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Sustainable Development Goals in Mine Tailings Management: Targets and Indicators †

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Abstract: Minerals and metals are essential to the economic and social development of our society, and they are critical to modern life. The continuous exploitation of mineral resources has led to a large amount of waste, which has a large impact on the environment. One of the main streams of wastes in mining is mine tailings, which are produced in mineral processing plants. The mining industry must enhance its contribution to achieving sustainable development by incorporating the sustainable development goals into its operations. The objective of this article is to define targets and indicators for mine tailings management to achieve the sustainable development goals, defined in the 2030 Agenda for Sustainable Development by the United Nations. The result of this study is a collection of indicators proposed to measure the progress of mine tailings management towards sustainable development.

Keywords: mining; mine tailings; sustainable development; sustainable development goals; sustainability

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1. Introduction

Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs [1]. The United Nations (UN) has an agenda to advance towards sustainable development consisting of seventeen (17) Sustainable Development Goals (SDGs), which aim to achieve sustainable development in all areas of society [2]. The UN also has guidelines and methodologies to apply sustainable development indicators [3]. Another framework to measure sustainable development is provided by the Global Reporting Initiative (GRI), a non-profit institution, that provides sustainability report standards, which are continuously updated [4]. Even though there are several frameworks and guidelines about sustainable development, sustainability, and circular economy, these are rather general. Various indicators are proposed as guidelines to be applied to different companies and regions but these have not been evaluated.

On the one hand, mining presents challenges and opportunities to achieve the SDGs. Mineral resources are non-renewable and finite. Due to the decline in ore grades, the amount of waste is increasing, having a considerable environmental and social impact, increasing the conflicts between local communities and mining companies. On the other hand, mining can also contribute to sustainable development in the economic dimension because it can bring fiscal revenues to a country, increase economic growth, and create jobs [5]. The congruence between mining and SDGs has been discussed by Monteiro et al.,

showing the current contribution and challenges of the mining industry to contribute to the achievement of the SDGs [6]. Mining companies can demonstrate their commitment and contribution to SDGs by applying three approaches: (1) tax contribution to national economies; (2) initiatives to place the sustainability agenda in their business operations; and (3) contributions to the provision of collective goods like education and health care [7].

Several frameworks have been developed to integrate sustainable development, sustainability, and circular economy concepts into the mining industry [8]. The World Economic Forum connects the mining industry with SDGs by presenting areas and targets that must be fulfilled to contribute to achieving the SDGs [9]. The International Council of Mining & Metals (ICMM) proposed a mitigation hierarchy to assess the management and impact of mining waste by providing guidelines for sustainable and responsible tailings management, which include mine closure planning, performance evaluation, and risk management, among other aspects [10–12]. A framework for sustainable development indicators for the mining and minerals industry was developed by Azapagic (2004) [13], which is compatible with the general GRI indicators. Nevertheless, there is a need to develop indicators to measure at the regional level the progress of mining around the production of mining waste.

The mining industry produces large amounts of waste, with mine tailings the main waste produced in mineral processing plants after separating valuable minerals and metals from an ore [14]. Without proper management, tailings can be a threat to communities, ecosystems, and water resources [15]. Therefore, mine tailings need to be appropriately managed and treated. Additionally, tailings management should aim to their valorization if possible, by re-processing, reusing, and/or recycling. Nowadays, tailings are also seen as secondary sources of metals [16], construction material [17], and a source to sequestrate CO_2 emissions [18]. The objective of this study is to define targets and indicators for the mining industry that can be applied to a regional or national level, focused on mine tailings management by metallic mining industries to achieve the sustainable development goals (SDGs), described in the 2030 Agenda for Sustainable Development by the UN. The mining industry must incorporate SDGs into its operations to achieve sustainable development goals.

2. Methodology

The methodology consists of the following steps:

Step 1: Identification and selection of targets from the SDGs related to the mining industry focused on mine tailings management;

Step 2: Development of indicators for the targets selected. The result of this step is a set of indicators that can be applied to the mining industry focused on tailings management;

Step 3: Identification of the contribution of indicators to the SDGs.

As a starting point, the UN report is used as a baseline to identify connections between mining and SDGs. In addition, literature research was conducted using the terms "sustainable development goals" and "mining", "sustainable development" and "mine tailings", "sustainability", and "mine tailings". Furthermore, articles about SDGs synergies between sustainability indicators were also looked into.

3. Results

The results of this study are the outcomes of the three steps presented in the methodology, which are presented in the following paragraphs.

3.1. Identification and Selection of Targets

The report entitled *Mapping Mining to the SDGs: An Atlas* [9] was used as a baseline to develop the targets related to mine tailings management. This report links the areas of the mining industry in which the industry can improve and help to achieve the SDGs. Based on this report and the guidelines provided by the UN, targets for mine tailings management are identified and connected to the SDGs. Mine tailings management can

be linked directly to seven of the seventeen SDGs, which are related to land use, water and energy management, ecosystems, sustainable productions and consumption, and climate change. The targets developed for mine tailings management and valorization are presented in Table 1.

Table 1. Targets for mine tailings management for achieving sustainable development goals.

SDGs	Targets for Mine Tailings Management and Valorization
SDG 6: Ensure availability and sustainable management of water and sanitation for all	-Minimize the impacts of tailings facilities and dams on water resources by minimizing acid mine drainage and the release of hazardous chemicals -Reduce the water consumption of continental water resources in tailings facilities by improving water recycling rate in tailings management, by using dewatering technologies
SDG 7: Ensure access to affordable, reliable, sustainable, and modern energy for all	-Achieve energy efficiency in tailings management by improving water-energy nexus -Encourage the use of renewables energies in mine tailings management
SDG 11: Make cities and human settlements inclusive, safe, resilient, and sustainable	-Reduce the impact of mine tailings deposits on communities nearby. -Planning land use considering the end-of-life of the mine -Recovery of nearby areas of mine tailing's deposits -Support the development of processes to reuse, recycle, and/or re-processing tailings
SDG 12: Ensure sustainable consumption and production patterns	-Achieve sustainable management of tailings by reducing using of water, energy, and land -Minimize production of tailings and encourage sustainable practices and monitoring of chemicals and water management in tailings -Encourage tailing dewatering technologies, appropriate management of acid drainage, safe storage of tailings -Encourage and achieve valorization of tailings by re-processing, reusing, and recycling tailings
SDG 13: Take urgent action to combat climate change and its impacts	-Recognize climate change in the planning of managing and re-processing tailings -Improve energy and water efficiency in mine tailings management -Measure direct and indirect emissions of treatments of tailings -Encourage the use of renewable energies in mine sites
SDG 14: Conserve and sustainably use the oceans, seas, and marine resources for sustainable development	-Reduce marine pollution associated with mining tailings and acid mine drainage -Plan for responsible tailings management that avoid tailings disposal into the sea
SDG 15: Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	-Conduct environmental impact assessment of tailings facilities and dams -Support projects that connect communities and biodiversity and encourage the participation of governments, communities, researchers, and NGOs in mine planning -Minimize the impact of tailings on freshwater ecosystems by reducing the water consumption of tailings management -Ensure the conservation, restoration, and sustainable use of freshwater sources -Avoid impacts of tailings facilities and dams to critical habitats by applying the mitigation hierarchy

3.2. Development of Indicators

In this step, indicators are developed according to the targets defined in step 1. Indicators can be divided into two groups: the aggregated single index where just one variable is reported, and the indicator set where many variables are reported [19]. A methodology based on an issue or theme-based framework was chosen following the guidelines provided by the UN [3]. Issue or theme-based frameworks are the most widely used frameworks to propose indicators, grouped into different issues relating to sustainable development, and they are usually determined by policy relevance [3]. The reason for the popularity of thematic frameworks is due to their ability to connect indicators to policy processes and targets [3]. Indicators must follow several criteria, from which we decided to follow the criteria: relevant to assessing sustainable development progress; understandable, clear, and unambiguous; conceptually sound; primarily national in scope [3]. Forty-three indicators are proposed for each target presented in Table 1. The set of indicators is presented in Table 2. The set of indicators is meant to be applied to metallic mining industries at a national scale.

Table 2. Set of indicators proposed in the study.

	Indicators	Unit
1	country with a plan of water management and water savings in tailings facilities	(YES = 1; NO = 0)
2	Mine tailings generated using conventional method no water saving	tonnes
3	Rate of mine tailings conventional tailings/total tailings disposed	No unit
4	Mine tailings generated using dewatering technologies (tonnes)	tonnes
5	Rate mine tailings generated using dewatering technologies/total tailings disposed	No unit
6	Total water use in tailings facilities	m^3/year
7	Water recycled and reused in tailings facilities	m^3/year
8	% of water recycled and reused in tailings facilities	%
9	Energy consumption tailings facilities	kW h/year
10	Country has a plan to reduce energy consumption in tailings facilities	(YES = 1; NO = 0)
11	Country has a plan to use more renewables energies in tailings facilities	(YES = 1; NO = 0)
12	The proportion of people living in areas near mine tailings deposits (people living near tailings dams/total population)	No unit
13	Land use for mine tailings facilities	m^2
14	Number of mortalities related to mine tailings disasters (number)	No unit
15	Number of accidents related to mine tailings disasters (number)	No unit
16	Number of mine plants with a closure plan according to tailings regulations (Number)	No unit
17	The proportion of mining waste managed or reused of all mining waste generated (rate)	No unit
18	The country has regulations about mine closure and rehabilitation of mine sites (YES = 1; NO = 0)	(YES = 1; NO = 0)
19	National organism in charge of tailings management policies	(YES = 1; NO = 0)
20	National plan of sustainable mine tailings management policies	(YES = 1; NO = 0)
21	Countries with a national organism in charge of mining	(YES = 1; NO= 0)
22	Countries with a national plan of recycling and repurpose tailings	(YES = 1; NO = 0)
23	Inactive and abandoned tailings	tonnes
24	Active tailings	tonnes
25	Rate inactive or abandoned tailings/total tailings	No unit
26	Total Tailings production rate	Tonne/year
27	Rate active tailings/total tailings	No unit
28	Tailings that are re-processed	Tonne/year
29	Policies about acid drainage management	(YES = 1; NO = 0)
30	Numbers of initiatives and agreements on mining waste management and valorization (Number)	No unit
31	Numbers of projects already re-using, re-processing, and recycling mine tailings (Number)	No unit
32	Greenhouse gas (GHG) emissions of mine tailings treatment per year	t CO_2 eq/kW h
33	GHG emissions of re-processing/re-use/recycle of tailings processes per year	t CO_2 eq/kW h
34	The concentration of hazardous elements in areas nearby tailings	mg/kg
35	Deep-sea disposal, is tailings disposal into oceans permitted?	(YES = 1; NO = 0)
36	Is riverine disposal permitted?	(YES = 1; NO = 0)
37	Regulations about marine disposal	(YES = 1; NO = 0)
38	Acid mine drainage potential because tailings are in an area with high precipitations	(YES = 1; NO = 0)
39	Accident probability because tailings facilities are located in seismic region	(YES = 1; NO = 0)
40	Regulations about tailings marine and riverine disposal	(YES = 1; NO = 0)
41	Number of protected ecosystems nearby tailing facilities	No unit
42	Mine closure plan must include reforestation	(YES = 1; NO = 0)
43	The country has environmental impact assessments requirements for new tailings facilities	(YES = 1; NO = 0)

3.3. Identification of the Contribution of Indicators to the SDGs

The set of indicators proposed in Table 2 contains both quantitative and qualitative indicators that are designed to assess the current situation of tailings management on a regional or national scale. For each target presented in Table 1, we proposed indicators to provide relevant information to understand the state of mine tailings regarding that target. Some indicators may provide information for more than one goal. The evaluation of the information of the current state of mine tailings will depend on the evaluation of one or more indicators. Figure 1 presents the relationship between each indicator and the SDGs assessed. It can be noted that the majority of indicators (38) provided information about SDG 12 (sustainable consumption and production patterns) since this goal can be directly linked to the production of industrial wastes. For the other SDGs, the representation of the indicator set is lesser: Twelve indicators are connected with SDG 15 (terrestrial ecosystems), twelve indicators with SDG 11 (sustainable cities and settlements), eleven with SDG 6 (water management), 8 indicators with SDG 13 (climate change), 6 indicators with SDG 7 (sustainable energy), and 5 indicators with SDG 14 (marine resources).

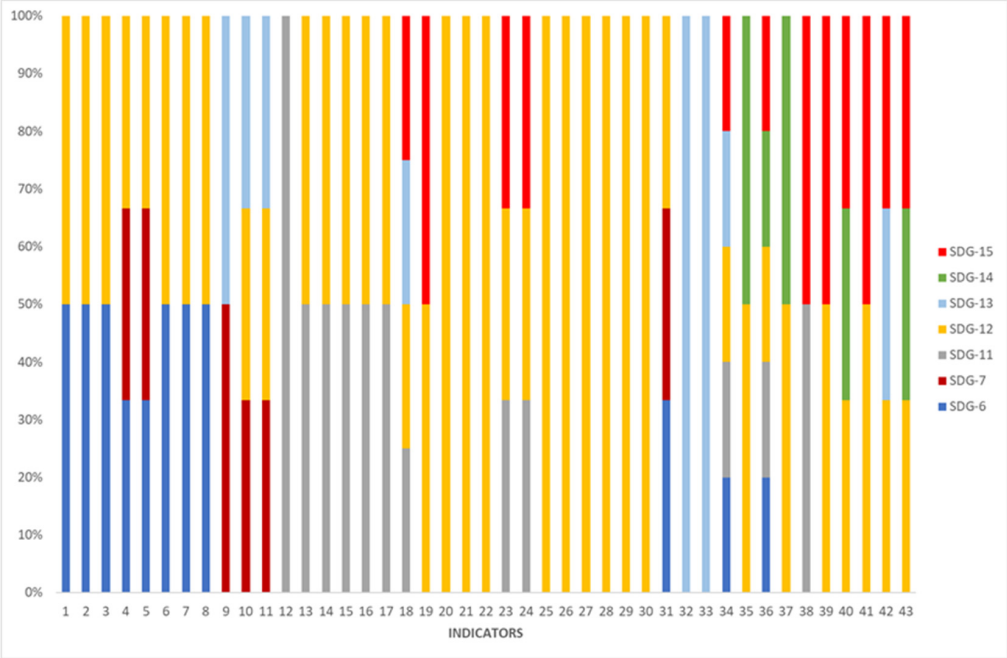

Figure 1. Contribution of the indicators to each SDG assessed on the study.

4. Conclusions

Targets to achieve the Sustainable Development Agenda for 2030 for the mining industry focused on mine tailings managements were defined following the guidelines provided by the UN and the framework provided by the World Economic Forum, which connects mining with the SDGs. Proper Mine tailings management is crucial to direct mining towards sustainable development. Nowadays, mine tailings facilities are the most significant water sink at mines. Hence, efforts to reduce water content are required. Recycling water and reducing water content can be achieved by using dewatering technologies. Achieving energy efficiency is a challenge when using such technologies. Land use of tailings facilities is another big issue, as tailings are usually stored in ponds or dams, and they can be a threat to communities and ecosystems nearby. Thus, reducing the probabilities of accidents and pollution is imperative. Reducing waste is another major issue; hence, the effort to reduce, recycle, and re-process tailings must be encouraged. Ultimately, all efforts should be focused on reducing climate change.

The novelty of this study is proposing a framework with indicators to measure sustainable development in mine tailings management, adding knowledge to the field of

sustainable development in mining, by making the connection between mining waste and the sustainable development goals.

The set of indicators proposed, meant to be applied at a national scale, will help assess the current state and evolution of mine tailings management towards practices that enable the circularity of materials and achieve sustainable development. This set of indicators allows identifying strong and weak areas for improvements towards reporting and achieving sustainable development. This set of indicators can be measured in several countries' regions to compare the advance between different countries towards sustainable development in mine tailings management.

Based on the targets for each SDG, a set of forty-three indicators were developed. The majority of indicators are directly related to SDG 12, which is about sustainable consumption and production patterns, indicating that a correct evaluation and respective approval of the projects based on achieving this goal is fundamental since proper tailing management is directly related to this goal. Some indicators measure information related to SDG 6, SDG 7, and SDG 12 as water, energy, and sustainable consumption and production are intrinsically related. The same happens with SDG 11, SDG 13, and SDG 12 indicators, which provide information to measure SDG 11 and also provide information to measure SDG 12. Indirectly the achievement of some goals improves the achievement of SDG 13, this is the case of SDG 14 and SDG 15 since the protection of ecosystems will improve CO_2 capture. The achievement of SDG 6 and SDG 7, water and energy, can also enhance SDG 13.

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