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PROPOSING A DYNAMIC MINING SUSTAINABILITY ASSESSMENT METHOD (MSAM) FOR DEEP OPEN-PIT COPPER MINES

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ABSTRACT

Mining Sustainability Assessment (MSA) is the process of evaluating the positive and negative environmental, economic, and social impacts of a proposed project prior to its implementation. The mining project may have positive or negative short or long-term effects on the surrounding environment, regional, or global community. Through a review of the relevant literature, it was determined that the lack of temporal and spatial scale consideration in MSA is a significant flaw. Copper is one of the most important resources for a variety of technologies, and its production is expected to increase significantly over the next few decades. Copper is named a crucial element for industries and human beings; therefore, this significant gap in the MSA studies of copper mining must be filled. Based on sustainable development indicators, the impacts of a deep open-pit copper mining project were identified and categorized into three groups in the current study. Using the fuzzy-AHP technique, each impact category was statistically rated. The dynamic weights were then calculated and normalized using the research-defined temporospatial scales. Certain impacts, such as land stability and climate (static weight: 6.8%, dynamic weight: 10.46%), fly rock (static weight:11.51%, dynamic weight:7.86%), income and profit (static weight:35.61%, dynamic weight:45.26%), workplace safety (static weight:13.81%, dynamic weight:8.57%), and revenue generation (static weight:10.74%, dynamic weight:14.99%), exhibited a significant difference between static and dynamic values. This difference demonstrates the significance of considering the spatial and temporal scale of the impacts when conducting a sustainability assessment for a mining project.

Keywords: *Temporospatial Scale, Dynamic Sustainability Assessment, Fuzzy-AHP, Open-Pit Copper Mines*

INTRODUCTION

The demand for copper has expanded significantly in recent years due to population growth, economic development, and the switch of the power industry to renewable energy. Copper is a critical component in renewable energy generation and storage systems because of its high conductivity and thermal storage capacity (Zhou et al., 2019). The total cumulative demand for copper posed by technologies up to 2040 is estimated to be 29 million tons (Figure 1). As a result, despite current recycling initiatives, the amount of minerals and metals available from secondary sources will not be sufficient to meet the increasing demand for copper (Fuentes, Negrete, Herrera-León, & Kraslawski, 2021). This means that primary copper production will continue to play an important role in the coming years (Seck, Hache, Bonnet, Simoën, & Carcanague, 2020).

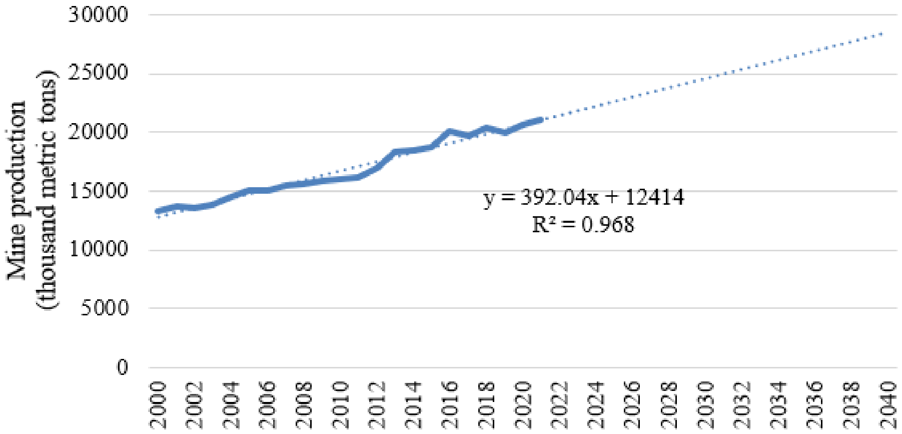

Figure 1. World Copper Production 2000-2022 (thousand metric tons) and estimation for 2040

Increased copper production has additional environmental consequences, necessitating an appropriate assessment of the environmental sustainability of copper mining. Sustainable development and sustainability are difficult concepts to grasp because of their economic, social, and environmental implications (Teodosiu, Hospido, & Fiore, 2022), and a variety of EIA models and indicators. So far, there is no general model available to users that considers all potential impacts. The majority of available models or techniques are case-based, taking into account a limited number of factors and ignoring the temporospatial scale of the factors. This is due to a large number of potential impacts of a mining project, as well as the large temporospatial scale of a mining operation, which makes EIA modeling difficult.

This study aims to classify the potential impact categories in deep open-pit copper mines into three groups environmental, economic, and social impact categories. In the methodology section, the new dynamic sustainability score calculation procedure is explained in detail. Then, after applying the temporospatial scale of the categories, the results are highlighted and discussed. Finally, the research conclusions are raised briefly. After all, this study intends to answer the following questions:

Question 1: How can we apply a temporospatial scale to MSA?

Question 2: Is it worth determining a dynamic sustainability assessment rather than a static one?

METHODOLOGY

Figure 2 demonstrates the method of the current study. According to this flowchart, the first step is to identify the potential impacting factors in a deep mining project and categorize them into major impacting categories. Next, these impacts are classified into three main groups representing sustainable development indicators: Environmental, Economic, and Social in the path toward sustainable mining. Then the temporal and spatial scale of each impact is recognized and, finally, the dynamic weight of each impacting category ($(S_d^i)_N$) is determined.

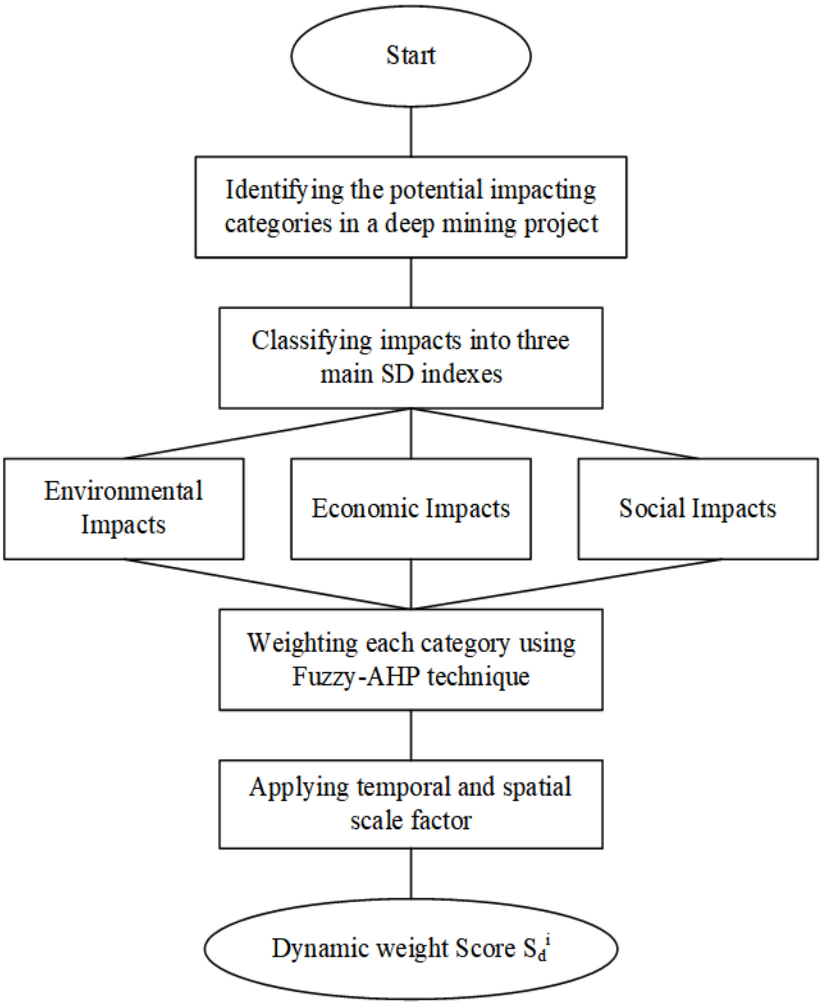

Figure 2. schematic flowchart of the methodology

While calculating a mining project's sustainability score, each category must be assigned a weight. Numerous weighting methods exist and must be selected based on the nature of the factors and the needs of the researchers. A mining project's influencing factors are qualitative and quantitative. Therefore, semi-qualitative methods are chosen for category weighting. In mining studies, fuzzy AHP is the most popular method for weighing distinct groups of factors (Amirshenava & Osanloo, 2019; Aryafar, Yousefi, & Doulati Ardejani, 2012; Banda, 2019; Shen, Muduli, & Barve, 2015; Soltanmohammadi, Osanloo, & Aghajani, 2008; Wu, Zhao, & Li, 2022).

The steps of the Chang (1996) fuzzy-AHP method are used for weighting the impact categories for each SD indicator (Due to the familiarity of the methodology, the formulation is not presented in this study).

The weights calculated by fuzzy-AHP are statically calculated. Toward defining the scores dynamically, the temporal and spatial scales are applied to each category's score (S_d) (Equation 1).

$$S_d^i = f_T \times f_S \times S_s^i \qquad (1)$$

where

S_d^i is the dynamic weight of the i^th^ category,

f_T is the temporal factor,

f_S is the spatial factor, and

S_s^i is the static score of the i^th^ category.

The dynamic weights should be normalized to be comparable with static weights (equation 2).

$$(S_d^i)_N = \frac{S_d^i}{\sum_{i=1}^{n} S_d^i} \qquad (2)$$

where

$(S_d^i)_N$ is the normalized dynamic weight of category i.

The Temporal and spatial factors defined in this research are according to tables 1 and 2, respectively.

Table 1. The spatial scale defined in this research.

Temporal scale	definition	score
Short-term	The impacts will be effective during the project and vanish after mine closure	1
Medium-term	The impacts will be effective for a medium period after the mine closure	1.2
Long-term	The impacts will be effective long after the mine closure	1.5

Table 2. The spatial scale defined in this research.

Spatial scale	definition	score
Local	The impacts will be effective for the local community	1
Regional	The impacts will be effective for the regional community	1.2
Global	The impacts will be effective for the global community	1.5

RESULTS

After reviewing the literature and surveying the world's deep open-pit copper mining projects, the potential impacting categories of a deep open-pit mine are recognized and classified into three sustainable development indicators' groups: environmental, economic, and social.

Figure 3 demonstrates the environmental impact categories recognized in a deep open-pit copper mine. As shown, 14 environmental impact categories are defined.

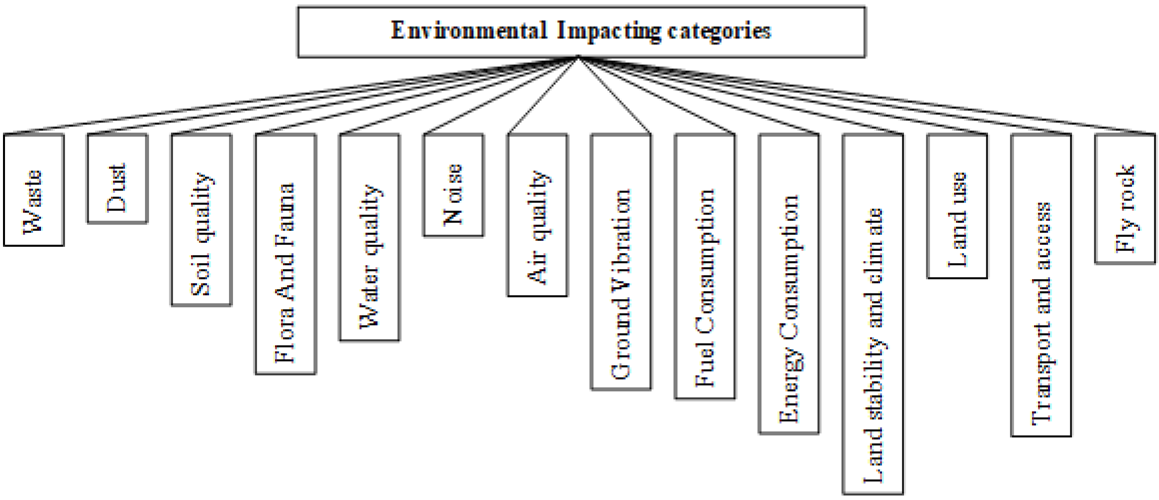

Figure 3. Environmental impacting categories in a deep open-pit copper mine

Table 3. Defining environmental impacting categories temporospatial scales

Impact category	Temporal scale	Spatial scale
Waste	Long-term	Local
Dust	Medium-term	Local
Soil quality	Long-term	Local
Flora And Fauna	Long-term	Global
Water quality	Long-term	Regional
Noise	Short-term	Local
Air quality	Medium-term	Regional
Ground Vibration	Short-term	Local
Fuel Consumption	Short-term	Global
Energy Consumption	Short-term	Global
Land stability and climate	Long-term	Global
Land use	Long-term	Local
Transport and access	Long-term	Regional
Fly rock	Short-term	Local

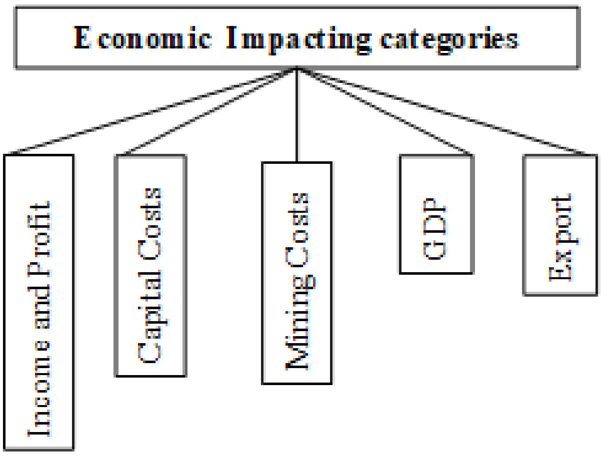

Figure 4. Economic impacting categories in a deep open-pit copper mine

Table 4. Defining economic impacting categories temporospatial scales

Impact category	Temporal scale	Spatial scale
Income and Profit	Long-term	Regional
Capital Costs	Short-term	Local
Mining Costs	Short-term	Local
GDP	Medium-term	Regional
Export	Medium-term	Global

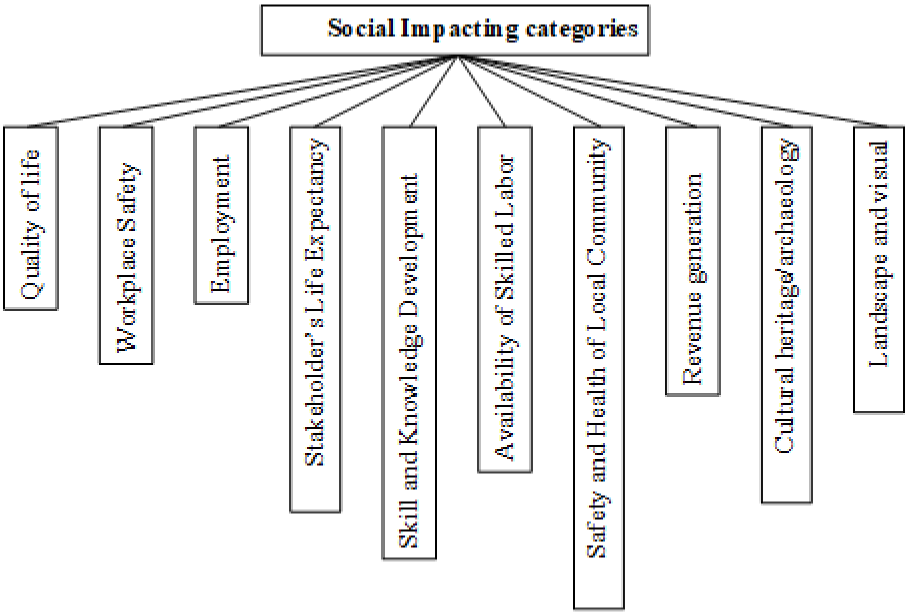

Figure 5. Social impacting categories in a deep open-pit copper mine

Table 5. Defining social impacting categories temporospatial scales

Impact category	Temporal scale	Spatial scale
Quality of life	Long-term	Local
Workplace Safety	Short-term	Local
Employment	Long-term	Regional
Stakeholder’s Life Expectancy	Long-term	Regional
Skill and Knowledge Development	Long-term	Regional
Availability of Skilled Labor	Long-term	Regional
Safety and Health of Local Community	Long-term	Local
Revenue generation	Long-term	Global
Cultural heritage/archaeology	Long-term	Regional
Landscape and visual	Long-term	Local

A questionnaire was distributed to experts worldwide to assess the importance of each impacting category using a pair-wise comparison, and 14 questionnaires were returned. The impact categories are then weighted using the fuzzy AHP technique. The outcome is shown in table 3, column 3: static weight. The dynamic weight of each impacting factor category is calculated by considering the temporal and spatial scale factors. The normalized dynamic weight of each category is shown in column 4 of table 3.

Table 3. The weights of each impact category

1	2	3	4
SD indicator	Impact Categories	Static weight (%)	Dynamic weight (%)
Environmental	Waste	8.5	8.71
	Dust	5.21	4.27
	Soil quality	5.3	5.43
	Flora And Fauna	5.78	8.89
	Water quality	7.22	8.88
	Noise	5.34	3.65
	Air quality	5.85	5.76
	Ground Vibration	6.76	4.62
	Fuel Consumption	7.69	7.88
	Energy Consumption	8.47	8.68
	Land stability and climate	6.8	10.46
	Land use	5.53	5.67
	Transport and access	7.51	9.24
	Fly rock	11.51	7.86
Economic	Income and Profit	35.61	45.26
	Capital Costs	19.7	13.91
	Mining Costs	16.9	11.93
	GDP	15.06	15.31
	Export	10.69	13.59
Social	Quality of life	10.5	9.77
	Workplace Safety	13.81	8.57
	Employment	10.95	12.23
	Stakeholder’s Life Expectancy	9.47	10.57
	Skill and Knowledge Development	8.6	9.60
	Availability of Skilled Labor	7.35	8.21
	Safety and Health of Local Community	10.81	10.06
	Revenue generation	10.74	14.99
	Cultural heritage/archaeology	7.35	8.21
	Landscape and visual	8.38	7.80

DISCUSSION

After applying the temporal and spatial coefficient factors into account, the dynamic weight of each impacting factor category was determined according to table 3. The results showed that the dynamic weights have a significant difference compared to static weights for some of the impact categories (figures 6-8).

Figure 5 clearly shows that dust, noise, air quality, ground vibration, and fly rock have a lower dynamic value than static weights. This is because these are short-term, local impacts, and their dynamic weights are reduced after normalization, whereas for land stability and climate, the dynamic weight is much higher than the static weight, because this impact is directly related to the global warming effect of mining activities, which is a long-term global impact.

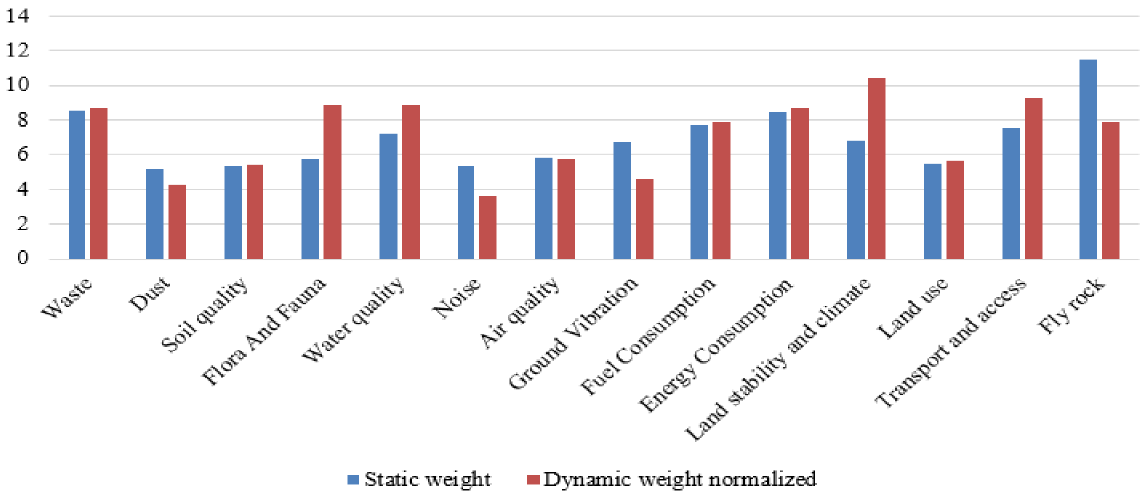

Figure 6. Static and Dynamic weights of environmental impact categories

Figure 6 shows that the dynamic weights of capital costs and mining costs are lower than the static weights, whereas the importance values of income and profit, and export are higher after temporospatial scale consideration. This result can be analyzed in light of the fact that the costs are short-term and have local effects that will disappear once the mine is closed. However, the positive effects of a mining project's income and profit are long-term and have an impact on the global community.

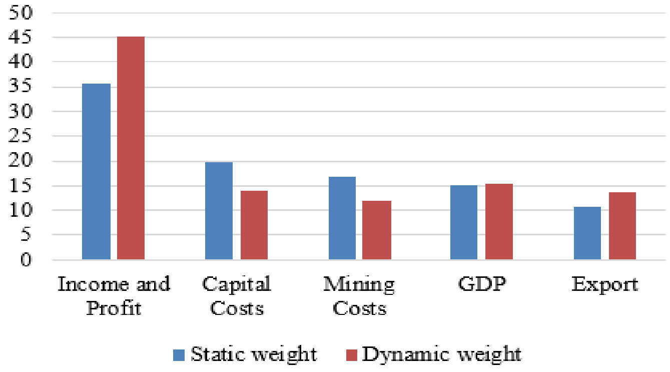

Figure 7 Static and Dynamic weights of economic impact categories

Without taking into account the temporospatial scales, Figure 7 shows that the most important factor category has been workplace safety. Workplace safety has a much lower dynamic weight than static weight, whereas revenue generation has the opposite value (dynamic value much higher than static). This demonstrates the importance of considering temporospatial scales when assessing social impact.

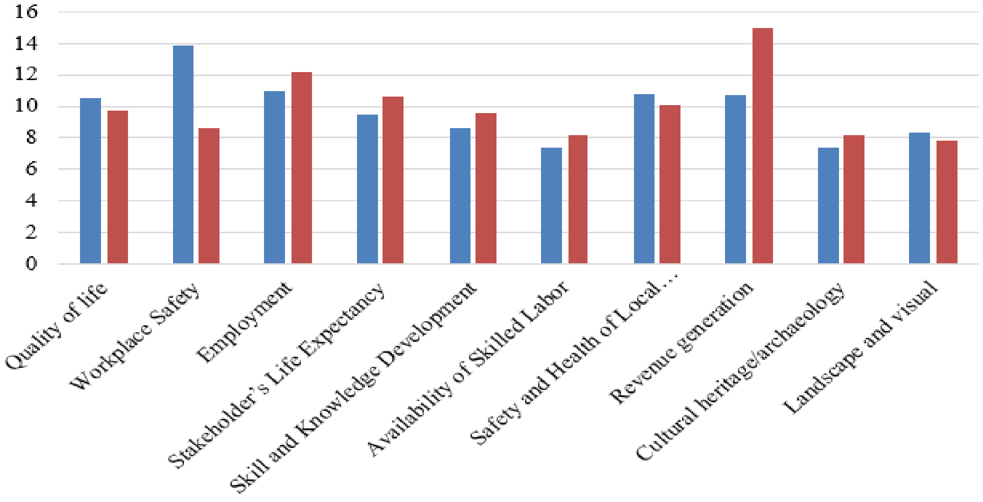

Figure 8. Static and Dynamic weights of social impact categories

To sum up, the results of the study show a considerable difference between static and dynamic weights of the impact categories. This difference indicates the importance of considering the temporospatial scale when assessing the impacts of a mining project. It implies that the dynamic weights reflect the importance of the long-term and global scale impacts more accurately. The dynamic weights guide the decision makers of the mining project for their corrective actions, showing them which negative impacts are more critical to be controlled and which positive impacts are more influential to be enhanced.

CONCLUSION

With the depletion of high-grade, surface, and near-surface ore reserves, mine planners are forced to mine deeper and low-grade ore bodies. Furthermore, as environmental awareness grows around the world, the sustainability assessment of mining operations is becoming an essential part of the mine planning stage. According to a review of the literature, the sustainability assessment methods presented to date are static, and the temporal and spatial (temporospatial) scales of the factors are ignored. However, mining impacts are dynamic, and an accurate sustainability assessment must take into account the temporospatial scale.

In a deep open-pit mining project, the following potential impacting factor categories are identified: 14 environmental impact categories, 5 economic impact categories, and 10 social impact categories. The Fuzzy-AHP technique is then used to statically weight these categories. After defining the temporospatial scales, the dynamic weight of each category is calculated.

For some impact categories, such as noise, ground vibration, and fly rock the static weight is greater than the dynamic weight. While for income and profit, climate, and revenue generation, the dynamic weights are greater than static weights. This difference implies that the dynamic weights more accurately reflect the importance of long-term and global scale impacts. The dynamic weights guide mining project decision-makers in their corrective actions, indicating which negative impacts are more critical to control and which positive impacts are more influential to improve.

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