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Assessing Mining Performance Indicators in Relation to the SDGs: Development of a Guided Methodology and Its Application in an Iron Ore Mine

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Abstract: The concept of sustainability has gained significant recognition across all industrial sectors, particularly in response to the potential global environmental crisis. In mining, sustainability ensures responsible operations by addressing environmental, social, and economic aspects. Performance indicators, categorized into environmental, social, economic, and governance groups, are monitored to oversee these aspects. In 2015, the UN established 17 Sustainable Development Goals (SDGs) as a global agenda for achieving equitable economic and social development. This study presents a methodology to evaluate performance indicators in an iron ore mine in southeast Pará, Brazil, to understand whether and how these indicators guide the mine's operations toward fulfilling the SDGs. This study was based on the application of a methodology specifically developed for this purpose, where a seven-step application was defined, with each step involving an activity to be carried out to verify the correlation performance indicators with the SDGs. By applying the proposed methodology, the assessment of 286 performance indicators was conducted, revealing that 55.24% aligned the mine's operation with the SDGs. Furthermore, the developed methodology may be applied to other mining enterprises, supporting their sustainability reports and compliance with the sector's regulatory standards and mine closure plan requirements.

Keywords: Sustainable Development Goals; qualitative approach; mine operations; performance indicators; sustainability

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1. Introduction

Discussions about the idea of sustainability have gained recognition and are being implemented across all branches of industry, especially in response to the perceived threat of a global environmental crisis. Consequently, there has been growing concerns about climate change, environmental degradation, and social disparities. This heightened awareness has led to increased demand from consumers, investors, and other stakeholders for companies to operate ethically and sustainably [1]. There is a complex relationship between mining and sustainability, making it essential to adopt sustainable practices in the mining industry, as it can cause significant environmental and social impacts [2].

Mining has always been part of humanity's trajectory, and what is seen today are increasingly complex and enterprising mineral extraction projects, designed to meet the growing demands of society. However, the rise in illegal extractive activities has caused severe and, in some cases, irreversible environmental and social impacts. The pursuit of sustainability in mining presents several challenges, including the need to reduce environmental impacts, promote social inclusion, and strengthen corporate governance. To face these challenges, it is necessary to adopt sustainable management practices, implement cleaner and more efficient technologies, manage waste responsibly, and execute effective programs for the recovery of degraded areas [3].

The term sustainable development is defined in the Brundtland Report [4] by the World Commission on Environment and Development as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Essentially, the report proposed a comprehensive agenda for global change that balances environmental preservation with economic development, consolidating what we now recognize as sustainable development [5].

Parris and Kates [6] discussed the inherent ambiguity in the definition of sustainable development. The authors highlight that, although the most widely accepted definition is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs", this definition is intentionally vague, allowing the concept to be applied in a wide variety of contexts. However, this same vagueness can lead to divergent interpretations and challenges in practical implementation. For example, different stakeholders may have distinct views on what constitutes "needs" and how to balance the economic, social, and environmental dimensions of sustainable development. Despite this, the authors argue that the broad definition provides the necessary flexibility to adapt the concept to various local and global realities and challenges.

The implementation of sustainable development in mining requires the integration of activities in three main areas: technical and economic activities, which ensure economic growth; the ecological sector, ensuring the protection of natural resources and the environment; and the social sector, that is, caring for the collaborator in the workplace and community development in the mining environment area. A suitable framework for sustainable development will be created through the interaction of these principles with activities carried out in different stages of the mining life cycle [7]. It should be emphasized that sustainable development is, in any case, a continuous process, not a temporary endeavor. It presents clearly defined goals and means to achieve them in all the key areas mentioned [8].

In this context, the challenge of mining in relation to sustainability lies in finding balance and seeking harmonization between interests for the development of a standard of sustainable activities founded on each pillar, each of which is composed of a range of complex and multifaceted problems. This is a challenge that requires multidirectional support from the sides of science and the mining industry [9,10].

Similarly, planning for the life cycle of a mine, with a focus on its closure, should be planned well in advance, transforming mining into transitory land use that can make a lasting contribution to regional development [11,12].

Sustainability indicators in mining are important tools to monitor and assess company performance, indicating whether activities are conducted responsibly and sustainably [13].

Moreover, these indicators are recognized as useful tools for policymaking and public communication in conveying information on countries' performances in fields such as environment, economy, society, or technological development [14]. Singh et al. provide a comprehensive review of sustainability assessment methodologies and analyze a broad spectrum of sustainability indicators, categorized into areas such as innovation, knowledge, and technology indices; development indices; market- and economy-based indices; and ecosystems-based indices, among others [14]. Successful implementation of sustainable management in mining requires active collaboration with civil society, local communities, government, and other stakeholders, ensuring transparency, participation, and accountability [15].

The Paris Agreement set goals for reducing greenhouse gas emissions, requiring all countries to engage in a decarbonization process. Climate, decarbonization, energy, and mining are interdependent, and the fulfillment of the Paris Agreement involves, among other things, expanding the production and use of mineral goods. Brazil plays a crucial role in this process as a significant provider of commodities and industrial solutions for the decarbonization of the global economy. Today, the country has a list of 22 materials established as critical and strategic, including copper, silicon, nickel, lithium, graphite, aluminum, and iron. Iron ore is on this list due to its abundant availability and the leading

position of Brazilian companies in international trade. It also has applications linked to sustainable energy sources, such as solar, wind, electric grids, hydrogen electrolyzers, nuclear, and hydroelectric, as well as its broad application in construction, transportation, and consumer goods [16].

The 17 Sustainable Development Goals (SDGs) proposed by the United Nations in 2015 aim to improve basic living conditions for people and the planet, eradicate poverty, protect the planet, and guarantee prosperity for all [17]. Each SDG has specific definitions and expectations [18]:

1. No Poverty: This objective aims to end poverty in all its forms, worldwide, providing equal access to basic resources, such as health, education, and decent work.
2. Zero Hunger: This objective aims to ensure food security, promote sustainable agriculture, and support local farmers, as well as promote the reduction of food waste and improve the efficiency of food production and distribution systems.
3. Good Health and Well-Being: This objective aims to ensure that all people have access to quality health services, including prevention, diagnosis, and treatment of diseases.
4. Quality Education: This objective aims to ensure that all people have access to quality education. This includes access to schools and qualified teachers, as well as the opportunity to learn skills relevant to the job market.
5. Gender Equality: This objective aims to end all forms of discrimination against women and girls, promoting equal opportunities and empowering women in all sectors of society.
6. Clean Water and Sanitation: This objective aims to ensure that all people have access to clean water and basic sanitation. This includes the protection and sustainable management of water resources, as well as access to water and sewage treatment systems.
7. Affordable and Clean Energy: This objective aims to ensure that all people have access to clean, safe, and affordable energy. This includes the promotion of renewable energy sources, such as solar, wind, and hydroelectric, and the adoption of more efficient and sustainable technologies to reduce dependence on fossil fuels and greenhouse gas emissions.
8. Decent Work and Economic Growth: This objective aims to promote sustainable and inclusive economic growth, ensuring that all people have access to decent and productive jobs.
9. Industry, Innovation, and Infrastructure: This objective aims to promote sustainable industrialization, innovation, and quality infrastructure that are accessible and sustainable. This includes the promotion of clean technologies and innovations that improve the efficiency of industrial processes, as well as the development of resilient and sustainable infrastructure to meet the needs of communities.
10. Reduced Inequalities: This objective aims to reduce economic, social, and political disparities among people and countries. This includes promoting policies that reduce income, gender, race, and ethnic inequalities, as well as strengthening citizen participation and transparency in political decisions.
11. Sustainable Cities and Communities: This objective aims to make cities more inclusive, safe, resilient, and sustainable, ensuring access to basic services, efficient transportation, and green infrastructure.
12. Responsible Consumption and Production: This objective aims to promote responsible consumption and production practices, including waste reduction, promotion of sustainable products, and improvement of production process efficiency.
13. Climate Action: This objective aims to take urgent action to combat its causes and impacts. This includes reducing greenhouse gas emissions, promoting clean and renewable energy sources, and adapting to ongoing climate changes.
14. Life Below Water: This objective seeks to ensure the conservation and sustainable use of oceans, seas, and marine resources for sustainable development.

15. Life on Land: This objective seeks to promote the conservation, restoration, and sustainable use of terrestrial ecosystems, as well as combat desertification, soil degradation, and biodiversity loss.
16. Peace, Justice, and Strong Institutions: This objective seeks to promote peaceful and inclusive societies, with effective and accountable institutions. This includes combating corruption and violence, ensuring access to justice and equal rights, and promoting democratic and transparent institutions.
17. Partnerships for the Goals: This objective seeks to strengthen partnerships between governments, civil society, and the private sector to mobilize the necessary resources and capacities for the implementation of the other sustainable development goals. This includes strengthening international cooperation and development assistance, promoting fair and sustainable trade, and increasing access to technologies and innovation.

Parris and Kates [6] emphasized the need to develop clear indicators and robust methodologies to measure progress towards the Sustainable Development Goals (SDGs) to overcome some of the limitations imposed by the ambiguous definition. Clear indicators allow governments, companies, and other stakeholders to monitor and report their performance concerning the SDGs transparently. This not only facilitates the identification of areas needing improvement but also promotes accountability and responsibility.

Neves (2019) [19] argues that mining companies can become leading partners in achieving the SDGs by generating profits, jobs, and economic growth in low-income countries and ensuring that the benefits of mining extend beyond the life of the mine. Mining companies will be called upon to extract responsibly, waste less, use safer processes, incorporate new sustainable technologies, promote the well-being of local communities, reduce emissions, and improve environmental management. Companies committed to the SDGs will benefit from better relationships with governments and communities and better access to financial resources. Those who do not engage significantly with the SDGs will put their operations at risk in the short and long term [20].

This research was conducted in response to the challenge of understanding whether and to what extent performance indicators in the mining sector align with the Sustainable Development Goals (SDGs). Given the complexity and importance of accurately assessing these indicators, our study developed a methodology to systematically evaluate how well these indicators support the broader goals of sustainable development. This approach not only addresses the current gap in the literature but also provides a practical and simple framework for assessing sustainability performance in the mining industry.

The research was designed while considering that monitoring and management of performance indicators is one of the main challenges faced by large companies, encompassing aspects such as standardization of indicators, data collection and analysis, transparency and communication, and the integration of these indicators with business strategy. This methodology was developed specifically to support this integration, aiming to help mining companies evaluate, in a simple and straightforward way, how their indicators support the achievement of the SDGs, providing visibility on how performance indicators contribute to each goal proposed by the UN. To evaluate these indicators, the proposed methodology was applied through a case study in an iron ore mining project located in the southeast of the state of Pará, Brazil.

2. Materials and Methods

This survey was qualitative, and, in terms of its objectives, it was classified as exploratory [21]. The technical procedure employed was a case study. Data collection involved bibliographic and document research techniques.

A specific methodology, outlined in Figure 1, was devised and tested for the preparation and development of this study.

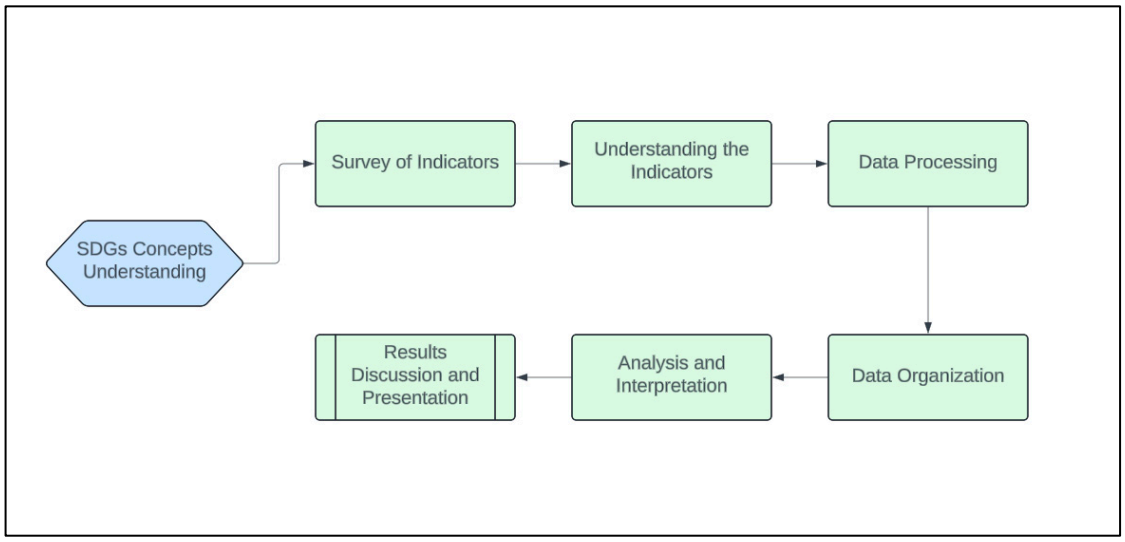

Figure 1. Flow for applying the research methodology.

The following guidelines apply to each of the stages described in Figure 1.

2.1. SDGs Concepts Understanding

The main objective of this stage is to deepen the understanding of the Sustainable Development Goals (SDGs) proposed by the UN. An in-depth analysis is essential to ensure that the evaluator's correlation assessment accurately reflects the scope of each goal and requirement. This involves studying the concepts and requirements of the SDGs through bibliographic research. The research focused on identifying relevant documents (articles, books, dissertations, and theses) primarily from three databases: (a) Google Scholar; (b) Virtual Library of São Paulo University (USP); and (c) International Scientific Articles from Emerald Publishing. Keywords used to locate these documents included: (a) 2030 Agenda; (b) 2030 Agenda–UN; and (c) sustainable mining.

2.2. Survey of Indicators

This is the initial stage involving the assessment of indicators. It requires defining which company-employed indicators will be used and compiling a list of these indicators, including details such as the indicator name, measurement methods, and application areas. This stage involves an internal document review, considering company information like the targets panel, and a thorough analysis of each indicator. The indicators selected for this study must be relevant, measurable, clear, and suitable for the survey's objectives. Table 1 provides an example of how to organize and group the indicators.

Table 1. Example of tabulation for organizing indicators.

Result Area	Indicator	Unit of Measure
Environmental	Indicator A	Total number
Social	Indicator B	Percentage (%)
Economic	Indicator C	Local currency ($)
Governance	Indicator D	Total number

2.3. Understanding the Indicators

The goal of this stage is to grasp the essence of each indicator to accurately determine its correlation with the Sustainable Development Goals (SDGs). It is also crucial to understand the details of how each indicator is measured and monitored, as well as its impact on the company's results.

2.4. Data Processing

This stage involves identifying and eliminating redundancies among the assessed indicators. If there are multiple indicators for the same goal or an indicator that produces a single result monitored across different areas, only one indicator should be retained in the correlation assessment matrix. For instance, if both the mine and processing plant monitor a water consumption indicator measured in liters of water consumed per ton shipped, only one indicator should be considered to avoid redundancy.

2.5. Data Organization

The collected data should be systematically organized to facilitate tabulation and analysis. This involves creating a database or electronic spreadsheet, where each indicator is listed in a row, and the SDGs are listed in columns, as shown in Table 2.

Table 2. Tabulation proposal for organizing survey data.

Indicator	SDG1	SDG2
Indicator A		
Indicator B		
Indicator C		

2.6. Indicators Analysis

Once the indicators are tabulated, they can be analyzed and interpreted to address the survey questions or study objectives. At this stage, each indicator is correlated with the SDG goals. This study used a binary system where a value of "1" (one) signified a correlation between the indicator and the assessed goal, and "0" (zero) indicated no correlation. By summing the values in each row and column, it became possible to quantify the strength of each correlation for the indicators, as demonstrated in Table 3. This approach allowed the indicators, regardless of their units of measurement, to be consistently evaluated in relation to their contribution to the SDGs. The sum of the values for each indicator provided a clear view of its relevance and impact concerning the global goals, thereby facilitating the interpretation of the results.

Table 3. Tabulation proposal to check the correlation of indicators vs. SDGs.

Indicator	SDG1	SDG2
Indicator A	1	0
Indicator B	0	1
Indicator C	1	1

This assessment should be conducted based on the literature and the concepts explored in the "SDGs Concepts Understanding" stage of this methodology, correlating the indicators with the principles outlined in the UN's Sustainable Development Goals (SDGs). Each indicator may be correlated with multiple goals.

2.7. Results Presentation

After analyzing and interpreting the indicators, the results should be presented clearly and objectively. To achieve this, the total correlations for each indicator are calculated by summing the existing correlations. This stage has two specific objectives: a) to determine the total number of indicators that correlate with the studied goals and b) to identify which indicators meet the most goals. The results should be plotted in graphs to facilitate understanding and identify trends.

2.8. Results Discussions

Finally, after the results are graphically presented, discussions should follow, evaluating the intensity of the correlation between each indicator and the SDGs to understand why certain indicators exhibit the observed levels of correlation.

For the case study, the proposed methodology was applied to assess the performance indicators of a mining company operating in Brazil, specifically in one of its iron ore mining operations in the state of Pará. Pará has been solidifying its position as a significant ore-producing state, accounting for 37% of exports in 2022, with iron ore being the main contributor. In the Brazilian mineral sector, the state generated BRL 2.926 billion in Financial Compensation for Mineral Exploration (CFEM) and directly employed 25 thousand people, with an additional 328 thousand employed indirectly [22,23].

3. Results and Discussion

The results of correlating the company's performance indicators with the Sustainable Development Goals (SDGs) proposed by the UN 2030 Agenda are presented in the section below (Section Correlation of Performance Indicators vs. Sustainable Development Goals–SDGs (UN)).

During the data gathering stage, a total of 286 indicators were identified from the company's databases. First, these indicators were grouped using the frameworks provided by UNCSD (United Nations Conference on Sustainable Development) [18], which provided a comprehensive framework for developing and using indicators to measure sustainable development and emphasized the importance of integrating economic, social, environmental, and governance dimensions to create a holistic view of progress. The company's indicators are shown in Table 4 based on their similarities, according to methodology.

Table 4. Distribution of indicators into groups based on their monitoring objectives.

Category	Total
Environmental	25
Social	92
Economic	31
Governance	138
Total	286

Source: Research data sourced from the company's database.

In addition to the categorization shown in Table 4, the indicators were further subdivided into subgroups, as detailed in Table 5. This division was made to segregate the indicators based on the company's departments and their specific impacts.

Table 5. Distribution of indicators into subgroups based on their monitoring objectives.

Category	Total
Strategic	8
Health and Safety	41
Environment	25
Communities	6
Risk Management	26
Financial	31
People Management	19
Maintenance	2
Operation	15
Productivity	36
Quality	17
Management System	60
TOTAL	286

Source: Research data sourced from the company's database.

Correlation of Performance Indicators vs. Sustainable Development Goals–SDGs (UN)

Based on the correlation assessment of the indicators in this survey, it was found that out of a total of 286 indicators evaluated, only 158 had a direct correlation with the SDGs, representing 55.24% of the indicators that guided the company towards contributing to one or more of the goals proposed by the UN in the 2030 Agenda. Conversely, 128 indicators monitored and controlled by the company did not show any correlation with the UN goals. Examples of these indicators include: (a) total dismantled mass available in the mine, (b) average time between failures, and (c) adherence to scheduled maintenance activities. This result is illustrated in Figure 2 below:

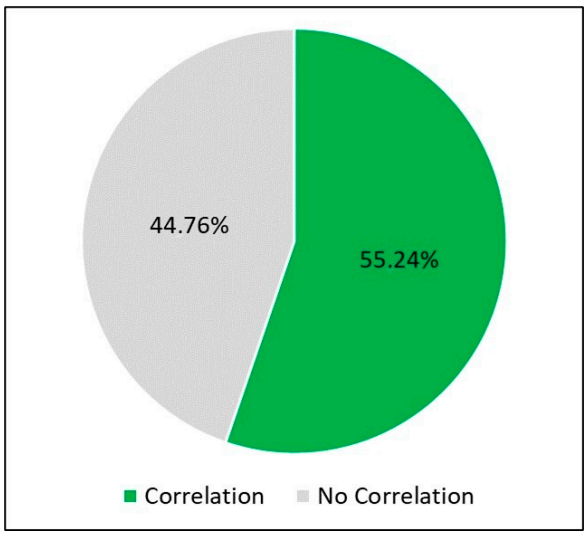

Figure 2. Number of indicators correlated to the SDGs.

It was observed that some of the evaluated indicators aligned with multiple SDGs. In other words, a single indicator can demonstrate the company's performance in achieving more than one goal. For example, the indicator assessing the "reduction of absolute greenhouse gas (GHG) emissions" can evaluate: (a) Good Health and Well-being, (b) Affordable and Clean Energy, (c) Sustainable Cities and Communities, (d) Responsible Consumption and Production, and (e) Climate Action. Therefore, this indicator supports five of the goals proposed by the 2030 Agenda.

Regarding "(a) Good Health and Well-being", it is important to note that heat-related mortality is identified as one of the primary extreme weather conditions posing a significant risk to human health. This underscores the urgent need for robust mitigation and adaptation strategies to reduce these impacts on human lives [24].

The graph below (Figure 3) illustrates the frequency of indicators that aligned with each of the SDGs, showing that some indicators addressed up to five goals, while others addressed only one.

Based on the graph above, it can be observed that 35.3% of the indicators monitored by the company aligned with only one goal, 11.9% aligned with two goals, 2.4% aligned with three goals, 4.5% aligned with four goals, and only 1.1% aligned with five goals. A significant portion, 44.8%, did not correlate with or meet any of the goals proposed by the 2030 Agenda.

In relation to Figure 4, the following indicators are highlighted as examples of those that addressed the largest number of goals (five each): (a) reduction in absolute greenhouse gas emissions; (b) specific use of new water; and (c) consumption of water obtained from primary sources.

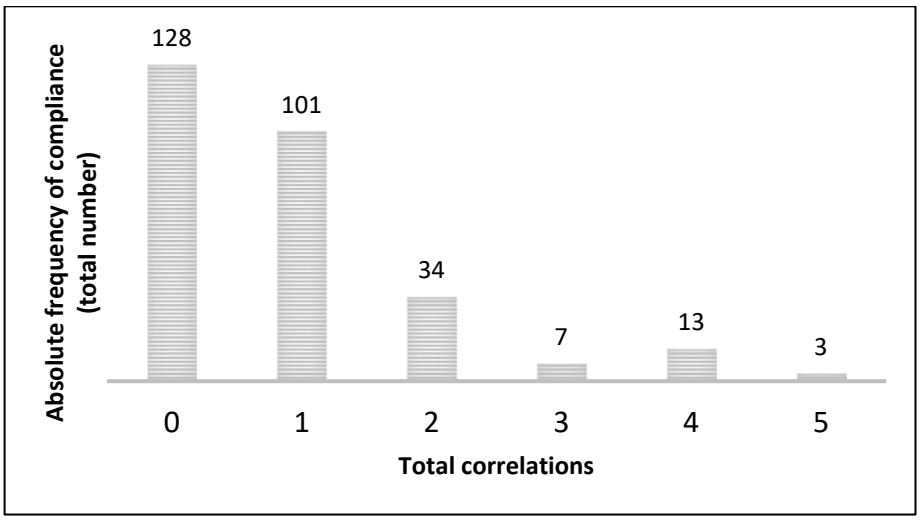

Figure 3. Frequency of compliance by indicators with the SDGs.

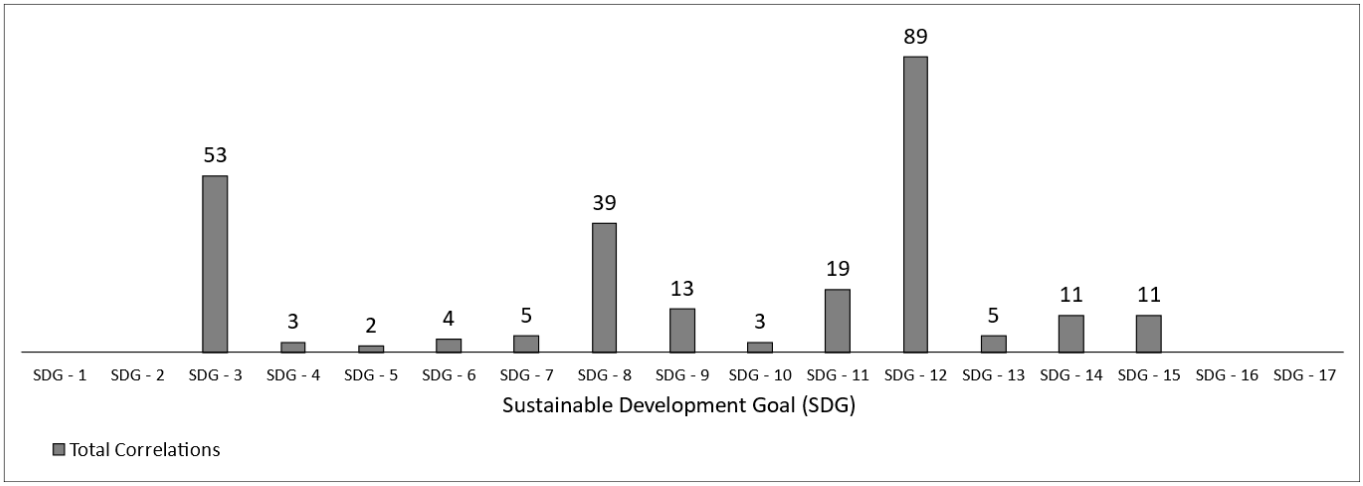

Figure 4. Total indicators correlated with each SDG.

Figure 4 shows the distribution of correlations among the assessed indicators, considering all 17 goals proposed by the 2030 Agenda and indicating whether the indicators met more than one goal.

It was evident that SDG 12 ("Responsible Consumption and Production") had the highest number of correlated indicators. This goal emphasizes production methods that work in harmony with the environment, aiming to minimize environmental impacts and reduce waste. With 89 indicators (31.12%) aligning with SDG 12, it was clear that the company prioritized sustainable consumption and production within its supply chain, thereby contributing to the global commitment to sustainability. Some specific actions include:

- Eliminating effluent discharge, monitoring water quality near the enterprise, and setting new water capturing and consumption targets. These indicators support SDG 12.2, which aims for the sustainable management and conscious use of natural resources by 2030;
- Monitoring and reducing specific fuel consumption, addressing SDG 12.4, which seeks the sound management of chemicals and the reduction of their release into water, air, and soil;
- Controlling total solid waste generation, aligning with SDG 12.5, which calls for a substantial reduction in waste generation through prevention, reduction, recycling, and reuse [18].

Following this, SDG 3 ("Good Health and Well-being") was the second major goal, with 53 correlated indicators, representing 18.53% of all evaluated indicators. Health and safety indicators significantly contributed to this, monitoring aspects such as employee risk exposure, workplace well-being, sickness absence rates, and injury records. These indicators are directly related to SDG 3.4, which aims to reduce premature mortality and to promote mental health and well-being [18].

SDG 8 ("Decent Work and Economic Growth"), which focuses on decent work for all and inclusive, sustainable economic growth, had 39 correlated indicators (13.64%). Examples include:

- Indicators related to monitoring the unit's energy matrix to ensure it is clean and renewable, correlating with SDG 8.4, which aims to improve global resource consumption efficiency by 2030;
- The total number of female employees and people with disabilities (PwD) and their proportion in the workforce, aligning with SDG 8.5, which aims for full, productive employment with equal pay for all, including people with disabilities;
- Monitoring investments and controlling unit costs, supporting SDG 8.1, which aims for economic growth in GDP, and SDG 8.2, which seeks higher productivity through technological modernization and innovation.

In this survey, no direct correlations were found between the assessed indicators and SDG 1 ("End Poverty"), SDG 2 ("Zero Hunger"), SDG 16 ("Peace, Justice, and Strong Institutions"), and SDG 17 ("Partnerships for the Goals"). These goals were primarily focused on public policies, with actions typically initiated by the state.

The proposed methodology has the limitation of having been applied to only one mine, in addition to the inherent limitations of the case study method (such as lack of generalization and dependence on specific contexts). To strengthen and improve the proposed methodology, it is essential to apply it to other mining companies, including medium- and small-scale operations, as well as mining activities involving different mineral substances. This diversification will allow for a more robust and comprehensive evaluation of the methodology's effectiveness and applicability in various contexts and operational conditions.

4. Conclusions

By implementing the proposed methodology, this study successfully achieved its objectives. A qualitative analysis of the performance indicators monitored by the mining enterprise was conducted, offering insights into how these indicators guide the business towards fulfilling the 17 Sustainable Development Goals (SDGs) set by the UN.

Of the 286 indicators monitored by the company, 158 directly correlated with the SDGs, representing 55.24% of all indicators. SDG 12 ("Responsible Consumption and Production"), SDG 3 ("Good Health and Well-being"), and SDG 8 ("Decent Work and Economic Growth") were the goals with the highest numbers of verified correlations, with 89, 53, and 39, respectively, correlated indicators. No correlations were found between the evaluated indicators and SDGs 1, 2, 16, and 17. This correlation suggests that the company's monitoring efforts are effectively steering its actions towards sustainability in alignment with the SDGs.

The study also found that 128 indicators, accounting for 44.76%, are primarily used for internal performance monitoring. These indicators do not directly contribute to sustainability aspects, meaning they do not significantly influence the environmental, social, and economic management of the mining activities.

The most relevant indicators (3 in total, 1.05%) in terms of UN goals mean that they encompass the maximum number of proposed objectives pertaining to "Health and Safety" (1 indicator, 0.35%) "Risk Management" (1 indicator, 0.35%), and "Financial Management" (1 indicator, 0.35%).

The developed methodology allows the company to better target efficient, sustainable management by validating its sustainability indicators. This tool aids in preparing the unit's sustainability reports and facilitates compliance with legal obligations related to

the Environmental Impact Study (EIA), Environmental Impact Report (RIMA), and Mine Closure Plan. It identifies which indicators support the actions proposed in these plans and highlights those that do not correlate, guiding the company to develop more effective sustainability indicators.

Using the proposed standard as a verification and guidance approach aligns the enterprise with ESG standards, favoring compliance with the Equator Principles. This alignment not only opens opportunities for raising funds but also positions the company towards sustainable transformation.

Finally, the methodology used in this study may be applicable to other mining companies and enterprises. It could serve as a guideline for achieving sustainability goals and meeting regulatory requirements outlined in sector documents and the Mine Closure Plan. It clarifies which process indicators are most relevant in the context of adherence to the SDGs and which should be prioritized for monitoring and action. Additionally, the methodology's application to a variety of mining operations, including those of different scales and involving various mineral substances, will enhance its robustness and generalizability. Conducting statistical studies and quantitative correlation analyses between each indicator and the SDGs is also recommended to reduce any subjectivity present in the methodology proposed by this research. This broader application will provide a more comprehensive evaluation of its effectiveness and applicability, ensuring that it can be adapted to diverse operational contexts and contribute to the continuous improvement of performance monitoring and sustainability practices in the mining industry.

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