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Critical Raw Materials Hidden in the Products Life Cycle: The Case Study of a Power Supply Unit

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ABSTRACT

Critical raw materials (CRMs) are crucial for the production of different products and technologies. The correct quantification of CRMs consumption, including hidden uses along the products life cycle, can be made through the application of the Life Cycle Assessment (LCA) methodology. Starting from the eco-profile of a power supply unit, obtained through a LCA study, this paper focuses on the assessment of the total CRMs consumption of this device. In order to free the assessment from the mass of each CRM, two different approaches are applied, based on the supply risk and economic value, respectively. Similar percentage results are obtained when the assessment is based on the CRMs mass or supply risk index (with some exceptions), while the approach based on the economic value seems more able to bring out materials that are considered more "critical" in terms of economic importance. This research is developed within the activities of the project LOV-Lowering Ortigia's Voltage, funded by POC 2014-2020, CUP G39J18000690007.

1. INTRODUCTION

In 2008, Europe published "The raw materials initiative" [1], highlighting the high dependence on import of numerous raw materials, not only energy materials but also non-energy ones. Consequently, in 2011 the first list of Critical Raw Materials (CRMs) for Europe was published [2] obtaining 14 CRMs.

Critical raw materials are those which display a particularly high risk of supply shortage in the next years and which are particularly important for the value chain.

The above list was updated every 3 years, indeed the last list was released in 2023, in which 34 CRMs were identified.

The correct identification and calculation of the CRMs used in a product must include not only the direct consumption of these materials in the products itself, but also CRMs used along the entire supply chains (hidden consumption of CRMs).

The quantification of CRMs used in a product, including both direct and indirect consumption, can be conducted by applying the Life cycle Assessment (LCA).

LCA is an internationally accepted methodology [3, 4], to evaluate the energy and environmental impacts considering the entire life cycle of a service or a product. Mancini et al. [5] highlighted the potential of this methodology to identify hot-spots and improvement of CRMs use.

To quantify the resource depletion in LCA there is a lack of consensus: Rørbech et al. [6] and Klinglmair et al. [7] showed that varying the assessment method leds to different results as in absolute value as in contribution analysis.

The differences among the methods mainly concern the choices of specific factors, defined as "characterization factors -CFs". CFs are used to quantify the consumption of each CRM with a "weighted" approach, which takes into account non only the mass of the CRM but also other characteristics, as the availability, the risk of supply, etc.

The most used index to assess the consumption of resources recommended by the European Commission is "Use of resource, minerals and metals" of "Abiotic depletion" [8]. However, the index is referred generally to minerals and metals and it is not specifically applied to CRMs.

Many authors investigated the best method to assess criticality, not only in a life cycle perspective. Calvo et al. [9], for instance, proposed a method based on thermodynamic rarity, that is the amount of exergy necessary for the material extraction. Mancini et al. [10] used the supply risk proposed by EU to assess criticality and, to extend the range of the characterization factors, this index was raised by an exponent. Cimprich et al. [11] analysed three different methods to assess supply risk in LCA (GeoPolRisk, ESP and ESSENZ), by obtaining differences among the three methods. Ardente et al. [12] developed a method to quantify criticality based on the economic value (in particular the market price) of the resources.

In the present study, two of the above cited methods are applied: the first is based on Supply Risk index [10], instead of the second utilizes characterization factors obtained by the 50 years average value of market prices [12]. These methods are applied to a case study, a power supply unit, which represents a typical electronic load frequently included in the places of work and houses.

In detail, this paper aims to measure the CRMs utilization by applying the LCA methodology and considering the two approaches described above, and to verify the incidence of direct and life cycle CRMs rate on the total consumption.

2. CRITICALITY FOR THE EUROPEAN UNION

2.1 Critical raw materials lists

The European Commission in 2011 identified 14 CRMs through the development of an innovative system to assess criticality. The risk of raw materials depended on the production concentrations in few countries characterized by instability from a political-economic perspective combined with low substitutability and recycling rates. The Commission developed three indexes based on Import dependency rate, Substitutability and Recycling rate, in collaboration with Member States and stakeholders [13]. From 2014, Supply Risk (SR) and Economic Importance (EI) have been introduced to evaluate criticality of raw materials: from fifty-four candidates twenty materials were judged critical [12]. Then, in 2017, twenty-six CRMs were identified starting from 61 with the same methodology. Similarly, in 2020, the study on CRMs was carried out analysing 66 candidates, 30 were identified as critical [14]. Overall, the evolution of these studies supports the idea that, presumably, the number of CRMs will continue to increase in the next years. Thus, it is necessary to detect the CRMs use to reduce or replace these materials, in an eco-design perspective.

Table 1. 2023 CRMs' list

CRMs	SR	EI
Aluminium/Bauxite	1.1	5.5
Antimony	1.8	5.4
Arsenic	1.9	2.9
Baryte	1.3	3.5
Beryllium	1.8	5.4
Bismuth	1.9	5.7
Boron/Borate	3.6	3.9
Cobalt	2.8	6.8
Coking Coal	1.0	3.1
Copper	0.1	4.0
Feldspar	1.5	3.2
Fluorspar	1.1	3.8
Gallium	3.9	3.7
Germanium	1.8	3.6
Hafnium	1.5	4.3
Helium	1.2	2.9
HREEs	5.1	4.2
Lithium	1.9	3.9
LREEs	3.7	5.9
Magnesium	4.1	7.4
Manganese	1.2	6.9
Natural graphite	1.8	3.4
Nickel	0.5	5.7
Niobium	4.4	6.5
PGMs	2.7	7.1
Phosphate rock	1.0	6.4
Phosphorus	3.3	4.7
Scandium	2.4	3.7
Silicon Metal	1.3	4.9
Strontium	2.6	6.5
Tantalum	1.3	4.8
Titanium Metal	1.6	6.3
Tungsten	1.2	8.7
Vanadium	2.3	3.9

In the last report of CRM (2023), 67 raw materials and 3 groups of materials were analyzed, in particular, Light Rare Earth Elements (LREEs) Heavy Rare Earth Elements (HREEs) and Platinum Group of Metals (PGMs). Consequently, 34 CRMs were rated as critical (31 raw materials and the 3 groups of materials) on the basis of the two indexes, SR and EI [15]. If a material has a SR exceeding 1.0 and simultaneously EI higher than 2.8 the raw material is critical [15] (with the exception of copper and nickel that are considered critical only for the high value of EI, respectively 4 and 5.7, despite a value lower than 1 in SR). The 2023 list of CRMs is showed in Table 1; in the groups of materials the values of SR and EI are obtained averaging the elements of each group, rounded to the first decimal place.

The groups include the following elements:

- cerium, lanthanum, neodymium, praseodymium and samarium (for LREEs);
- Dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium, yttrium (for HREEs);
- Iridium, palladium, platinum, rhodium, ruthenium (for PGMs).

The total amount of CRMs is 50 obtained by disaggregating all the group of materials.

2.2 Description of the European indexes to assess criticality

The following equations are used to calculate the European indexes to assess criticality [16]. The SR index is obtained through Eq. (1):

$$SR=\left[\begin{array}{c}\left(HHI_{WGI,t}\right)_{GS}\cdot\dfrac{IR}{2}\\ +\left(HHI_{WGI,t}\right)_{EU\ sourcing}\cdot\left(1-\dfrac{IR}{2}\right)\end{array}\right]\cdot(1+-EoL_{RIR})\cdot SI_{SR} \qquad (1)$$

where:

- HHI is the Herfindahl-Hirschman Index, a measure of market concentration;
- WGI is the scaled World Governance Index;
- t is the trade factor regulating WGI;
- GS is the global annual production of a raw material in a reference period;
- IR is the import reliance;
- EU sourcing include the internal production of EU and the exports;
- EOL_{RIR} is referred to end-of-life recycling input rate;
- SI_{SR} is the substitution index related to the supply risk, it evaluates the availability of substitute of a material.

The EI index is calculated in Eq. (2):

$$EI=\sum\nolimits_{s}(A_s\cdot Q_s)\cdot SI_{EI} \qquad (2)$$

where:

- A_s is the quantity of raw material utilised in one of NACE (acronyms for European nomenclature of economic activities) sector;
- Q_s is a value added on the basis of the relevance of the sector;

- SI_{EI} is the substitution index of the economic importance, that is similar to SI_{SR} but related to the economic sphere.

2.3 The need for an index to measure critical raw materials consumption

LCA includes the analysis of all energy and material flows exchanged between the product system and the environment [5]. It can be a useful methodology to quantify the total CRMs consumption considering the whole life cycle.

In LCA, the concept of abiotic resource depletion includes many factors (extraction rates, reserves in environment and economy, ultimate extractable reserve) [17]. The index used to describe the use of resource (minerals and metals), measured in kg of equivalent antimony, does not include all the CRMs; it only involves 25/50 CRMs (Table 2) [18]. Thus, with the increasing importance of raw material consumption it is clear that a method referred specifically to CRMs can be useful to quantify the use of these materials.

Table 2. CFs of the two approaches

CRM	Characterization Factor	
Aluminium	1.09E-09	kg Sb_{eq} /kg
Antimony	1.00E+00	kg Sb_{eq} /kg
Arsenic	2.97E-03	kg Sb_{eq} /kg
Beryllium	1.26E-05	kg Sb_{eq} /kg
Bismuth	4.11E-02	kg Sb_{eq} /kg
Boron	4.27E-03	kg Sb_{eq} /kg
Cobalt	1.57E-05	kg Sb_{eq} /kg
Copper	1.37E-03	kg Sb_{eq} /kg
Gallium	1.46E-07	kg Sb_{eq} /kg
Germanium	6.52E-07	kg Sb_{eq} /kg
Lithium	1.15E-05	kg Sb_{eq} /kg
Magnesium	2.02E-09	kg Sb_{eq} /kg
Manganese	2.54E-06	kg Sb_{eq} /kg
Nickel	6.53E-05	kg Sb_{eq} /kg
Niobium	1.93E-05	kg Sb_{eq} /kg
Palladium	5.71E-01	kg Sb_{eq} /kg
Phosphorus	5.52E-06	kg Sb_{eq} /kg
Platinum	2.22E+00	kg Sb_{eq} /kg
Silicon	1.40E-11	kg Sb_{eq} /kg
Strontium	7.07E-07	kg Sb_{eq} /kg
Tantalum	4.06E-05	kg Sb_{eq} /kg
Titanium	2.79E-08	kg Sb_{eq} /kg
Tungsten	4.52E-03	kg Sb_{eq} /kg
Vanadium	7.70E-07	kg Sb_{eq} /kg
Yttrium	5.69E-07	kg Sb_{eq} /kg

3. THE CASE STUDY: CRMs OF A POWER SUPPLY UNIT

The present study focuses on the CRMs analysis of a Power Supply Unit (PSU) (Figure 1), which is the component responsible for conversion of alternating current from the grid to direct current feeding all computer components. This component is selected because it is not present only in computers, but in fact it is necessary in all electronic loads.

This section is organized following the structure of a LCA study, according to the international standards of ISO 14040 [3] and ISO 14044 [4]. Indeed, the first paragraph describes the goal and scope definition in which the reasons to carry out the study are explained as well as the intended outcomes and applications. Moreover, the functional unit and the system boundaries of the study are defined. At last, the approach to quantify the CRMs consumption is defined, specifying the CFs used. The second paragraph is about the inventory analysis that consists of quantifying all inputs (such as materials or energy) and outputs (products, direct emissions, wastes) of the system under study considering the whole life cycle. In the third and final part of this chapter, the results are obtained multiplying the inventory results and the CFs defined in the goal and scope stage.

Figure 1. Power supply unit

3.1 Goal and scope definition

The goals of the study are:

1) to demonstrate that direct use of CRMs is a small fraction of the total consumption and to highlight the importance to quantify the whole life cycle CRMs consumption;

2) to quantify the CRMs consumption applying two methods, the first one based on SR index and the other one based on economic value, to show the remarkable difference between the two diverse methods.

The system boundaries are considered “from cradle to gate”, that is from raw materials supply to the product’s assembly.

The PSU is selected as functional unit, which is the reference unit for the impacts.

Focusing on the CFs, SR is used for the first impact assessment method, as suggested by the study [10]. For the second method, the economic value is used, as proposed by Ardente et al. [12]. In particular, the average market price is considered, taking into account prices in 50 years referred to 1998 U.S. dollars (assumed as reference year), found in USGS site [19]. Reporting mineral prices to 1998 dollars is useful to adjust for inflation, indeed, it can affect the value of currency making the comparison between different materials difficult.

The CFs of the two approaches are shown in Table 3: CFs_1 are referred to SR method, CFs_2 to the economic approach.

For the second method certain values are missing in the USGS site

Table 3 shows that CF_2 are more variable than the CF_1, indeed there are six orders of magnitude from the larger value (Platinum) and the smaller (Baryte). This is a positive aspect because several CRMs, characterized by a high supply risk, are utilized in small amounts and a bigger CF can emphasize criticality. In contrast, in the first method the values are closed each other, the maximum (5.6) is reached by HREEs, such as dysprosium and erbium, and the minimum (0.1) by copper. This small difference between the factors makes final results heavily affected by the mass of the component and attribute less importance to criticality of materials. The radar chart in logarithmic scale in Figure 2) shows the variability of CFs_1 and CFs_2. Every circle represents one order of magnitude. It is clear that for the first method the CFs are of the same order of magnitude, while relevant differences can be observed for the second method. Thus, the second method can give more importance to materials that are characterized by a small mass but a high criticality.

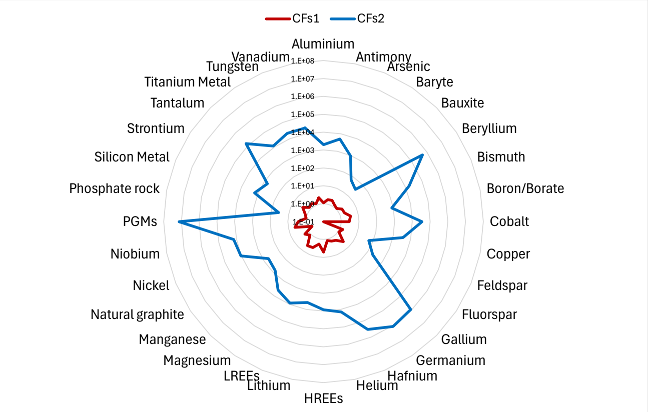

Figure 2. CFs in a radar chart in logarithmic scale

Table 3. CFs of the two approaches

CRMs	CFs₁ [-]	CFs₂ ['98 $]
Aluminium	1.20	1.97E+03
Antimony	1.80	5.07E+03
Arsenic	1.90	9.30E+02
Bauxite	1.20	6.29E+01
Baryte	1.30	3.45E+01
Beryllium	1.80	5.17E+05
Bismuth	1.90	1.68E+04
Boron	3.60	8.47E+02
Cerium	4.00	8.66E+03
Cobalt	2.80	3.49E+04
Copper	0.10	3.63E+03
Dysprosium	5.60	8.66E+03
Erbium	5.60	8.66E+03
Europium	5.60	8.66E+03
Feldspar	1.50	5.82E+01
Fluorspar	1.10	2.20E+02
Gadolinium	3.30	8.66E+03
Gallium	3.90	9.00E+05
Germanium	1.80	1.14E+06
Natural graphite	1.80	5.40E+02
Hafnium	1.50	3.31E+05
Helium	1.20	1.43E+04
Holmium	5.60	8.66E+03
Iridium	3.90	1.34E+07
Lanthanum	3.50	8.66E+03
Lithium	1.90	4.13E+03
Lutetium	5.60	8.66E+03
Magnesium	4.10	4.00E+03
Manganese	1.20	7.17E+02
Neodymium	4.50	8.66E+03
Nickel	0.50	1.09E+04
Niobium	4.40	1.43E+04
Palladium	1.50	1.34E+07
Phosphate rock	1.00	3.81E+01
Phosphorus	3.30	-
Platinum	2.13	1.34E+07
Praseodymium	3.20	8.66E+03
Rhodium	2.40	1.34E+07
Ruthenium	3.80	1.34E+07
Samarium	3.50	8.66E+03
Scandium	2.40	-
Silicon metal	1.40	1.58E+03
Strontium	2.60	6.39E+02
Tantalum	1.30	1.45E+05
Terbium	4.90	8.66E+03
Thulium	5.60	8.66E+03
Titanium metal	1.60	1.22E+04
Tungsten	1.20	2.17E+04
Vanadium	2.30	2.14E+04
Ytterbium	5.60	8.66E+03
Yttrium	3.50	8.66E+03

3.2 Inventory analysis

The inventory analysis consists in the compilation and quantification of the inputs (materials, energy) and outputs (direct emissions, products, wastes) of the product throughout its life cycle.

The examined product is a Power Supply Unit. This product is composed of a steel case, the fan, the cables, and the Printed Wiring Board (PWB).

In order to acquire the comprehensive list of all components and sub-components the PSU was completely disassembled, then all components were identified and weighted, with a particular attention to PWB and its sub-components (Table 4). Secondary data are taken from Ecoinvent database [20], referred to the global context.

Table 4. Components and sub-components of the PSU

Components	Sub-Components	Quantity	Unit
Cables		4.41E-02	kg
Fan		7.37E-02	kg
Plug		1	pc
PWB	Aluminium heat sinks	7.42E-02	kg
	Capacitors	5.77E-02	kg
	Diodes	4.26E-03	kg
	Inductors	7.88E-02	kg
	Integrated circuits	4.94E-04	kg
	Resistors	2.55E-03	kg
	Transformers	6.51E-02	kg
	Transistors	1.14E-02	kg
Steel		5.67E-01	kg

3.3 Results

The first step of the analysis of the results is the comparison between the direct consumption and the life cycle consumption of CRMs. The concept of direct consumption refers to the quantity of resources or materials physically enclosed within a product; it represents the tangible utilization of the resources in the final product.

Conversely, life cycle consumption is characterized by a more comprehensive view, including not only the materials utilized within the product but also accounting all resources utilized throughout the whole supply chain, in this specific case from the raw material extraction to the end of the manufacturing stage.

In detail, Table 5 shows that only 9 of the total 37 CRMs are considered in the direct consumption. Specifically, the direct consumption includes aluminum (65% of the life cycle consumption), tantalum (37%) copper (35%), phosphorus (12%), and other materials (magnesium, manganese, nickel, silicon and titanium) that have a percentage less than 1%. These results highlight that measuring only the direct use of CRMs hide a large amount of CRMs consumption. Indeed, a comprehensive analysis considering the entire life cycle can give a more detailed understanding of CRMs consumption in an eco-design perspective.

The second step of the analysis consists in the calculation of

CRMs considering two approaches based on SR and EI. The results are obtained by multiplying the CFs of Table 3 and the CRMs masses.

Table 5. CRMs consumption

CRM	Direct Consumption [kg]	Life Cycle Consumption [kg]
Aluminium	8.88E-02	1.37E-01
Antimony	-	1.52E-07
Arsenic	-	8.91E-07
Barite	-	5.26E-03
Boron	-	8.48E-05
Cerium	-	3.03E-05
Cobalt	-	4.22E-05
Copper	3.60E-02	1.02E-01
Dysprosium	-	1.78E-09
Europium	-	1.22E-07
Feldspar	-	3.83E-07
Fluorspar	-	8.43E-03
Gadolinium	-	4.24E-07
Gallium	-	2.15E-06
Graphite	-	1.83E-04
Hafnium	-	1.74E-06
Lanthanum	-	1.41E-05
Lithium	-	5.55E-09
Magnesium	6.24E-06	2.73E-03
Manganese	1.92E-05	3.67E-02
Neodymium	-	1.12E-05
Nickel	2.78E-04	8.83E-01
Niobium	-	2.70E-06
Palladium	-	3.95E-08
Phosphorus	9.72E-05	8.19E-04
Platinum	-	2.17E-08
Praseodymium	-	3.75E-06
Rhodium	-	2.48E-09
Samarium	-	4.91E-07
Scandium	-	5.50E-08
Silicon	5.43E-06	2.27E-03
Strontium	-	8.42E-06
Tantalum	7.86E-05	2.20E-04
Terbium	-	1.07E-09
Titanium	8.92E-07	8.29E-04
Vanadium	-	1.00E-07
Yttrium	-	6.54E-09

In accordance with Figure 2, also the obtained results highlight the difference between the coefficient in terms of magnitude orders. The first method, based on SR index, shows a strong connection between the results and the masses of the materials.

Table 6 illustrates the minimal difference between the mass of the elements and the corresponding results.

For instance, aluminium, with a mass of 1.37E-01, obtains a value of 1.64E-01. Likewise, nickel that is the element with the highest mass (8.83E-01) achieves a value of 4.42E-01, which is closely related to its mass. Similarly, dysprosium, characterised by the highest CF, starts with a mass of 1.78E-09 kg and acquires a final result of 9.98E-09. Despite being one of the elements exhibiting the highest supply risk, its mass significantly influences the final results. From these outcomes, it is evident that the mass plays a considerable role on the results. However, the main challenge to quantify criticality is that CRMs are typically contained in small quantities, thus, an effective method must enhance criticality over mass to provide a more accurate assessment.

Table 6. Results

CRM	Mass [kg]	Method 1 [-]	Method 2 ['98 $]
Aluminium	1.37E-01	1.64E-01	2.69E+02
Antimony	1.52E-07	2.73E-07	7.68E-04
Arsenic	8.91E-07	1.69E-06	8.28E-04
Baryte	5.26E-03	6.83E-03	1.82E-01
Boron	8.48E-05	3.05E-04	7.18E-02
Cerium	3.03E-05	1.21E-04	2.63E-01
Cobalt	4.22E-05	1.18E-04	1.47E+00
Copper	1.02E-01	1.02E-02	3.70E+02
Dysprosium	1.78E-09	9.98E-09	1.54E-05
Europium	1.22E-07	6.83E-07	1.06E-03
Feldspar	3.83E-07	5.75E-07	2.23E-05
Fluorspar	8.43E-03	9.27E-03	1.85E+00
Gadolinium	4.24E-07	1.40E-06	3.67E-03
Gallium	2.15E-06	8.40E-06	1.94E+00
Graphite	1.83E-04	3.29E-04	9.86E-02
Hafnium	1.74E-06	2.61E-06	5.76E-01
Lanthanum	1.41E-05	4.93E-05	1.22E-01
Lithium	5.55E-09	1.05E-08	2.29E-05
Magnesium	2.73E-03	1.12E-02	1.09E+01
Manganese	3.67E-02	4.40E-02	2.63E+01
Neodymium	1.12E-05	5.04E-05	9.69E-02
Nickel	8.83E-01	4.42E-01	9.59E+03
Niobium	2.70E-06	1.19E-05	3.87E-02
Palladium	3.95E-08	5.92E-08	5.31E-01
Phosphorus	8.19E-04	2.70E-03	-
Platinum	2.17E-08	4.62E-08	2.92E-01
Praseodymium	3.75E-06	1.20E-05	3.24E-02
Rhodium	2.48E-09	5.95E-09	3.33E-02
Samarium	4.91E-07	1.72E-06	4.25E-03
Scandium	5.50E-08	1.32E-07	-
Silicon	2.27E-03	3.18E-03	3.58E+00
Strontium	8.42E-06	2.19E-05	5.38E-03
Tantalum	2.20E-04	2.86E-04	3.19E+01
Terbium	1.07E-09	5.24E-09	9.26E-06
Titanium	8.29E-04	1.33E-03	1.02E+01
Vanadium	1.00E-07	2.31E-07	2.15E-03
Yttrium	6.54E-09	2.29E-08	5.66E-05

Conversely, the second method demonstrates a different behaviour. For instance, aluminium leads to a value of 2.69E+02 '98 $, that is a value not directly related with its mass.

To understand the difference between the two methods it is useful to shows a contribution analysis of each material on the total value of CRMs consumption (Figure 3).

Aluminium, for example reduces its incidence on the total CRMs consumption when the method 2 is applied in substitution to the first method or to the mass analysis. On the contrary, nickel obtains an increasing incidence for this method 2 if compared with the other two options.

Elements with a small mass but high supply risk, such as dysprosium, have negligible incidence in the final results in any case.

Another consideration coming from the results is that, by listing the CRMs is a sort of "ranking", the order of importance of each material can change: e.g., copper is the third most relevant element when the mass is considered, but it moves to be the fifth with method 1 (SR) and the second with method 2 (EI). Thus, the selection of the method can affect the results.

The analysis developed in this study demonstrate the substantial differences in results when criticality is measured. This highlights the necessity of a unified approach to obtain coherent results when comparing various studies.

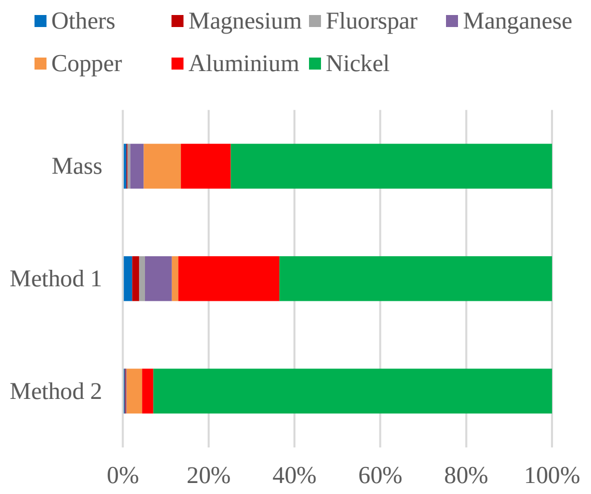

Figure 3. Results comparison between mass and the two methods

4. CONCLUSIONS

This paper explored the concept of criticality as defined by the European Union, focusing on the CRMs list released from 2011 to 2023. It was evident that the number of CRMs has been progressively increasing over these years, suggesting a rising trend likely to continue in the foreseeable future. Moreover, the criteria to include raw materials in the list were introduced describing SR and EI which are the two indexes used by European Union to assess criticality. Then, LCA was introduced, which, through the analysis of all material and energy flows within the product system, could accurately measure the consumption of all CRMs. An index already exist to measure the use of resources (minerals and metals). However, as observed, it only covered half of the CRMs.

The analysis of the case study demonstrates that direct consumption constituted only a small percentage of the overall life cycle consumption. Out of the 37 CRMs present in the case study, direct consumption accounted for only 9. However, even within this subgroup, direct consumption was considered a small portion of their overall use, with the exception of aluminium, which constituted 65% of the life cycle consumption. These outcomes suggests that only a comprehensive analysis considering the whole life cycle can provide a detailed understanding of CRMs consumption in an eco-design perspective.

The second part of the study involved the application of two methods based on SR and EI. The results indicated that the first method is highly related to the mass of the elements, with the CFs assuming less significance compared to mass. In contrast, the second approach showed a different behaviour, it demonstrated an improved capability to identify and prioritize the most critical CRMs more effectively. However, the purpose of this study was not to determine the superiority of one approach over the other. Rather, it aimed to highlight the differences from the two methods, drawing attention to the necessity for a universally method accepted by the scientific community.

In conclusion, this study highlights the efficacy of employing LCA for evaluating CRMs within an eco-design framework. By analysing the total consumption across the entire life cycle of a product system, LCA provides valuable insights into CRMs utilization. This holistic approach underscores the importance of considering the entire life cycle to encourage sustainable resource management practices and eco-design initiatives.

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