

# Life-Cycle environmental impact assessment of mineral industries

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**Abstract.** Mining is the extraction and processing of valuable ferro and non-ferro metals and minerals to be further used in manufacturing industries. Valuable metals and minerals are extracted from the geological deposits and ores deep in the surface through complex manufacturing technologies. The extraction and processing of mining industries involve particle emission to air or water, toxicity to the environment, contamination of water resources, ozone layer depletion and most importantly decay of human health. Despite all these negative impacts towards sustainability, mining industries are working throughout the world to facilitate the employment sector, economy and technological growth. The five most important miners in the world are South Africa, Russia, Australia, Ukraine, Guinea. The mining industries contributes to their GDP significantly. However, the most important issue is making the mining world sustainable thus reducing the emissions. To address the environmental impacts caused by the mining sectors, this paper is going to analyse the environmental impacts caused by the 5 major minerals extraction processes, which are bauxite, ilmenite, iron ore, rutile and uranium by using the life-cycle impact assessment technologies. The analysis is done here using SimaPro software version 8.4 using ReCipe, CML and Australian indicator method.

## 1. Introduction

Mining is the most dominant industrial sector in many countries with precious metal reserves. These countries already attracted industries and investors with ample opportunity for world economy, investment and development. At the same time, it is also valuable in terms of environmental effects, sustainability and global warming as the deeper it goes, the negative impact to environment increases. This issue is more feasible for those countries where mining industry in the leading industrial sector like in South Africa, Russia, Australia, Ukraine and Guinea. These countries have largest mineral and mining reserves. Similarly, China, USA, Mexico these countries are contributing as one of the largest metal producers. With 2.5 trillion-dollar worth mineral reserve, South Africa holds the largest resource and production for platinum, black coal, diamond, base metal and uranium. In Russia, with 794 billion-dollar reserves, it has resources and production for cobalt, nickel, coal and iron. The third position goes for Australia, which holds the reserve worth 737 billion-dollar. It is also the world's largest producer of bauxite, nickel. Ukraine holds 510 billion-dollar worth reserve while mostly it is iron ore. Lastly, in Guinea it worth's 222 billion-dollar reserves with bauxite deposits. On the other hand, in terms of sustainability, mining industries are harmful for air, land, water, human health and biodiversity. The major reasons behind these effects are the harmful emissions from the mining sites and mining methods, mining tailings which gets mixed with air/water, extensive mechanism and machinery used in the extraction of deep mining deposits, humans living in the mining area who are



exposed to harmful emissions, emitted particles which are non-decayable and works as a restraint for plant and soil growth. During mining time, the soil and plants in the deposit area should be removed which leads to deforestation and soil erosion. Mining metal particles gets mixed with soil which restrains it from plantation thus driving towards destruction to surrounding lands. Water becomes contaminated from acid mine drainage, metal contamination, processing plants, tailing ponds, waste-disposal area, active or abandoned surface haulage etc. At the similar way, biodiversity gets affected from the massive modification of pre-mined landscape and infrastructure. This paper is going to address the environmental impacts caused by the leading mineral extraction processes in a global context through life-cycle environmental impact assessment. Section 2 illustrates the leading mineral industries, their use and environmental concerns caused by them. Section 3 elaborates life-cycle environmental impact assessment core methodologies used in this research. Section 4 describes the impact analysis results in the category of human health, global warming and ecotoxicity. Section 5 discussed the conclusion and future recommendation [1-7].

## 2. Mineral industries and Sustainability

Five of the major mineral industries and their manufacturing technologies are chosen here in this paper for sustainability analysis. These are bauxite, ilmenite, iron ore, rutile and uranium. These minerals and their key features are briefly described here.

**Bauxite:** Bauxite is the principle ore of aluminium which is not a mineral but a laterite ore. Bauxite is a mixture of aluminium oxide, hydroxide, clay minerals and insoluble metals. Bauxite is crushed and purified using the Bayer process to produce aluminium. Bauxite is commonly used as abrasive made by crushing it to form powder. Sintered bauxite is also used as oil-field propellant. The whole process of aluminium production from raw bauxite requires enormous amount of energy in the form of electricity, water and resources because of relatively stable form of aluminium. During installation, bauxite mine requires to remove all the plants and soils to start mining and extraction, which eventually lead to contamination of soils by mining tailings. During smelting and processing, greenhouse gases are released [8-10].

**Ilmenite:** Ilmenite is the most important ore of titanium-oxide which is considered as weakly magnetic mineral sand, grey-black in colour and solid in form. The major environmental concern associated with the mineral-sands industry is the radiation hazards. Ionizing radiation is responsible for this radiation hazards. These are mostly associated with titanium-oxide mining operations. Other issues of concern are pollution of ground-water resources, mineral transport with heavy vehicles, dredging operations in fragile coastal area and clearing of forest [11, 12, 13, and 14].

**Iron:** Iron in its metal form extracted from the non-metallic iron ore minerals which is a mixture and magnetic in nature. World's 95% metal is produced from iron. Iron is a shiny matter that rusts in damp air. Most of the iron is used in civil engineering for making structure and in the manufacturing sector in the form of stainless steel. The main source of environmental emissions during iron mining includes the construction and operation of iron mines which leads to several oxide emissions. However, huge amount of energy is used during iron ore extraction [11, 15, and 16].

**Rutile:** rutile is another most commonly found form of titanium-oxide. The common forms of the rutile are to be found in sediments, indigenous and sedimentary rocks. Rutile mining and extraction operation includes the mining from the ore body which requires cleaning using chlorine, which causes environmental problems such as toxicity, thus detrimental for habitats and plants. Moreover, like ilmenite the mining process of the rutile releases radioactive elements such as radionuclides, dust, metals and rare-earth elements [17, 18 and 19].

**Uranium:** Uranium is a radioactive, ductile and dense metal which can be coated with uranium oxide when in contact with air. Uranium is used widely for producing nuclear energy through chain reactions, making shields in bullets or missiles or making fertilizers. Uranium can be found in environments like soil, water or rocks. Uranium is the heaviest metal naturally found in earth's crust and is used as nuclear fuel throughout the world; previously it was used as coloring agent to decorate ceramics and glass. Over the last decades, tailings and waste management in uranium mills have been a focus, and regulations are also changing for environmental hazards and radiological risks. In addition to producing radioactive wastes, these heaps of wastes possess detrimental health effects towards the

surrounding community of uranium mines and mills. The process of making yellow-cakes involves highly toxic substances. The waste rock is a slurry and excessively radioactive [20, 21 and 22].

### **3. Life-cycle impact analysis**

Lifecycle assessment or LCA is a systematic tool to analyse and calculate the environmental effects and impacts caused by manufacturing of a product, process or activity throughout its entire lifecycle from cradle to grave, cradle to gate, gate to grave or whatever. In any life cycle assessment works, there are four basic steps which are required to be accomplished. Those are: 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. In the goal and scope definition stage( ISO 14040), product/process/activity definition and description are made. The system boundary is necessary to be outlined here for detailed analysis; assumptions need to be made. Life-cycle Inventory Analysis (ISO 14041) stage consequentially tries to identify the materials, resources and energy inputs, output products, wastes and emissions. Life cycle inventory datasets are there to quantify their respective amounts per unit process included in the system boundary for life-cycle assessment. Allocation based on mass, economics or casual also might be required to be mentioned depending on the process under consideration. At the third stage, life-cycle impact assessment (ISO 14042) in the analysis phase is based on different methods like ILCD, TRACI, CML, Recipe etc. The major differences among these methods are the geographic context covered by their methodology. For example, TRACI method is designed based on North American geographic context. Similarly, ReCipe and CML method is applicable for European context. This phase assesses the impacts of the process/system/ activity on human health, ecosystem, water, land or economy. In addition, the results can be further analysed and presented through normalization, grouping or weighting of the indicator result. At the last phase of life cycle assessment, interpretation of the results and recommendation (ISO 14043) phase evaluates and interprets the results from the inventory-analysis and impact-assessment phase which compares and analyses among the production stages or the product systems and estimate the impacts per production phase. Similarly, impacts on ecosystems and environment and human health are considered and the results are presented. Uncertainty analysis and sensitivity analysis could also be carried out to decide among various cases and scenarios.

In this paper, the goal of this research work is to analyse and compare the life-cycle environmental impact of bauxite, ilmenite, iron, rutile and uranium, to access their impacts on human health, ecosystems and global warming under various categories. The scope of this research work is the inventories collected from the AusLCI database for different mines in Australia. Even though they are collected from Australian life cycle assessment database, their geographic region covered is global. The lifecycle impact assessment is done using SimaPro software version 8.4. The datasets are collected from Australian System Process database (AusLCI). The analysis methods are chosen as the Australian Indicator method, 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 [22-25].

### **4. Results and discussion**

Table 1, 2 and 3 sequentially shows the life cycle impact analysis results under human health, ecotoxicity and global warming category. The table combines the various human health impact categories covered by different life cycle assessment methods. The human health category is divided into the subcategories like carcinogenic, non-carcinogenic, global warming or ozone formation. In ecotoxicity, categories are based on the groundwater resources like marine, freshwater or aquatic. Or it can be based on the soil resources. Under the global warming category, it is categorized based on human health or ecosystems.

**Table 1.** Lifecycle impact analysis results on human health category using various methods.

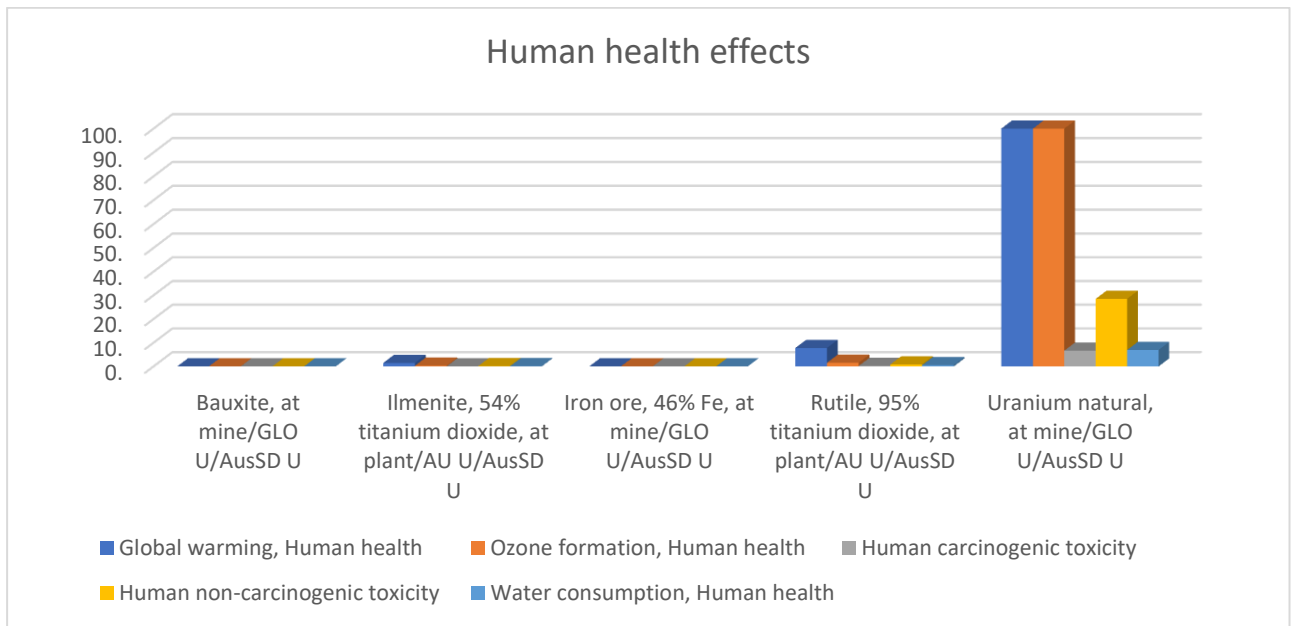
Label	Bauxite	Ilmenite, 54% titanium dioxide	Iron ore, 46% Fe	Rutile, 95% titanium dioxide	Uranium natural
Human toxicity - non-carcinogenic	0.0001	0.0119	0.0001	0.0619	10.7958
Human toxicity - carcinogenic	0.0003	0.0155	0.0002	0.0808	12.431
Human toxicity	0.001	0.0227	0.0008	0.1177	29.1899
Global warming, Human health	0.0469	1.4946	0.0275	7.7641	100
Ozone formation, Human health	0.0349	0.2953	0.0357	1.5339	100
Human carcinogenic toxicity	0.0018	0.0358	0.0013	0.1858	6.6861
Human non-carcinogenic toxicity	0.0049	0.1586	0.0031	0.8238	28.524
Water consumption, Human health	0.0025	0.0977	0.0013	0.5073	6.9415

**Table 2.** Lifecycle impact analysis results on ecotoxicity category using various methods.

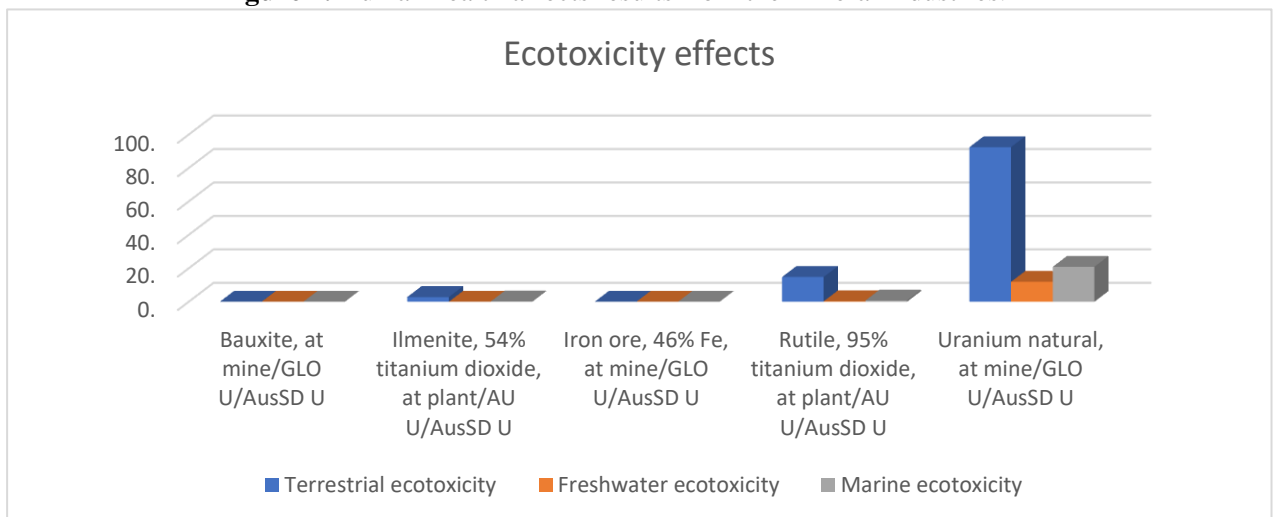
Label	Bauxite	Ilmenite, 54% titanium dioxide	Iron ore, 46% Fe	Rutile, 95% titanium dioxide	Uranium natural
Ecotoxicity-freshwater	0.0001	0.0047	9.07E-05	0.0243	1.6626
Ecotoxicity-marine	8.82E-05	0.003	8.09E-05	0.0154	0.192
Ecotoxicity-terrestrial	0.0307	1.2927	0.0179	6.7154	47.8598
Fresh water aquatic ecotox.	0.0004	0.0218	0.0003	0.1133	6.1769
Marine aquatic ecotoxicity	0.0005	0.0299	0.0004	0.1556	6.4993
Terrestrial ecotoxicity	0.0676	3.3479	0.0374	17.3917	79.5809
Terrestrial ecotoxicity	0.0696	2.8521	0.0415	14.816	92.4882
Freshwater ecotoxicity	0.0017	0.0573	0.0011	0.2977	11.9519
Marine ecotoxicity	0.0047	0.1478	0.0032	0.7679	20.9167

**Table 3.** Lifecycle impact analysis results on global warming category using various methods.

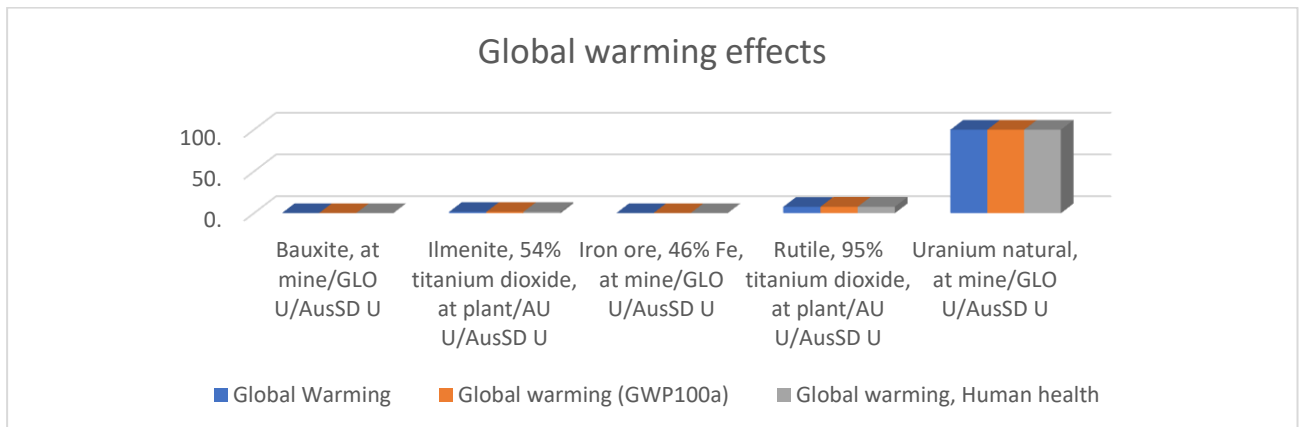
Label	Bauxite, at mine	Ilmenite, 54% titanium dioxide	Iron ore, 46% Fe, at mine	Rutile, 95% titanium dioxide	Uranium natural, at mine
Global Warming	0.0468	1.4847	0.0279	7.7124	100
Global warming (GWP100a)	0.0469	1.491	0.0279	7.7457	100
Global warming, Human health	0.0469	1.4946	0.0275	7.7641	100
Global warming, Terrestrial ecosystems	0.0469	1.4946	0.0275	7.7642	100
Global warming, Freshwater ecosystems	0.0469	1.4946	0.0275	7.7642	100



**Figure 1.** Human health affects results from the mineral industries.



**Figure 2.** Ecotoxicity affects results from the mineral industries.



**Figure 3.** Global warming affects results from the mineral industries.

In all the categories of human health, ecotoxicity and global warming, uranium mining and extraction processing routes contribute mostly rather than other mineral commodities considered in this research. The reason should obviously be the radioactive particles and radionuclides emitted from the uranium processing mills and the radioactive uranium tailings. The second largest contributor is the rutile mining sector. Even though ilmenite and rutile are produced from the same mines and processing systems, rutile mining requires much more processing technologies than ilmenite mining due to ore grade and mining depth. This reason obviously draws the lesson that why rutile mining is more impactful towards environmental effects rather than ilmenite mining. Fourth position goes for bauxite and lastly comes iron ore. This trend is consistent among the considered mining industries using the CML, ReCipe and Australian indicator method. This result also indicates the consistency among the life-cycle impact assessment methods towards the mineral industries routes. These results are clearly demonstrated through Figure 1-3[22, 24, 26, 27 and 28].

## 5. Conclusion

In the era of global warming and sustainability, mining companies and their operating bodies should ensure their risk-free and environment-friendly mining methodologies. To quantify the impacts of mineral mining extraction and processing technologies, this paper addressed the environmental effects caused by the mineral industries and their technologies through life-cycle assessment. Using the SimaPro software and CML, ReCipe and Australian indicator methodologies, this paper indicates that the largest contributor to global warming and greenhouse gas emissions is uranium mining due to their radionuclides and radioactivity, followed by the rutile and ilmenite mining. Countries where economy is strongly dependent on mining industries, specially on minerals, 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.

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