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Life cycle assessment on metal supply from environmental perspective

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Abstract. Metal supply is very important for economic development and the environmental effect on metal supply has become a serious problem. The main challenge is to decide how to quantify the environmental effect. A series of researches have promoted different methods. This paper promotes an improved approach for assessment of environmental effect on metal supply. LCA method was used and system steps of the mining and processing during LCA method of a specific metal was first identified. The midpoint and endpoint data were derived separately for Al and Cu as case study. Then normalization was applied to the endpoint data and the section with biggest value was considered most serious environmental effect. And the endpoint value for this section is chosen as environmental implication for a specific metal. We hope this approach can be a convenient and practical method for the environmental effect assessment.

1. Introduction

Metals play an important material foundation for human's survival, economic development and the social progress. And with rapid economic development of emerging countries, which has an accelerating spread of new technologies, the industrial metals have a strongly increasing demand trend [1,2]. Some metals do have an extremely unsecure supply situation. This has led to growing concerns about the security of metal supply [2-5]. As a result, numerous agencies have published their research progress about the critical metal assessment and a series of indicators has been identified. Among these factors, environmental effect on the metal supply has been proposed recently.

The environmental pollution during metal production including gas, water, and soil pollution from industrial waste and mineral process, which have occurred in many parts of the world. In effect, governments make a series of tough regulations on environmental protection and sustainable development to improve the environmental performance of mining and manufacturing companies [2, 6]. These regulations restricted the exploration and exploitation of the mineral resources, which may in turn result the metal supply risk. So environmental effect on metal supply is an important issue during metal critical assessment.

Environmental consideration during metal supply assessment has not been adopted by all researchers. US government (2008, 2016) and didn't include the environmental factors in the first critical assessment report [7, 8]. And report on critical raw materials for the EU in 2014 and 2017 abandoned environmental factor for the reason that most of the environmental factors can't be obtained by EU countries [9, 10].



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While there are also some supporters who tried to focus on the environmental effect. Morely and Eatherley (2008) included climate-change emissions use the ecoinvent database [11]. Goe and Gaustad (2014) talked about the toxicity from cradle to metal refinery gate [12]. Graedel et al. (2011) first use environmental implications as a separate factor in critical assessment [13]. While Graedel et al. (2015) improved the environmental implications using the ecoinvent database from Nuss and Eckelman (2014) and 62 elements were considered [4, 14]. During above methods, the Life Cycle Assessment method (LCA) were chosen as a effective method to quantify the environmental effect. LCA is an analytical tool for quantifying the resource environmental impacts associated with a product, process or activity during the entire life cycle, which is also called the ‘cradle-to-grave’ analysis [15].

In this paper, we proposed an improved environmental effect assessment method for the metal supply evaluation. This improve approach using LCA method based on the ecoinvent database [16]. The ReCiPe 2008 were used to give the midpoint and endpoint data. After all the environmental effect data were got, normalization was adopted to analyze the section with biggest value and this value can be used to quantify the environmental effect for a specific metal supply assessment. In order to show the whole analysis process of this method, copper (Cu) and aluminum (Al) were chosen as the case study.

2. Methodology

In this research, we focused on the environmental effect on the metal supply, so the environmental impacts of metal production from cradle to gate were acquired using LCA method. According to International Standard ISO 14044 (2006) [15], LCA involves three stages to give the interpretation of results, including goal and scope definition, inventory analysis and impact assessment (Fig.1).

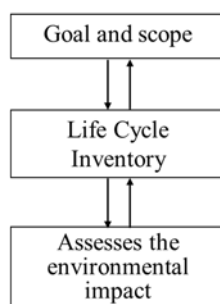


Figure 1. LCA stages according to ISO 14044:2006.

The scientific foundation of LCA method was first published by the CML LCA-guide in 1992. Then, the Eco-indicator 95 and its later version, Eco-indicator 99 were introduced. Both of the CML-guide and the Eco-indicator guide are currently widely accepted. However, they are based on different points of departure. The CML-guide focused on the midpoint approach, while the Eco-indicator guide focused on the endpoint approach. In order to combine the advantage of these two guides, the report ‘ReCiPe’ was introduced to calculate life cycle impact category indicators [17-18].

In this paper, we used ReCiPe 2008, which builds on the Eco-indicator 99 and the CML Handbook on LCA (2002). ReCiPe 2008 included two sets of categories, midpoint and endpoint category. The midpoint category contains 13 indicators, climate change (CC), ozone depletion potential (ODP), terrestrial acidification (TA), freshwater eutrophication (FE), marine eutrophication (MET), human toxicity (HT), photochemical oxidant formation (POF), particulate matter formation (PM), terrestrial ecotoxicity (TET), freshwater ecotoxicity (FET), marine ecotoxicity (MET), ionizing radiation (IR), agricultural land occupation (ALO), urban land occupation (ULO), natural land transformation (NLT), and water depletion (WD).

Impact categories at the endpoint level are human health, ecosystem quality and resource availability. While with the development of new exploration and exploitation technology, the construction of recycle system and new material substitute, the resource depletion will not be considered as a main concern. So human health and ecosystem quality are considered in raw material supply, while resource availability is not adopted in this study.

The process of LCA for the metal including the following 6 sections in Fig.2: (1) mineral resources; (2) mine sands; (3) raw material; (4) materials; (5) components; (6) products. The related process of every section was also expressed on the figure.

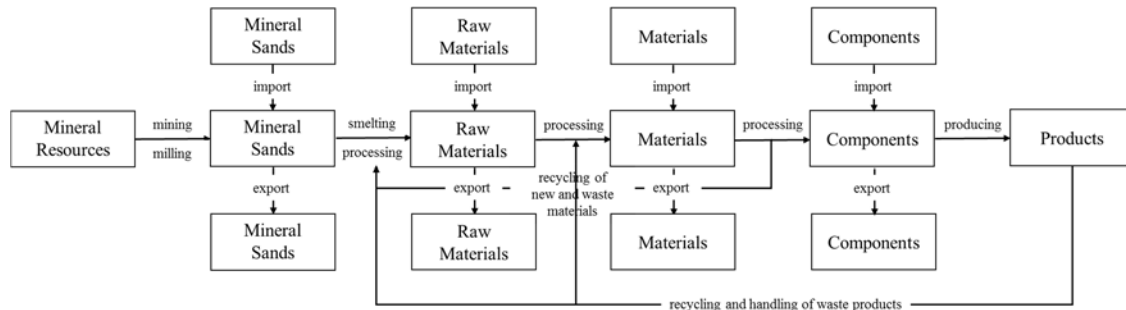


Figure 2. System step of the mining and processing for a specific metal

During the mineral supply risk assessment, the origins of the risk results of different effects are different or measured by different units, normalization of these risk results are required. So once the end-point data were got, normalization was used to transform the environmental factor to 0-1. In this study, we use the following types of normalization.

$$\chi_i = \frac{\chi_i(k) - \min \chi_i(k)}{\max \chi_i(k) - \min \chi_i(k)} \quad (1)$$

Where $\chi_i(k)$ is the endpoint data for human health and ecosystem.

3. Result and discussion

In this research, copper (Cu) and aluminium (Al) were chosen as the cause study. All the data were derived using SimaPro8.0.3 LCA software and the ReCiPe v1.10 Endpoint World H/H impact assessment method. Table 1 and Table 2 show the midpoint data for Al and Cu respectively.

Table 1. Midpoint data for Al

Element	Weighting (%)	CC	ODP	TA	FE	ME	HT
		kg CO ₂ eq	kg CFC-11 eq	kg SO ₂ eq	kg P eq	kg N eq	kg 1,4-DB eq
origin	64%	1.2E+01	7.4E-07	5.0E-02	5.3E-03	1.9E-03	5.0E+00
new scrap	20%	4.2E-01	6.9E-08	2.3E-03	6.7E-04	9.9E-05	1.2E+00
old scrap	16%	1.4E+00	4.5E-07	5.6E-03	7.7E-04	2.4E-04	1.4E+00
total	100%	8.2E+00	5.7E-07	3.4E-02	3.7E-03	1.3E-03	3.7E+00
Element	Weighting (%)	POF	PM	TET	FET	MET	IR
		kg NMVOC	kg PM10 eq	kg 1,4-DB eq	kg 1,4-DB eq	kg 1,4-DB eq	kBq U ²³⁵ eq
origin	64%	3.0E-02	2.5E-02	7.5E-04	1.4E-01	1.5E-01	3.2E+00
new scrap	20%	1.2E-03	8.2E-04	6.0E-05	2.1E-02	2.2E-02	9.7E-02
old scrap	16%	3.5E-03	1.8E-03	2.6E-04	2.2E-02	2.6E-02	2.4E-01
total	100%	2.0E-02	1.6E-02	5.4E-04	1.0E-01	1.0E-01	2.1E+00
Element	Weighting (%)	ALO	ULO	NLT	WD		
		m ² a	m ² a	m ²	m ³		
origin	64%	1.2E-01	5.7E-02	2.1E-03	3.2E+02		
new scrap	20%	1.9E-02	1.0E-02	1.6E-04	1.6E+00		
old scrap	16%	4.4E-02	1.7E-02	3.7E-04	6.9E+00		
total	100%	8.9E-02	4.1E-02	1.5E-03	2.1E+02		

Table 2. Midpoint data for Cu

Element	Weighting (%)	CC	ODP	TA	FE	ME	HT
		kg CO ₂ eq	kg CFC-11 eq	kg SO ₂ eq	kg P eq	kg N eq	kg 1,4-DB eq
from Mo electronic scrap	85%	3.1E+00	2.4E-07	4.7E-01	1.7E-01	1.4E-02	4.1E+02
	7%	2.1E-01	1.5E-08	4.1E-04	3.3E-05	1.5E-05	3.2E-02
secondary	8%	1.8E+00	8.5E-08	1.9E-02	4.1E-03	7.5E-04	8.7E+00
total	100%	2.8E+00	2.1E-07	4.0E-01	1.5E-01	1.2E-02	3.5E+02

Element	Weighting (%)	POF	PM	TET	FET	MET	IR
		kg NMVOC	kg PM10 eq	kg 1,4-DB eq	kg 1,4-DB eq	kg 1,4-DB eq	kBq U ²³⁵ eq
from Mo electronic scrap	85%	9.4E-02	1.5E-01	2.3E-02	5.8E+00	6.4E+00	9.2E-01
	7%	3.3E-04	1.5E-04	2.5E-06	2.3E-02	2.3E-02	3.3E-02
secondary	8%	8.7E-03	8.2E-03	1.3E-03	1.3E-01	1.8E-01	5.7E-01
total	100%	8.1E-02	1.3E-01	1.9E-02	4.9E+00	5.5E+00	8.3E-01

Element	Weighting (%)	ALO	ULO	NLT	WD
		m ² a	m ² a	m ²	m ³
from Mo electronic scrap	85%	2.1E-01	4.8E-01	2.3E-03	1.2E+02
	7%	5.8E-04	1.7E-03	-4.8E-06	8.2E-01
secondary	8%	5.4E-02	2.7E-02	3.8E-04	1.1E+01
total	100%	1.9E-01	4.1E-01	2.0E-03	1.0E+02

After the midpoint data was acquired, endpoint data for Al and Cu were shown on Table 3 and Table 4 respectively. CCH is climate change human health, ODP is ozone depletion potential, HT is human toxicity. POF is photochemical oxidant formation, PM is particulate matter formation, IR is ionizing radiation, CCE is climate change ecosystems, TA is terrestrial acidification, FE is freshwater eutrophication, TET is terrestrial ecotoxicity, FET is freshwater ecotoxicity, MET is marine ecotoxicity, ALO is agricultural land occupation, ULO is urban land occupation, and NLT is natural land transformation.

Table 3. Endpoint data for Al

Element	[A] Human Health Damage					
	CCH	ODP	HT	POF	PM	IR
	DALY	DALY	DALY	DALY	DALY	DALY
origin	1.7E-05	1.9E-09	3.5E-06	1.2E-09	6.4E-06	5.2E-08
new scrap	5.9E-07	1.2E-10	8.7E-07	4.6E-11	2.1E-07	1.6E-09
old scrap	1.9E-06	3.7E-10	9.6E-07	1.4E-10	4.7E-07	4.0E-09
total	1.1E-05	1.3E-09	2.6E-06	8.0E-10	4.2E-06	3.4E-08

Element	[B] Ecosystem Damage					
	CCE	TA	FE	TET	FET	MET
	species. yr	species. yr	species. yr	species. yr	species. yr	species. yr
origin	9.7E-08	2.9E-10	2.4E-10	1.1E-10	1.2E-10	2.6E-11
new scrap	3.3E-09	1.3E-11	3.0E-11	9.1E-12	1.8E-11	3.8E-12
old scrap	1.1E-08	3.3E-11	3.4E-11	3.9E-11	1.9E-11	4.5E-12
total	6.5E-08	2.0E-10	1.6E-10	8.1E-11	8.7E-11	1.8E-11

Element	[B] Ecosystem Damage		
	ALO	ULO	NLT
	species. yr	species. yr	species. yr
origin	1.5E-09	1.2E-09	3.5E-09
new scrap	2.3E-10	2.2E-10	2.4E-10
old scrap	5.3E-10	3.5E-10	5.2E-10
total	1.1E-09	8.5E-10	2.4E-09

Table 4. Endpoint data for Cu

Element	[A] Human Health Damage					
	CCH	ODP	HT	POF	PM	IR
	DALY	DALY	DALY	DALY	DALY	DALY
from Mo	4.3E-06	6.4E-10	2.8E-04	3.7E-09	3.9E-05	1.5E-08
electronic scrap	2.9E-07	3.9E-11	2.2E-08	1.3E-11	3.8E-08	5.4E-10
secondary	2.5E-06	2.2E-10	6.1E-06	3.4E-10	2.1E-06	9.3E-09
total	3.9E-06	5.7E-10	2.4E-04	3.2E-09	3.3E-05	1.4E-08

Element	[B] Ecosystem Damage					
	CCE	TA	FE	TET	FET	MET
	species. yr	species. yr	species. yr	species. yr	species. yr	species. yr
from Mo	2.4E-08	2.7E-09	7.6E-09	3.4E-09	4.9E-09	1.1E-09
electronic scrap	1.7E-09	2.4E-12	1.5E-12	3.8E-13	2.0E-11	4.0E-12
secondary	1.4E-08	1.1E-10	1.8E-10	1.9E-10	1.1E-10	3.2E-11
total	2.2E-08	2.3E-09	6.5E-09	2.9E-09	4.2E-09	9.6E-10

Element	[B] Ecosystem Damage		
	ALO	ULO	NLT
	species. yr	species. yr	species. yr
from Mo	2.6E-09	9.9E-09	4.2E-09
electronic scrap	7.3E-12	3.5E-11	-1.1E-11
secondary	6.4E-10	5.7E-10	6.2E-10
total	2.2E-09	8.5E-09	3.6E-09

After the endpoint data was acquired, we use the normalization method mentioned in Section 2 and the results for normalization are shown in Table 5.

Table 5. Normalized endpoint data for Al and Cu

		Al		Cu	
		Origin data	normalized data	Origin data	normalized data
[A] Human Health Damage	CCH	1.1E-05	1.0E+00	3.9E-06	1.6E-02
	ODP	1.3E-09	1.2E-04	5.7E-10	0.0E+00
	HT	2.6E-06	2.4E-01	2.4E-04	1.0E+00
	POF	8.0E-10	7.1E-05	3.2E-09	1.1E-05
	PM	4.2E-06	3.8E-01	3.3E-05	1.4E-01
	IR	3.4E-08	3.1E-03	1.4E-08	5.6E-05
[B] Ecosystem Damage	CCE	6.5E-08	5.9E-03	2.2E-08	8.9E-05
	TA	2.0E-10	1.7E-05	2.3E-09	7.2E-06
	FE	1.6E-10	1.3E-05	6.5E-09	2.5E-05
	TET	8.1E-11	5.7E-06	2.9E-09	9.7E-06
	FET	8.7E-11	6.3E-06	4.2E-09	1.5E-05
	MET	1.8E-11	0.0E+00	9.6E-10	1.6E-06
	ALO	1.1E-09	9.8E-05	2.2E-09	6.8E-06
	ULO	8.5E-10	7.6E-05	8.5E-09	3.3E-05
	NLT	2.4E-09	2.2E-04	3.6E-09	1.3E-05

It can be seen from Table 5 that for Al, the biggest value for the result is CCH. In this research, all the environmental effect in the endpoint are considered equally, which means the section with biggest value represents the most serious environmental effect. So the section with the biggest value is chosen as the environmental implications and this endpoint value is the environmental effect for this metal. For Al, the assessment of environmental effect is considered to be 1.1E-05 and for Cu, it is 2.4E-04.

4. Conclusion

In this paper, we give an improved approach for the assessment of environmental effect on metal supply. LCA method was used based on the ecoinvent database. The system steps of the mining and processing during LCA method of a specific metal was first identified. Then all the midpoint and endpoint data were derived using SimaPro8.0.3 LCA software. After the endpoint were given, normalization was applied to the endpoint data. As all the endpoint section were considered equally, so the section with biggest value was considered to be the most serious part and this endpoint value would be the environmental implications for the metal supply evaluation. Al and Cu were chosen as the study case and the environmental effect are $1.1\text{E-}05$ and $2.4\text{E-}04$ respectively.

Although this improved approach has partly solved the problem of environmental effect assessment on metal supply, however all the data were still universal. In the metal supply assessment, the environmental effect will differ with different countries or area, which means the LCA data should be more specific for a country or area. For China, there is China CI database with small amounts of data. So more attentions should paid to the established of database for specific area in future research. And the normalization in this research is one of effective methods to deal with the endpoint of different units. More methods will be investigated in our future research to make a more reasonable assessment.

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