

Environmental impact assessment of european non-ferro mining industries through life-cycle assessment

Shahjadi Hisan FARJANA ¹, Nazmul HUDA ², M. A. Parvez MAHMUD ³

¹ Ph.D. candidate, School of Engineering, Macquarie University, Sydney, Australia

² Lecturers, School of Engineering, Macquarie University, Sydney, Australia

³ Ph.D. candidates, School of Engineering, Macquarie University, Sydney, Australia

E-mail: nazmul.huda@mq.edu.au

Abstract. European mining industries are the vast industrial sector which contributes largely on their economy which constitutes of ferro and non-ferro metals and minerals industries. The non-ferro metals extraction and processing industries require focus of attention due to sustainability concerns as their manufacturing processes are highly energy intensive and impacts globally on environment. This paper analyses major environmental effects caused by European metal industries based on the life-cycle impact analysis technologies. This research work is the first work in considering the comparative environmental impact analysis of European non-ferro metal industries which will reveal their technological similarities and dissimilarities to assess their environmental loads. The life-cycle inventory datasets are collected from the EcoInvent database while the analysis is done using the CML baseline and ReCipe endpoint method using SimaPro software version 8.4. The CML and ReCipe method are chosen because they are specialized impact assessment methods for European continent. The impact categories outlined for discussion here are human health, global warming and ecotoxicity. The analysis results reveal that the gold industry is vulnerable for the environment due to waste emission and similar result retained by silver mines a little bit. But copper, lead, manganese and zinc mining processes and industries are environment friendly in terms of metal extraction technologies and waste emissions.

1. Introduction

The European Union metals and minerals industry is an important producer of chromium, copper, lead, silver, and zinc. Europe is rich in metal mining resources where the investment and the production is increasing. In last 5 years, 13 new mines are opened in the sector of nickel, gold, cobalt, copper, tungsten and zinc mining sector. The challenges in the European mining industries are cost of energy, skills, infrastructure development, technologies and export revenue. Despite the economic benefits, mining industries are responsible for a major share of environmental impacts and global warming effects experiencing by the European subcontinent. Wastes generated from the mining extraction processing steps are one of the leading causes of significant environmental effects. The non-ferro metal mining industries are most of the countries from European union. For example, copper is found and produced in Bulgaria, France, Poland and Russia. Gold is obtained from Russia, Sweden, Bulgaria and Finland. Lead is produced from Ireland, Macedonia- the former Yugoslav Republic of, Poland and Sweden. Manganese mines are distributed in Ukraine, Bulgaria, Greece and Bosnia and Herzegovina. Silver is produced in Poland, Russia Sweden and Greece. And lastly zinc mines are located and running in Ireland, Finland, Poland, Portugal, Russia and Sweden. So, it can be easily inherent that non-ferro mining industries are prevalent everywhere in Europe. Even though these mining industries



are in different countries within the European continent, they share same technologies or electricity generation loads which made it easy to discuss them in the same platform. Due to the position and reserve of non-ferro metal mines in European countries, they are the focus of attention in terms of environmental sustainability [1]-[5].

2. Non-ferro mining industries and sustainability concerns

Among numerous non-ferro mining industries, few well known and easily found non-ferro mining industries are chosen for the analysis here in this paper. These are copper, gold, lead, manganese, silver and zinc. These metals and their sustainability values are discussed here shortly in brief.

2.1. Copper

Copper is a soft, malleable and ductile metal which is a high thermal and electrical conductive metal. Copper is used as building material and for making alloys. It is a naturally occurring stable metal to be used in the same form. The main application of copper is in the field of electrical wire, industrial machinery, and plumbing and electronics devices. In terms of sustainability, when copper gets mixed with aquatic environment, it is harmful for all marine species and plants, which is toxic and can hinder the survival and growth of the plants in extreme levels. High levels of copper exposure are detrimental for human health in terms of toxicity which can cause nausea, vomiting and diarrhoea, liver damage even death. Copper mining is also responsible for deforestation, land degradation and water pollution [3], [4], [8], [10], [12].

2.2. Gold

Gold is a bright, soft, malleable and ductile metal which found in a solid solution in combination with silver. Due to its alloying capability, gold is widely used to make jewellery by polishing and colouring. Among other applications, gold metallic compounds are used for making medicine, electronics. In case of environmental impact, gold mining effects largely due to its large amount of wastes released from the mining sites. From open-pit mining and heap leaching process, gold mines release a huge amount of toxic waste per year. These toxic wastes easily get mixed with nearby soil or water to destroy the environment. Moreover, due to underground rock distributed over the mining, gold mines are responsible for acid mine drainage. Use of mercury in the gold mining process thus increases the pollution [1], [6], [7], [9], [13], [14].

2.3. Lead

Lead is a soft malleable denser metal which is post-transition metal. Due to the mechanical properties like low melting point, lead metals are used to make bullets. It is also used to make the architectural metals. The extraction and production technologies of lead mining have significant impact on soil and environment. Accumulation of lead in the plants and soils can remain in the same form for hundreds of years without any decay which can hinder their reproduction and development [2], [11].

2.4. Manganese

Manganese is a free element which is found in combination with iron in nature and is a free element. It is an essential element for iron and steel production due to its alloying and subsidizing properties. Manganese is also used in alloying aluminium. Mining of manganese is highly impactful for soil, water and human health [5], [17].

2.5. Silver

Silver is a lustrous, highly conductive, transition chemical element. Silver has high electrical conductivity and mechanical conductivity. Silver is a highly reflective precious metal which is mostly used for making jewellery and silverware. Silver is also used for wound dressing and making electronic devices. In terms of sustainable mining, silver mining causes erosion which contaminates soil water, land and groundwater as well. It also leads to the formation of sinkhole and loss of biodiversity [1], [6], [7].

2.6. Zinc

Zinc is one of the most abundant chemical element found in earth which is like magnesium due to chemical properties. Zinc is widely used as abrasive agent and used in batteries. Zinc is an alloying element. Zinc compounds with variable solubility gets mixed with the environment during extraction and processing in zinc mining, which make further reactions while meets soil, water and environment. Zinc mining is also harmful for human health due to metallic compound emission [11], [15], [16].

Table 1. Life-cycle impact analysis results-human health.

	Label	Copper	Gold	Lead	Manganese	Silver	Zinc
CML	Human toxicity	0.0321	100	0.0006	0.0005	0.4546	0.0026
ReCipe	Global warming, Human health	0.0048	33.9909	0.0029	0.0097	0.2482	0.0122
	Ozone formation, Human health	0.0176	92.3299	0.0043	0.0154	0.7228	0.0178
	Human carcinogenic toxicity	0.0228	100	0.001	0.0008	0.3908	0.0025
	Human non-carcinogenic toxicity	0.0932	73.7804	0.0052	0.0027	0.7627	0.599
	Water consumption, Human health	0.1277	100	0.002	0.2435	2.0986	0.0082

Table 2. Life-cycle impact analysis results-ecotoxicity.

	Label	Copper	Gold	Lead	Manganese	Silver	Zinc
CML	Fresh water aquatic ecotox.	0.0227	100	0.0005	0.0006	0.3718	0.0025
ReCipe	Freshwater ecotoxicity	0.0283	100	0.0009	0.0017	0.4201	0.0175
	Marine aquatic ecotoxicity	0.0225	100	0.0005	0.0006	0.3719	0.0026
	Marine ecotoxicity	0.1049	80.4767	0.0045	0.0024	0.8611	0.5461
	Terrestrial ecotoxicity	0.0182	100	0.0024	0.007	0.2267	0.0329
	Terrestrial ecotoxicity	0.2382	18.7327	0.003	0.0065	1.7905	0.0889

3. Life-cycle assessment

Life cycle assessment is a powerful tool to assess the environmental effects caused by a manufacturing process throughout its whole life. The type of life cycle assessment could be from cradle to grave which includes each input materials, output emissions and waste emissions. Life cycle assessment can be of cradle to gate which only considers the input materials and output final product up to the gate of manufacturing factory. The life cycle assessment consists of 4 individual steps: goal and scope definition, life-cycle inventory or data collection, life-cycle impact assessment or environmental effect analysis and interpretation and recommendation of the inventory and results. At the first stage, the goals of the particular life cycle assessment are clarified for better understanding of the producers and consumers according to ISO 14040. This stage defines the products and processes with informative

description of the assessment. The system boundary and software, methodologies and allocation techniques are also discussed. In the second step, life cycle inventory analysis is made to identify, quantify and report all the input materials, output emissions, output products, waste emissions according to ISO 14041. Allocation on the basis of mass, economics or causal basis also required to be mentioned. In the third step, life cycle impact assessment is carried out according to ISO 14042. The methodologies followed for the assessment procedure should be based on ISO standard. There are many standard methodologies based on different regional and geographical context. For example, in the Oceania there is Australian Indicator method. For European geographic context, there are CML and ReCipe method. For North American region there is TRACI method. According to the methodology, the impacts on land, water, air, ecosystem or human health are assessed. The analysis results can be presented in their exact form or can be presented using characterization or normalization. There are optional or additional results like normalization, grouping or weighting of the indicator results and data quality analysis techniques. These elements are –Category indicator and classification, Characterization, Normalization and Valuation/weighting using ISO 14043. The goal of this research work is to analyse the cradle-to-grave life-cycle environmental effects of non-ferro metals like copper, gold, lead, manganese, silver and zinc where the mining inventory datasets are collected from EcoInvent database focusing on European continent to assess their impacts on human health, ecosystems and global warming under various categories. The lifecycle impact assessment is done using SimaPro software version 8.4.. The analysis methods are chosen as the Recipe method and the CML method. These methods are the most common ones used for life-cycle impact assessments related to mining and mineral-extraction activities [5]-[14].

4. Results and discussion

Table 1, 2 and 3 illustrates the analysis results obtained from the SimaPro software. In terms of human health, ecotoxicity and global warming, gold mining and extraction processing routes contribute largely compared with other non-ferro metal commodities considered in this research. The reason should obviously be the large amount of wastes released during the gold extraction in open-pit mining and heap leaching process. All the other mines show similar and non-major impact assessment results rather than gold mining process in European continent. Similar results are found from both CML and ReCipe method. This similarity also clarifies the consistency among the life-cycle impact assessment methods towards the mineral industries routes.

Table 3. Life-cycle impact analysis results-global warming.

Label	Copper	Gold	Lead	Manganese	Silver	Zinc
Global warming (GWP100a)	0.0048	33.8841	0.0029	0.0097	0.2466	0.0121
Global warming, Human health	0.0048	33.9909	0.0029	0.0097	0.2482	0.0122
Global warming, Terrestrial ecosystems	0.0048	33.9906	0.0029	0.0097	0.2482	0.0122
Global warming, Freshwater ecosystems	0.0048	33.9907	0.0029	0.0097	0.2482	0.0122

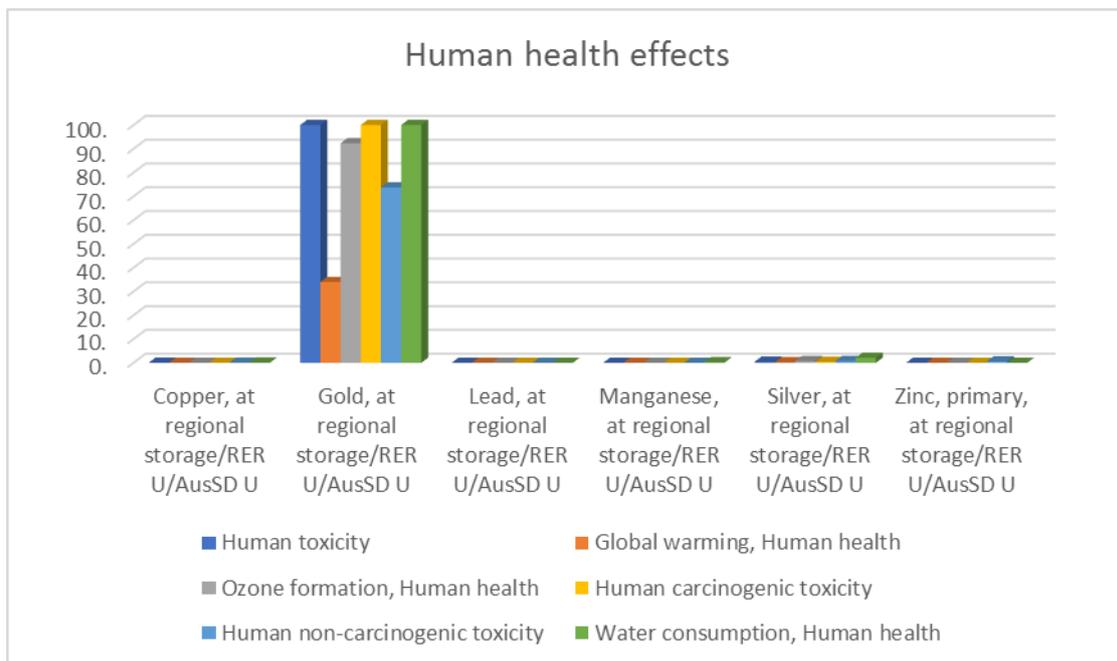


Figure 1. Comparative results of life-cycle assessment- human health category.

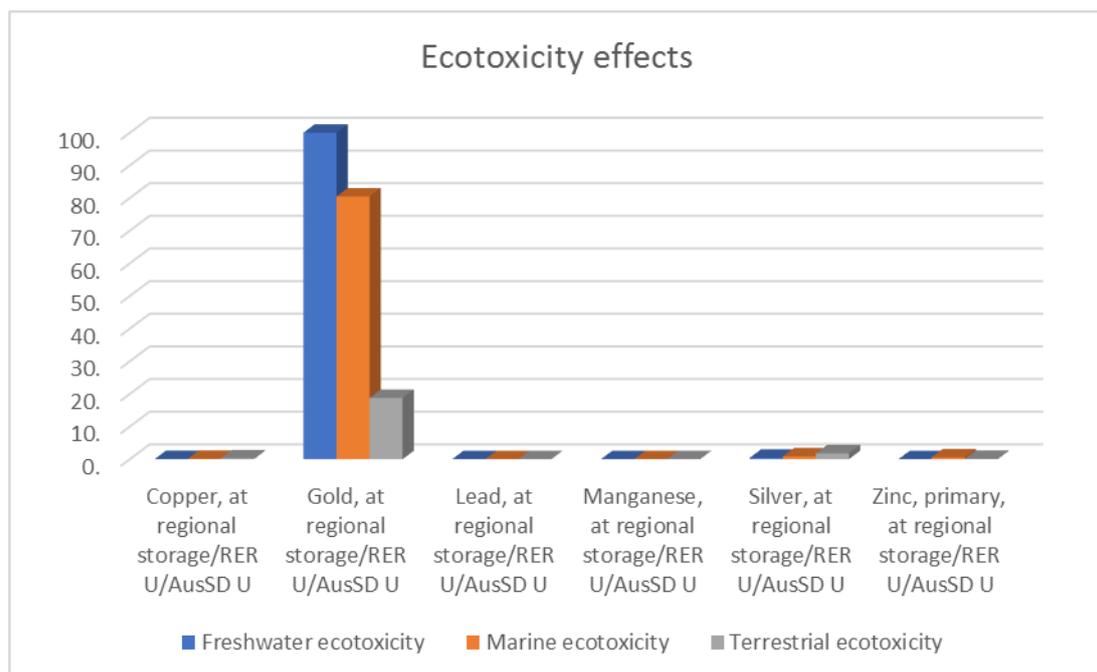


Figure 2. Comparative results of life-cycle assessment- ecotoxicity category.

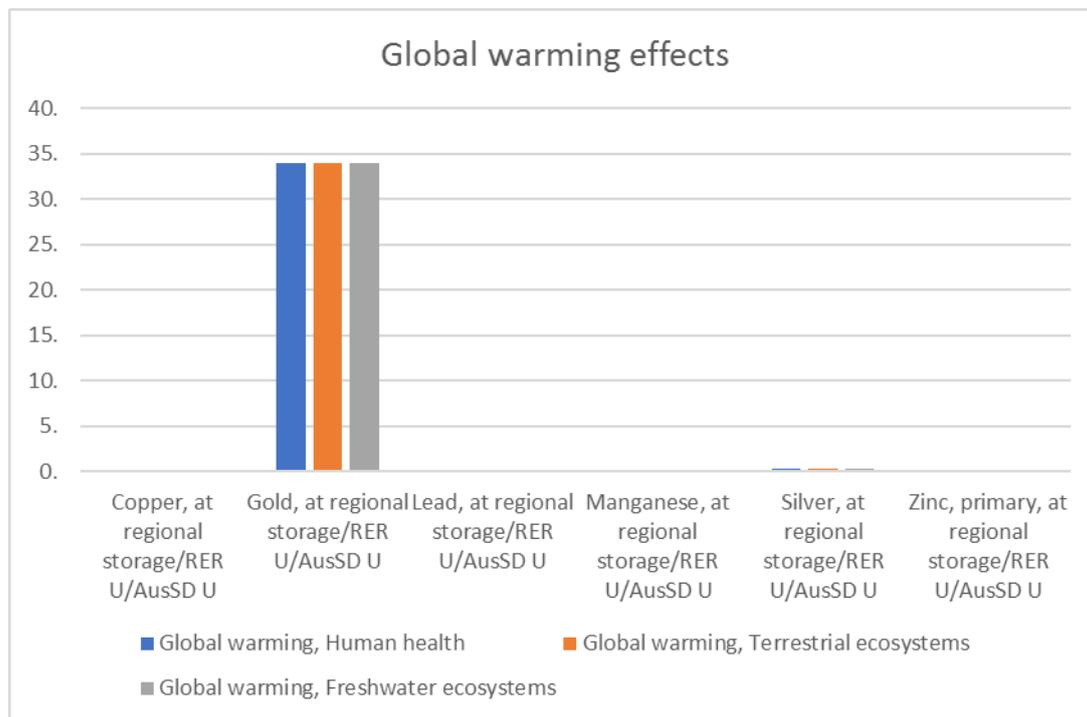


Figure 3. Comparative results of life-cycle assessment- global warming category.

5. Conclusion

In conclusion, this research work assesses the environmental effects caused by the leading non-ferro mineral industries in European continent. The major categories under consideration were global warming, ecotoxicity and human health using CML and ReCipe method. The results reveal that the gold industry is effecting the whole environment largely rather than other non-ferro mining industries. This paper indicates that the largest contributor to global warming and greenhouse gas emissions is gold mining due to their large amount of waste release towards the environment. Countries where economy is strongly dependent on mining industries, especially on gold-mining, should focus on to their key manufacturing technologies to protect their own environment and country from the negative effects of global warming both on their resources and human health. Effective measures should be taken to control the waste emissions from gold industries to reduce the effects.

6. References

- [1] M. Ackley. 2008 Evaluating Environmental Risks in Mining: A perceptual study at the Vatukoula gold mine in Fiji 180
- [2] L. C. Assessment, International P E and Inventory L C Lead Metal Production LCA
- [3] J. Castro-Molinare. 2013 Sustainability analysis of copper extraction and processing using LCA methods **53** 243
- [4] K. U. Copper. Environmental Profile
- [5] IMnI 2014 Lifecycle Assessment of Global Manganese Alloy Production
- [6] W. W. Ingwersen. 2010 Advances in life cycle assessment and emergy evaluation with case studies in gold mining and pineapple production 1–134
- [7] W. W. Ingwersen. 2011 Emergy as a Life Cycle Impact Assessment Indicator: A Gold Mining Case Study *J. Ind. Ecol.* **15** 550–67
- [8] J. Kelly, Q. Dai, A. Elgowainy, S. A. Group and E. S. Division 2015 Updated Life Cycle Inventory of Copper : Imports from Chile
- [9] D. Korpela. 2014 Costa Rica Crucitas gold mining project ESIA
- [10] D. Kupferinstitut, L. Cycle, C. Am, G. Tel and A. Klassert 2002 Life Cycle Assessment of Copper Products *Int. J. Life Cycle Assess.* **7** 156–63

- [11] S. Nazari and M. Gharabaghi. 2015 Investigation on life cycle assessment of lead and zinc production *Int. Journal Min. Geo-Engineering* **49** 245–52
- [12] T. E. Norgate. 2001 A Comparative Life Cycle Assessment of Copper Production Processes
- [13] Norgate T and Haque N 2012 Using life cycle assessment to evaluate some environmental impacts of gold production *J. Clean. Prod.* **29–30** 53–63
- [14] P. K. Tsang. 2014 Sustainable Gold Mining- Life Cycle Assessment of Cyanidation and Thiosulphate Leaching
- [15] E. Van Genderen, M. Wildnauer, N. Santero and N. Sidi 2016 A global life cycle assessment for primary zinc production *Int. J. Life Cycle Assess.* **21** 1580–93
- [16] M. Werder and A. Steinfeld 2000 Life Cycle Assessment of the Conventional and Solar Thermal Production of Zinc and Synthesis Gas *Energy* **25** 395–409
- [17] L. A. Westfall, J. Davourie, M. Ali and D. McGough 2016 Cradle-to-gate life cycle assessment of global manganese alloy production *Int. J. Life Cycle Assess.* **21** 1573–9.