	0%
Praseodymium	36,35	5,88	42,98	4	20,54	538,69	0,31	1%	0%
Iron	1,99	0,11	0,13	2	1,68	21,45	0,01	75%	42%
Steel	2,53	0,04	0,06	2	2,23	26,44	0,01	75%	42%
Concrete	0,99	0,00	0,00	1	0,08	0,46	0,00	30%	8%
Graphite	1,05	0,00	0,03	0	1,69	51,26	0,01	0%	0%
Phosphorous	8,00	0,00	0,00	2	11,50	213,29	0,12	0%	0%

TABLE 5: Impact categories of primary raw materials – percentage contribution of mining refining and production phases.

Materials	GHG emissions			Energy use			Water use		
	Mining	Refining	Production	Mining	Refining	Production	Mining	Refining	Production
Copper	17,7%	14,9%	67,4%	13,8%	20,3%	65,9%	66,3%	6,2%	27,6%
Lead	20,8%	11,9%	67,4%	16,7%	19,3%	64,0%	39,2%	16,0%	44,9%
Aluminium	0,3%	18,4%	81,3%	0,4%	17,5%	82,1%	2,4%	14,3%	83,3%
Nickel	24,9%	50,0%	25,1%	15,5%	63,2%	21,3%	55,9%	41,2%	2,9%
Platinum	42,8%	16,7%	40,5%	43,0%	16,9%	40,1%	n.a.	n.a.	n.a.
Iridium	43,1%	16,8%	40,1%	43,3%	17,1%	39,6%	n.a.	n.a.	n.a.
Indium	14,9%	81,0%	4,1%	14,7%	80,2%	5,1%	23,7%	73,4%	2,9%
Lithium	0,9%	47,5%	51,6%	1,0%	41,9%	57,1%	0,2%	66,1%	33,7%
Cobalt	52,5%	40,0%	7,5%	34,3%	47,7%	18,0%	77,5%	18,9%	3,7%
Silicon	0,1%	0,8%	99,2%	0,1%	0,6%	99,3%	3,1%	0,1%	96,8%
Manganese	1,1%	0,5%	98,4%	0,8%	0,6%	98,6%	0,4%	3,2%	96,4%
Vanadium	3,5%	88,6%	7,9%	13,6%	79,1%	7,3%	2,4%	77,9%	19,7%
Titanium	7,9%	25,2%	66,9%	7,6%	21,4%	71,0%	10,6%	35,8%	53,6%
Neodymium	0,4%	22,4%	77,3%	0,2%	11,9%	87,9%	0,1%	17,3%	82,6%
Dysprosium	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Praseodymium	0,4%	22,4%	77,3%	0,2%	11,9%	87,9%	0,1%	17,3%	82,6%
Iron	6,9%	64,7%	28,4%	8,3%	55,4%	36,3%	6,3%	22,8%	70,9%
Steel	6,6%	61,2%	32,2%	8,5%	56,3%	35,2%	4,7%	16,7%	78,6%
Concrete	4,2%	85,0%	10,7%	10,8%	60,6%	28,5%	84,0%	9,3%	6,7%
Graphite	0,1%	99,5%	0,4%	0,1%	99,8%	0,2%	0,1%	99,5%	0,5%
Phosphorous	0,9%	16,0%	83,2%	0,7%	13,8%	85,4%	0,1%	28,1%	71,8%

platinum, lithium, manganese and steel. Other materials are listed as 'not applicable' (n.a.).

Coherently with the reported results for recycled materials, Figures 7-9 show the trends of the residual impact with respect to primary materials according to recycled content assessed for global warming potential (GWP), energy use and water use. Each trendline presents a circle indicator highlighting the actual recycled content at global level. For the comparison, not a 1:1 substitution ratio has been applied but the substitution factors from a recent European Commission study have been considered (European Commission, 2017). The substitution factors were set equal to 1 for copper, lead, manganese and steel, equal to 0,9 for nickel, platinum and lithium and equal to 0,8 for aluminium. The graphs consequently present linear trendlines but, for substitution factors below 1, an increased amount of total raw material is considered at increasing recycled content.

Among the materials, manganese shows the best impact reduction potential in all the categories due to the low residual impact allocated to its recovery at end of life.

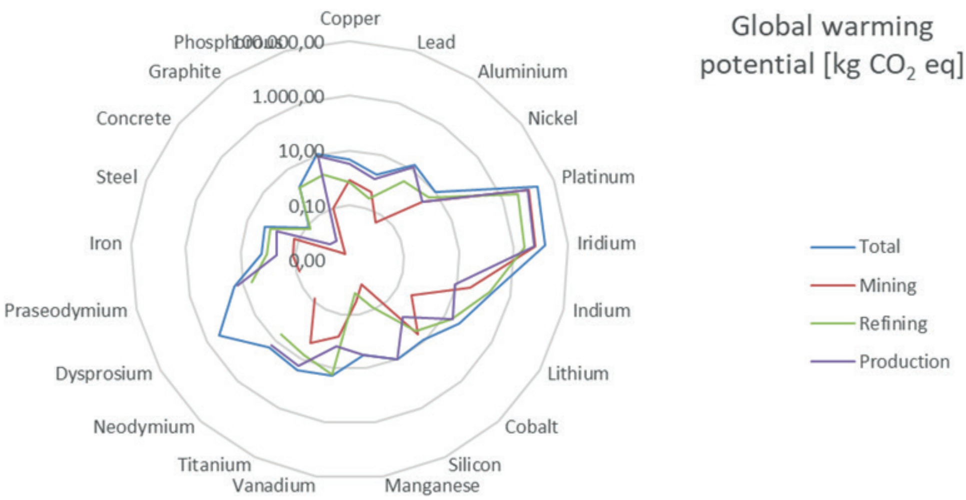

FIGURE 1: Graphical summary of LCA comparison of primary materials (Global warming potential).

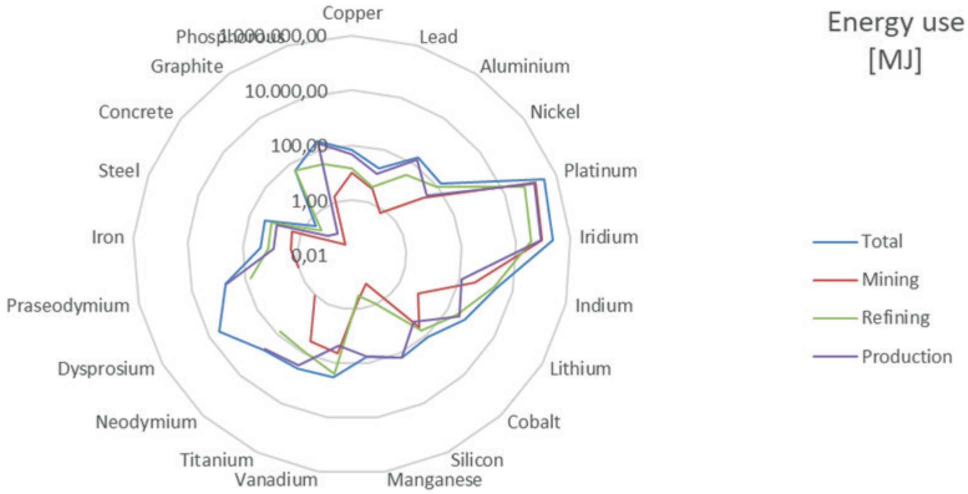

FIGURE 2: Graphical summary of LCA comparison of primary materials (Energy use).

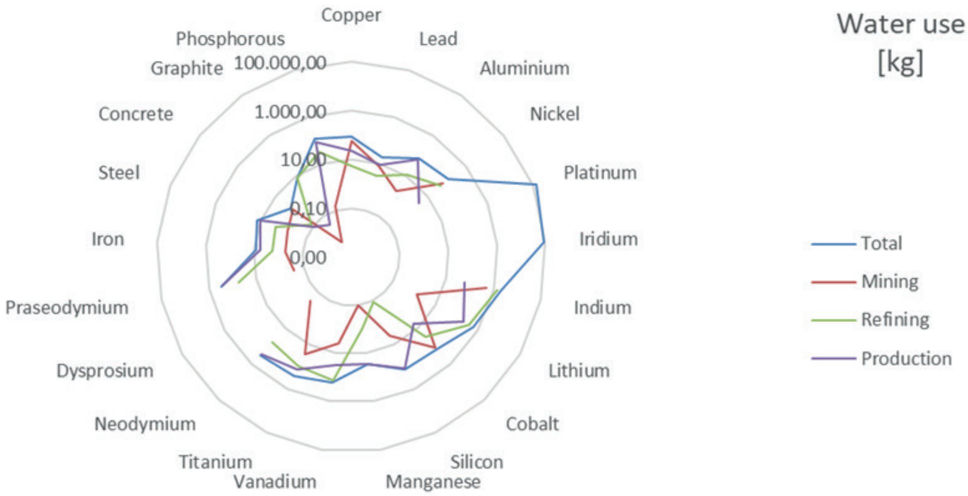

FIGURE 3: Graphical summary of LCA comparison of primary materials (Water use).

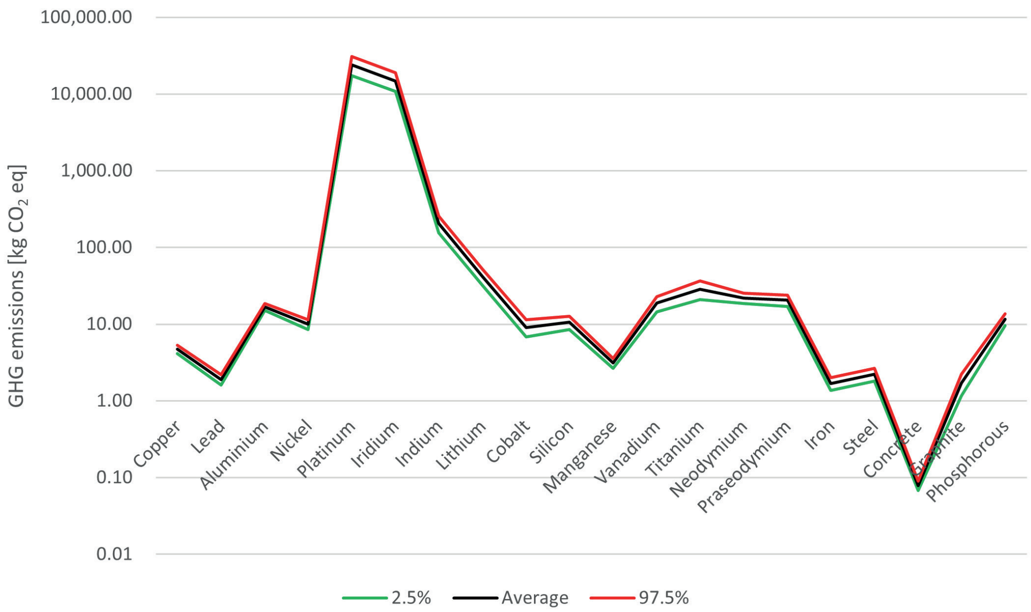

FIGURE 4: Lower and upper boundaries for result uncertainty – 95% probability range (Global warming potential).

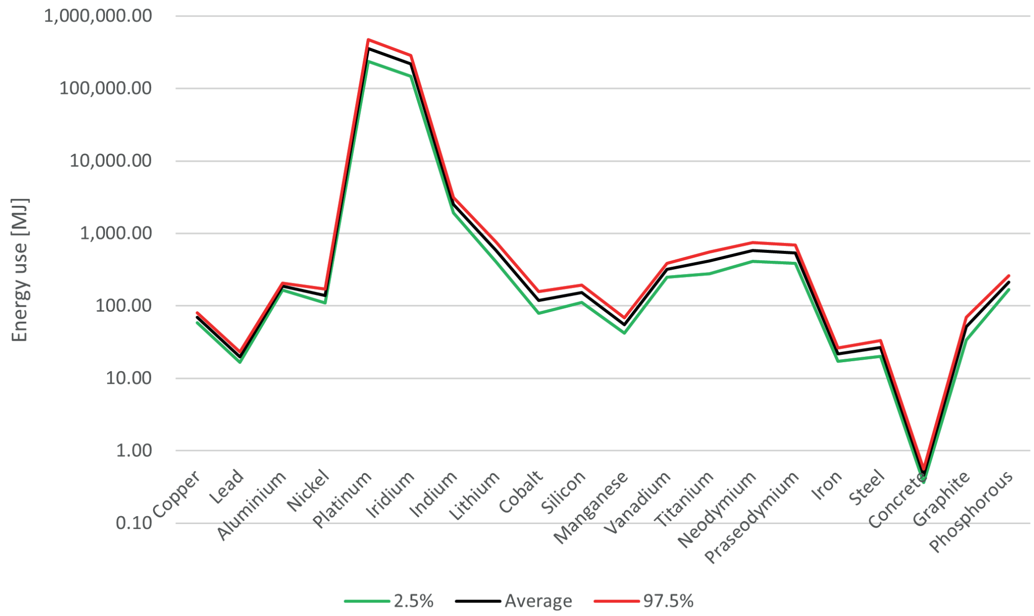

FIGURE 5: Lower and upper boundaries for result uncertainty – 95% probability range (Energy use).

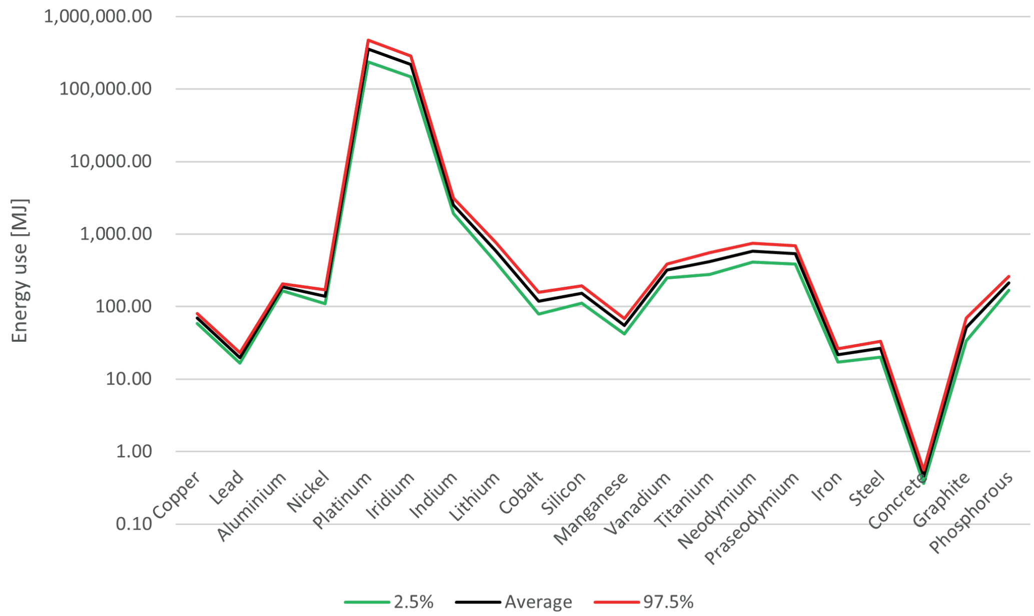

FIGURE 6: Lower and upper boundaries for result uncertainty – 95% probability range (Water use).

However, a global recycled content of 9% shows the need for further improvement in closing the gap for such potential. Considering the actual recycled contents, the highest impact reduction for the combination of recycled materials with virgin ones is shown by lead: at a recycled content of 80% the GWP is reduced by 60%, energy use by 51% and water use by 40% with respect to the sole virgin material. Due to the very low recycled content (1%), impact reduction for lithium is quite negligible despite a good reduction potential for the recycled material. Concerning the remaining materials, at the actual recycled contents they show impact reductions around 30%-40% for GWP, 25%-35% for energy use and 20%-35% for water use.

Nevertheless, aiming at a constant increase in recycled content of raw materials, the analysed recycled materials show a potential reduction of at least 70% for the GWP, 60% for the energy use (excluding the 13% reduction for lithium), and 44% for water use (excluding the 25% reduction for lithium).

According to the environmental results and indicators of both primary and recycled materials, Table 7 classifies the analysed materials within an environmental hierarchy according to the overall environmental performance assessed in the analysis.

The assessment has been performed through a quantitative and qualitative approach: each of the selected

TABLE 6: Environmental indicators (results) of recycled materials.

Materials	Hazardous waste [kg]	Total waste [kg]	Hazardous chemicals [n°]	GHG emissions [kg CO_2 eq]	Energy use [MJ]	Water use [kg]
Copper	0,00	0,00	1	0,57	7,54	0,01
Lead	0,00	0,00	4	0,49	7,18	0,01
Aluminium	0,02	0,04	5	0,77	9,37	0,02
Nickel	0,00	0,00	2	0,78	5,54	0,00
Platinum	0,02	530,65	1	1.024,14	15.356,80	7,13
Iridium	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Indium	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Lithium	0,00	0,00	2	10,93	453,63	0,41
Cobalt	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Silicon	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Manganese	0,00	0,00	1	0,01	0,12	0,00
Vanadium	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Titanium	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Neodymium	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Dysprosium	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Praseodymium	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Iron	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Steel	0,10	0,11	1	0,65	10,69	0,01
Concrete	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Graphite	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Phosphorous	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

indicators has been compared within the set of the analysed materials. The set of each indicator has been colour-ranked according to minimum, maximum and average values of each impact category (green=low and red=high). Specific indicators presenting values extremely far from the average of the set have been discarded from the ranking: i.e., all the indicators derived from the life cycle impact assessment for concrete, platinum and iridium and also the indicators of material extraction and waste production for primary platinum and iridium. Indicators on recycling rate at end of life and rate of recycled material have not been included in the assessment as the data sourcing is not uniform and as recycled materials are already considered if possible.

Coherently with the formatting of the indicators, each material has been associated with a different level of environmental impact according to the following criterion:

- LOW if 5 or more indicators resulted in being green-coloured;
- MEDIUM if at least 5 indicators resulted in being green- or yellow-coloured;
- HIGH if 3 or more indicators resulted in being orange- or red-coloured.

Low-risk materials present no relevant environmental issues, whereas high-risk materials must be monitored.

As shown, the use of recycled materials indeed reduces the associated environmental impacts and allows the lowering in the hierarchy level of the environmental risk: whereas steel, lithium and platinum maintain the impact level of the primary materials, copper, lead, aluminium, nickel and manganese switch from medium to low.

CONCLUSIONS

This study aimed at identifying, mapping and defining a priority for the environmental risks generated along the life-cycle of strategic raw materials, from mineral extraction, to first transformation phases and raw material production process. The influence of data uncertainty linked to the selected database was assessed and water use was found to represent a potential issue in terms of a quantitative assessment of the environmental impact. Nevertheless, no critical issue was found concerning the qualitative comparison needed for the hierarchisation according to the overall environmental risk.

Low-risk materials are mainly linked to supporting structures for energy plant installation and are in general characterised by good availability and low material losses

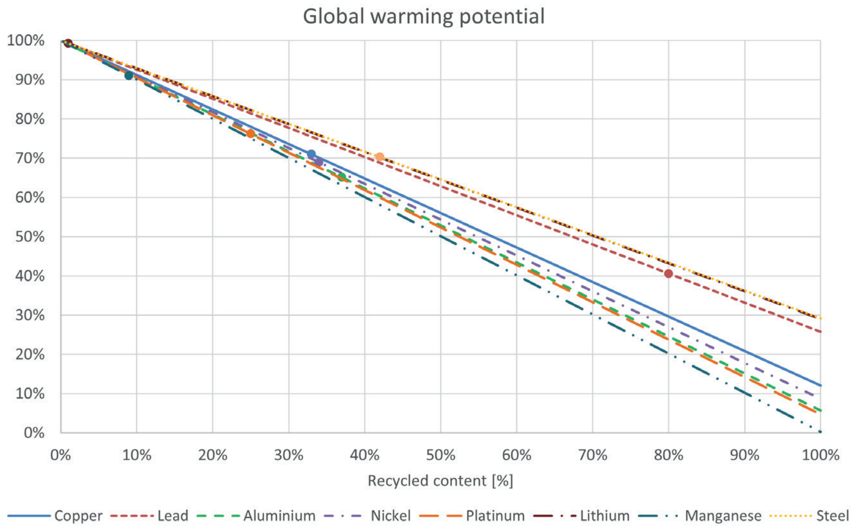

FIGURE 7: Impact reduction potential for recycled content (Global warming potential).

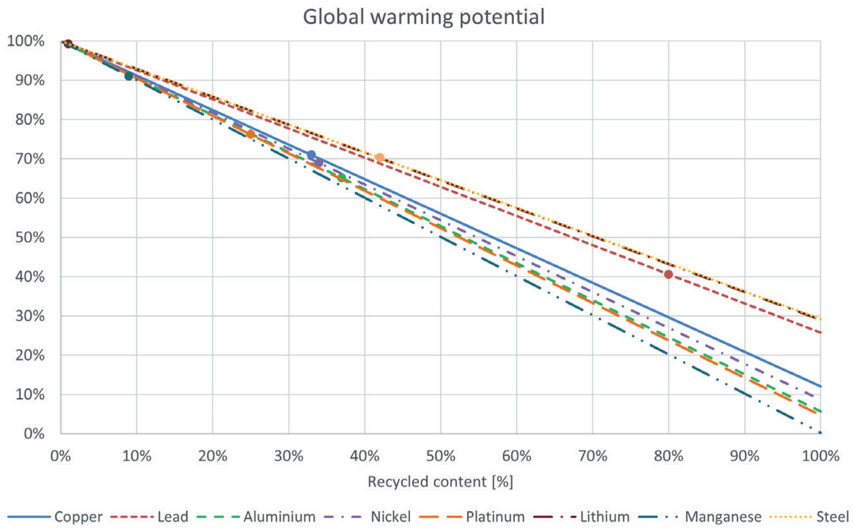

FIGURE 8: Impact reduction potential for recycled content (Energy use).

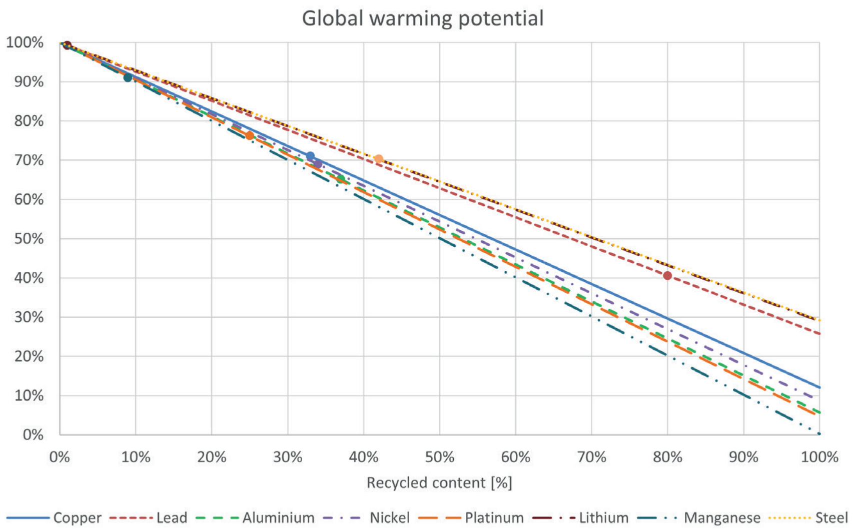

FIGURE 9: Impact reduction potential for recycled content (Water use).

TABLE 7: Environmental risk hierarchy of primary raw materials.

LOW	MEDIUM		HIGH
Iron Steel (primary) Steel (recycled) Concrete Graphite Copper (recycled) Lead (recycled) Aluminium (recycled) Nickel (recycled) Manganese (recycled)	Copper (primary) Lead (primary) Aluminium (primary) Nickel (primary) Lithium (primary) Lithium (recycled) Cobalt Silicon	Manganese (primary) Vanadium Titanium Neodymium Praseodymium Phosphorus	Platinum (primary) Platinum (recycled) Iridium Indium Dysprosium

through the production process. Moreover, despite ranking among medium-risk virgin materials, several materials - such as copper, aluminum, nickel, etc. - already present high percentages of recycling rate and recycled material which enable to considerably reduce the environmental risk associated with the supply chain.

Among the high-risk materials, impacts are mainly due to the high and above-average quantity of material extracted from the quarry, also leading to a higher need of refining steps. Currently indium and dysprosium – and generally REOs – show a negligible value of recycling rate and recycled content, whereas platinum and iridium present relevant values but for non-energy-related technologies.

Standard construction material such as iron, steel and concrete showed the lowest environmental risks whereas platinum and iridium presented by far the highest impacts (respectively about 24.100 and 14.700 kg CO_2 eq, 354.000 and 216.000 MJ, and 140 and 83 m^3 of water for 1 kg of raw material). Recycled materials have shown to enable the lowering of the environmental risk associated with some raw material production processes (i.e. copper, lead, aluminium, nickel, manganese), whereas specific materials (i.e. platinum, iridium, indium, REOs) and related applications – especially wind turbines for REOs and electrolysers for precious metals – will need to be monitored to allow a scientific development in their recycling process and/or substitution and to guarantee a sustainable transition towards renewable energies.

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