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Integrating Emissions into Supplier Selection Criteria in Mining

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Abstract

In today's environmentally conscious world, sustainable development has become an imperative pursuit, especially in the context of greenhouse gas (GHG) emissions. This has compelled companies to include environmental considerations into their frameworks. This paper investigates the integration of emissions criteria into supplier selection processes using the Analytical Hierarchy Process(AHP) to provide a systematic and justified approach to decision-making. The scope of research is within the mining industry, with a case study on Debswana Diamond Company, one of the largest diamond mining companies in the world. The Suppliers used to analyse this research problem are Hitachi, Komatsu and Caterpillar.

The research looks at identifying the best possible supplier for Debswana using the Analytical Hierarchy Process(AHP) through qualitative and quantitative analysis of the secondary data collected. The findings reveal the complexities of finding a balance between traditional supplier selection criteria like quality and carbon footprint considerations. The AHP models developed in this study provide a structured analysis of carbon footprint analysis against other supplier selection criteria like quality, company size and strength, delivery and capacity in order to provide a suitable recommendation.

Keywords: GHG Emissions; Supplier selection; Sustainability; Multi-criteria decision-making models; Analytical Hierarchy Process; Mining

Introduction

The Sustainable Procurement Task Force in 2006 defined sustainable procurement as "a process whereby organisations meet their needs for goods, services, works and utilities in a way that achieves value for money on a whole life basis in terms of generating benefits not only to the organisation, but also to society and the economy minimising damage to the environment" [1]. This term may be used interchangeably with sustainable supplier selection. This activity would involve setting clear sustainability goals and criteria, engaging with suppliers to encourage sustainability practices, conducting lifecycle assessments, and monitoring and reporting sustainability performance against set objectives.

Brundtland [2] defined sustainability as "meeting the present needs without compromising the ability of future generations to meet their own needs". With a growing emphasis on integrating sustainable practices throughout supply chains, the sustainability landscape has undergone substantial changes. Identifying sustainable suppliers has become paramount in sectors such as mining, where environmental and social impacts are significant. The scope for the corporate social responsibility of the company has been expanded over the years, and many departments have adjusted to achieve these goals, which consequently mitigate risks, especially those associated with environmental degradation.

The mining sector is a multifaceted and high-value sector that hinges upon a reliable and efficient supply chain infrastructure. Suppliers play a vital role within this framework, contributing essential functions such as providing machinery, maintenance services and cutting-edge technology to optimise supply chains. This paper endeavours to present a comprehensive overview of the current supplier selection criteria in mining while proposing strategies for integrating carbon footprint or emissions considerations into the criteria. This is achieved through the aims and objectives as well as a narrowed down methodology to put focus on the case study, Debswana.

This research is focused on the development of Debswana Diamond Company's supplier selection criteria development. Considering global movements towards more sustainable practices within production and supply chains, it is becoming

more imperative that companies adopt sustainable methods. Debswana Diamond Company, situated in Botswana, stands out as one of the largest diamond producers worldwide in terms of value and volume. According to the company's annual report, they recovered 24.1 million carats [3]. Botswana also signed an agreement at the Paris Agreement in 2015, which had a domino effect on the pledge for local companies to put plans in place to aid the country in honouring its agreement. The Paris Agreement 2015 is an agreement between many countries worldwide to work together to reduce emissions to achieve carbon neutrality by 2030 [4]. Given Debswana's significant economic influence in Botswana, there is heightened pressure for the company to contribute meaningfully to the country's commitment to carbon neutrality by 2030.

To achieve operational efficiency, it is imperative for a company to establish a reliable supply chain. Therefore, this paper endeavours to develop a methodological approach that not only takes into account factors like cost but also ensures strategic decision-making. Moreover, through extensive research, this research identifies the existing deficiencies in metrics and frameworks mining companies can adopt to incorporate carbon footprint into their supplier selection process and procedure.

Traditional supplier selection methods and criteria often disregard sustainability in favour of costs and quality. According to Van Hock and Erasmus [5], Rao and Holt [6], and Carvalho et al. [7], Green supply chain management is a crucial organisational philosophy that aids in fostering productivity and collaboration among partners. This has been evident in the continuous pressure for companies to uphold more holistic approaches that account for environmental, social, and governance (ESG) factors when making decisions.

Additionally, the intricate environments that mining companies operate in result in consequences of their activities beyond financial matters. Preserving the environment, involving communities and ensuring ethical sourcing have emerged as crucial elements of sustainable mining practices. Despite the recognition of these aspects, many mining companies struggle with incorporating sustainability, more especially environmental metrics into supplier selection frameworks.

Research Rationale

The research's rationale is achieved using a mathematically justified strategic decision-making tool called the Analytic Hierarchy Process [8]. The validity of the model is critically evaluated. Subsequently, a conclusion is drawn based on the findings and accompanied by suitable recommendations. However, due to the lack of existing metrics and information available for the company's suppliers to measure scope three emissions, it may take time and resources to fully implement recommendations.

Problem statement

Many companies worldwide are looking to invest and incorporate more sustainable practices in procurement. This has been evident in the forums and conferences held all over the globe to discuss sustainability issues in supply chains. Countries worldwide have signed a pledge with the United Nations to achieve carbon zero in 2030 at the Paris Agreement in 2015. Botswana is a member of COP28, which means it has an obligation to achieve or provide substantial evidence of its efforts to achieve Carbon Zero 2030 goals. Therefore, as Debswana is one of the major contributors to the country's economy, it is imperative that they lead by example. Furthermore, the lack of extensive research on this topic from a mining perspective motivated this thesis. Debswana currently lacks a metrics and framework that incorporates sustainability but has an obligation to include this factor; therefore, this research aids in incorporating one of the ESG attributes, CO_2e emissions, and positions them as a benchmark for other mining companies in the country and around the world.

Aims and Objectives

This paper aims to bridge the gap by analysing the current metrics and supplier selection frameworks utilised by Debswana by identifying the best possible supplier in mining according to a set of selection criteria that includes carbon footprint using a suitable tool. Through conducting a critical analysis of the existing practices, this research would endeavour to pinpoint areas for improvement and opportunities to incorporate carbon footprint factors in their metrics effectively. Utilising the Analytic Hierarchy Process (AHP) and other strategic tools, the study seeks to develop a refined supplier selection framework that would prioritise sustainability criteria alongside traditional metrics. The case study company (Debswana) currently has three main global machinery and equipment suppliers: Komatsu, Hitachi and Caterpillar, which are used in this paper for analysis.

The objectives set out to achieve the aim are:

i. To critically analyse the literature on the current commonly used selection criteria for suppliers in mining

ii. To develop a framework and selection criteria for the selection of machinery and equipment suppliers using a strategic decision-making method that incorporates emissions

iii. To evaluate the feasibility of implementing a strategic decision-making method when selecting suppliers in mining

Paper Outline

The paper's subsequent sections comprise an extensive literature review, aimed at synthesising various themes for in-depth discussion and facilitating a comprehensive comprehension of the subject matter. Additionally, a methodology is presented, showing a systematic analysis of the suppliers

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under consideration. Next, the findings present the results of the methodology implementation, which serve as a basis for offering suitable recommendations.

Literature Review

Technical supplier criteria

The current technical supplier criteria used at Debswana is as follows:

a. Technical Ability(Company and project team) - 25%

b. Technical Approach (Proposed method or strategy) - 30%

c. Technical Capacity - 25%

d. Tendered programme and delivery schedule - 10%

e. SHE program - 10%

Their current criteria does not account for any sustainability criteria; however, recent developments in their procurement policy have called for a need to evaluate carbon footprint in their criteria. The new policy signed in 2023 shows that they must comply with responsible sourcing as well as carbon neutrality. It states that Debswana's business partners must embed and support responsible sourcing within their organisations [3]. This policy also required Debswana to include this factor in their evaluation matrix. In regard to carbon neutrality, as the company endeavours to support the 2030 Carbon neutrality goal, they are commiting themselves to sourcing low carbon footprint goods and services [3]. This requires the supply chain team to reevaluate the criteria for integrating sustainability in the matrix and show a reflective weighting of importance.

Sustainable Supplier Selection Criteria

Supplier selection involves multiple factors put into consideration to select the most suitable candidate/company [9-14]. In the past few years, companies have been exploring methods to concurrently enhance the sustainability of their processes, including social, environmental and economic factors. Conventional supplier selection methods have included factors like price, delivery time and quality in most cases. However, according to extensive research done between 1991 and 2011, Igarashi et al. [15] published papers on incorporating environmental factors in selecting of sustainable suppliers, which led to some firms adopting these factors into their supplier selection criteria. Some researchers defined sustainability with three pillars being environmental, economic and social [16].

Over the years, conventional supplier selection criteria have been critical to companies, especially to maximise profit, as they enabled companies to evaluate supplier performance. However, studies have shown that in order to remain competitive, it is imperative that they incorporate more sustainable methods in their supplier selection and evaluation criteria. According to Green, Morton, and New [17], incorporating environmental evaluation criteria would lead to selecting more compliant suppliers. Finding a balance where all three pillars are incorporated in the selection of suppliers is considered sustainable. Studies have also shown that critical decisions regarding the review of metrics, frameworks and evaluation of the social responsibility of companies can improve the sustainability of supply chains [18]. Although research exists on this topic, there is a lack of extensive research within the context of the mining industry. Currently, Debswana is looking into using the responsible sourcing standard by Anglo American as a benchmark due to the lack of extensive research on implementing sustainable procurement in mining. Furthermore, this research aims to act as a guide not just for Debswana but also for other mining companies that are looking into implementing green sourcing. Inadequate documentation regarding the application of supplier selection criteria within the mining industry could result in the sector falling behind, potentially exacerbating its role as a significant contributor to global warming over time.

Diamond exploration/mining often requires the utilisation of two energy sources, namely electricity and hydrocarbons (e.g. oil, diesel, petrol, etc). The by-product of these forms of energy is carbon dioxide, which is considered a major contributor to global warming and climate change [19]. Due to this fact, Debswana has gone further to develop a strategy they called 'Building Forever', which incorporates all aspects of environmental, social and governance (ESG).

The company's commitment to the industry underscores the importance of investigating the adoption of sustainable supplier selection criteria. As a way of making strides towards achieving sustainability standards Debswana has also made efforts to measure their CO2 emissions however these measurements have not yet included scope three emissions. This is a challenge for the company due to a lack of awareness or knowledge in the community regarding factors like metrics used to measure CO2 emissions and ensuring supplier engagements and commitments. The CO2 emissions of the past few years are illustrated in Figure 1; this information could also help them identify suppliers that offer machinery that uses alternative fuel sources, e.g. bio-oil instead of diesel. It shows that 2020 was their least recorded emissions year and 2021 being the highest in the 4 years analysed in regard to the total Debswana emissions recorded.

Integration Of Strategic Multi-Criteria Decision Making Models (MCDM) In Sustainable Supplier Selection

Extensive strategic multi-criteria models have been proposed by various researchers to select and evaluate suppliers. Some of these include but are not limited to analytic network process (ANP), data envelopment analysis (DEA), analytic hierarchy process (AHP), cost-benefit analysis (CBA) and Multi-criteria analysis (MCA). This research paper narrowed down the tools of focus to AHP, MCA and CBA in order to provide a clear and concise scope to address the research problem.

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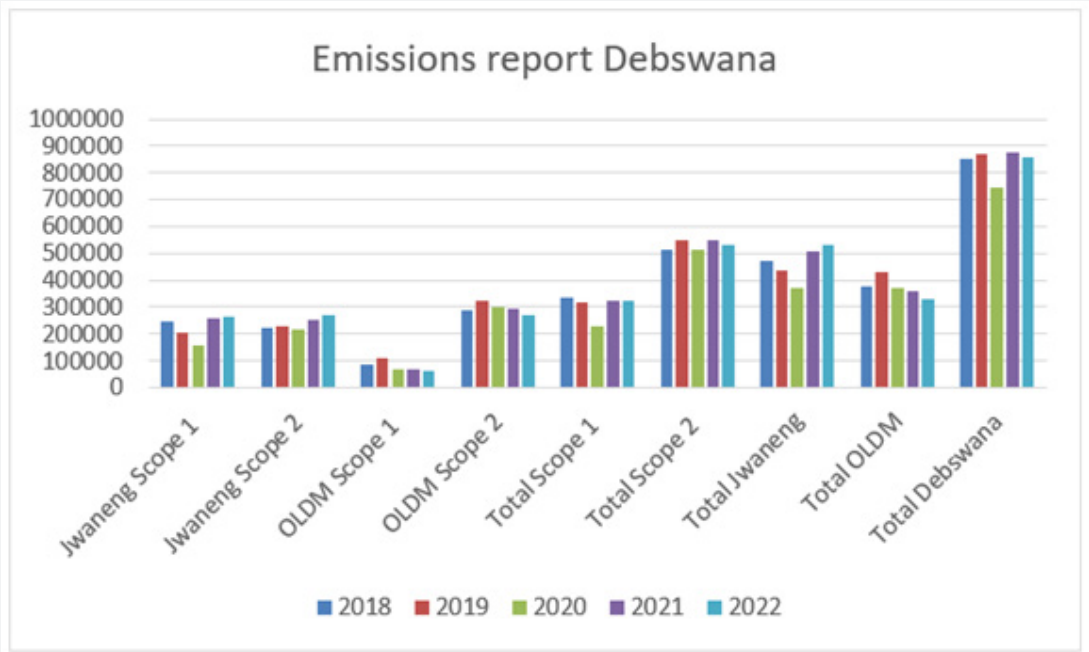

Figure 1: Total Co2 emissions for debswana operations (Tco2 Eqv) (Debswana, 2022).

Harvard Business School, in the Business Insights blog [20], defined CBA as comparing the estimated or projected costs and benefits associated with a project to analyse whether it makes sense from a business perspective. With this approach, the benefits and costs of a supplier are identified and monetised to evaluate and justify the decision. To provide a weighting to illustrate the analysis, a cost-benefit ratio (CBR) is expressed. There is a spectrum between poor and very high value for money categories. Poor having less than 1.0 benefit-cost ratio, low being between 1.0 and 1.5, medium being between 1.5 and 2.0, high being between 2.0 and 4.0 and very high being greater than 4.0.

Although this is a good method to justify a decision, this tool also has disadvantages. For example, due to ambiguity and inaccuracies in assigning monetary value to intangible items, this may lead to biased results [21]. This researcher went on to identify other disadvantages like the inaccuracy in calculations for the present value, which may result in skewed analysis, and the CBA ending up as a project budget instead of a tool used to aid in making a decision. This analysis only considers quantitative results, which is often inaccurate.

The second tool analysed in this paper is the Multi Criteria Analysis (MCA). MCA takes into account both the quantitative factors as well as the qualitative ones in comparison to CBA [22]. The major flaw identified regarding CBA is the need to quantify the factors with a common unit. EuropeAid [23] defined MCA purpose as "Multi-criteria analysis breaks down the components of complex situations and structures them, to progressively find a solution transparently".

The third tool analysed in this paper is the Analytical Hierarchy Process (AHP). AHP entails constructing a framework by deconstructing intricate decisions into their constituent parts and assigning numerical values-based assessments of their relative importance. Thereafter, these options are combined to ascertain the most advantageous decision based on mathematical calculations and prioritisation of orders [24]. According to Ho, Xu and Dey [25], seven (8.97%) of 78 journal articles proposed AHP to address supplier selection problems. Furthermore, studies have shown that the effectiveness and reliability of AHP as a decision-making methodology have been consistently substantiated and endorsed across a diverse array of scenarios. Additionally, AHP has proven in different industries where they had different suppliers that the method could be justified; therefore, due to its numerous benefits, it was chosen as the main tool for this case study.

Methodology

Data Collection and Design

The research design for this study is a mixed-method approach, which is a combination of both qualitative and quantitative data. A convergent parallel design was used.

Quantitative Aspect:

i. Analytical Hierarchy Process: Use of AHP to quantitively assess and prioritise sustainability criteria in supplier selection. This involves structuring pairwise comparisons to determine the relative importance of different factors.

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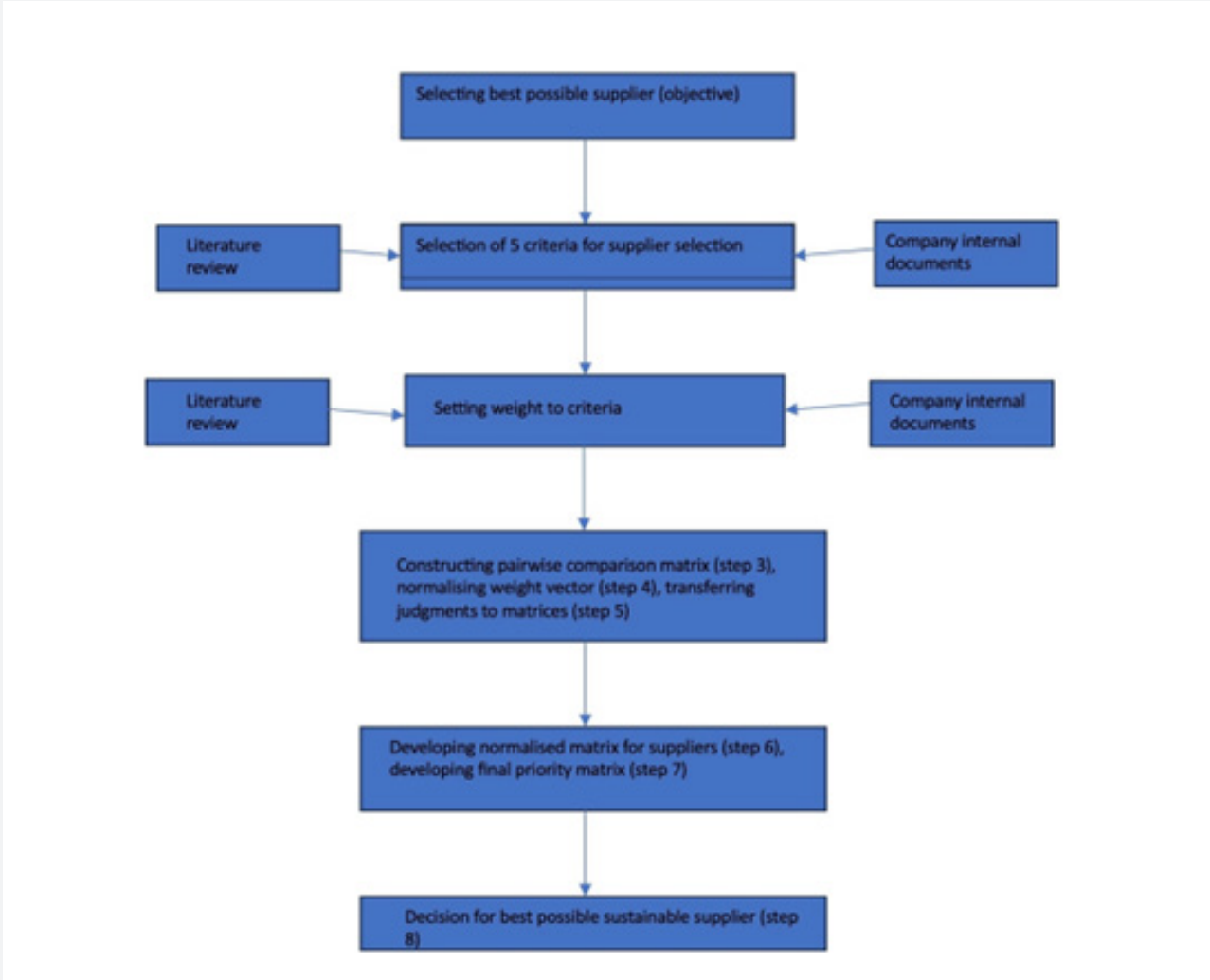

Figure 2: AHP methodology steps.

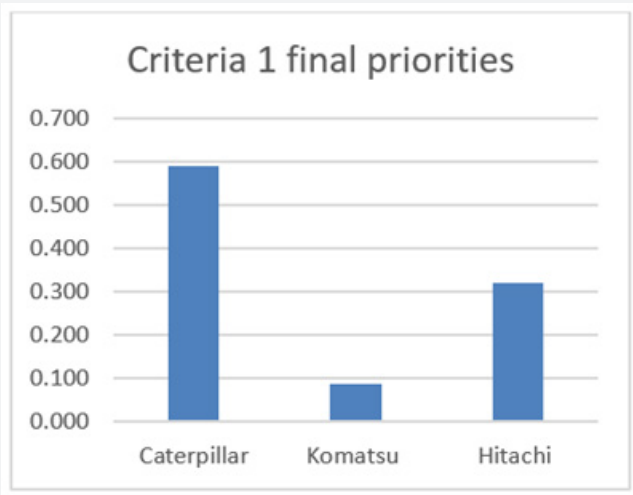

Figure 3: Criteria 1 priority graph.

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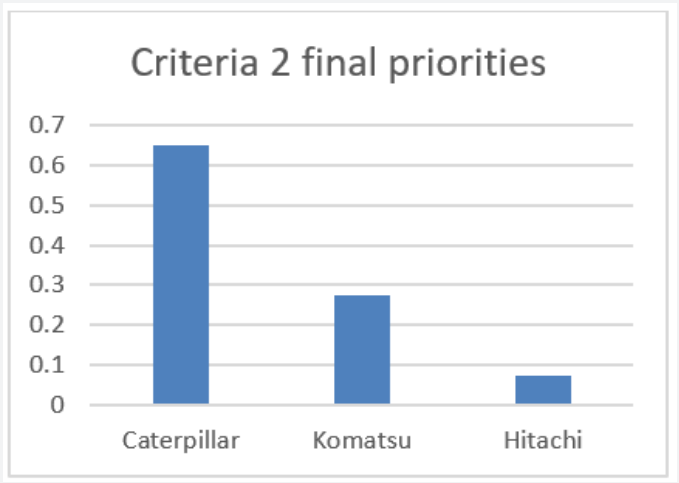

Figure 4: Criteria 2 priorities graph.

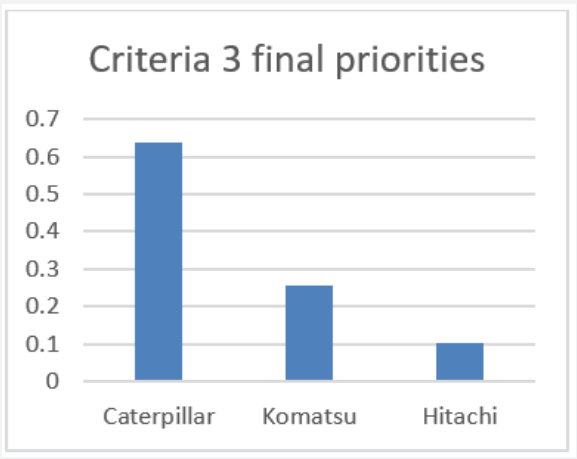

Figure 5: Criteria 3 priorities graph.

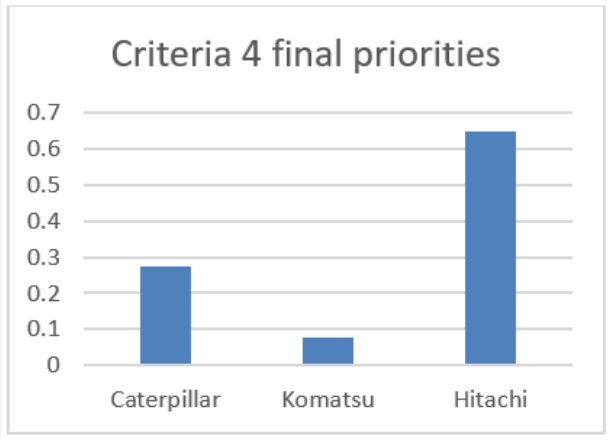

Figure 6: Criteria 4 priorities graph.

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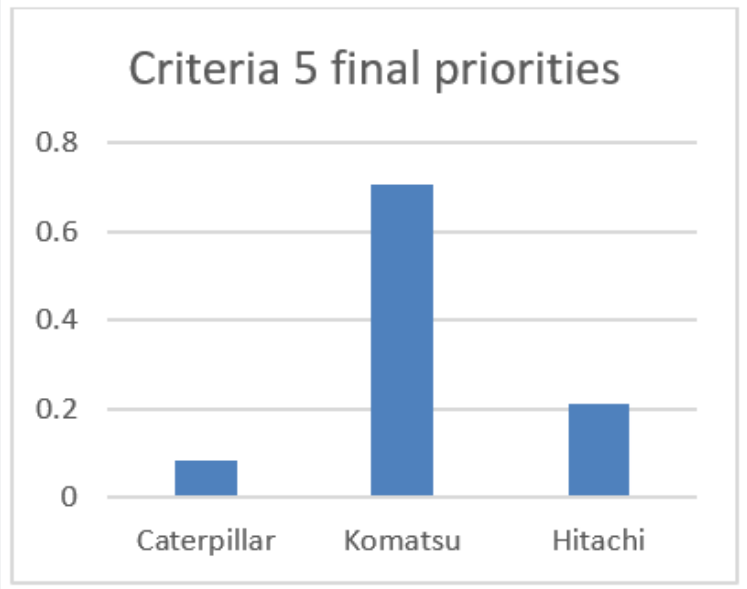

Figure 7: Criteria 5 priorities graph.

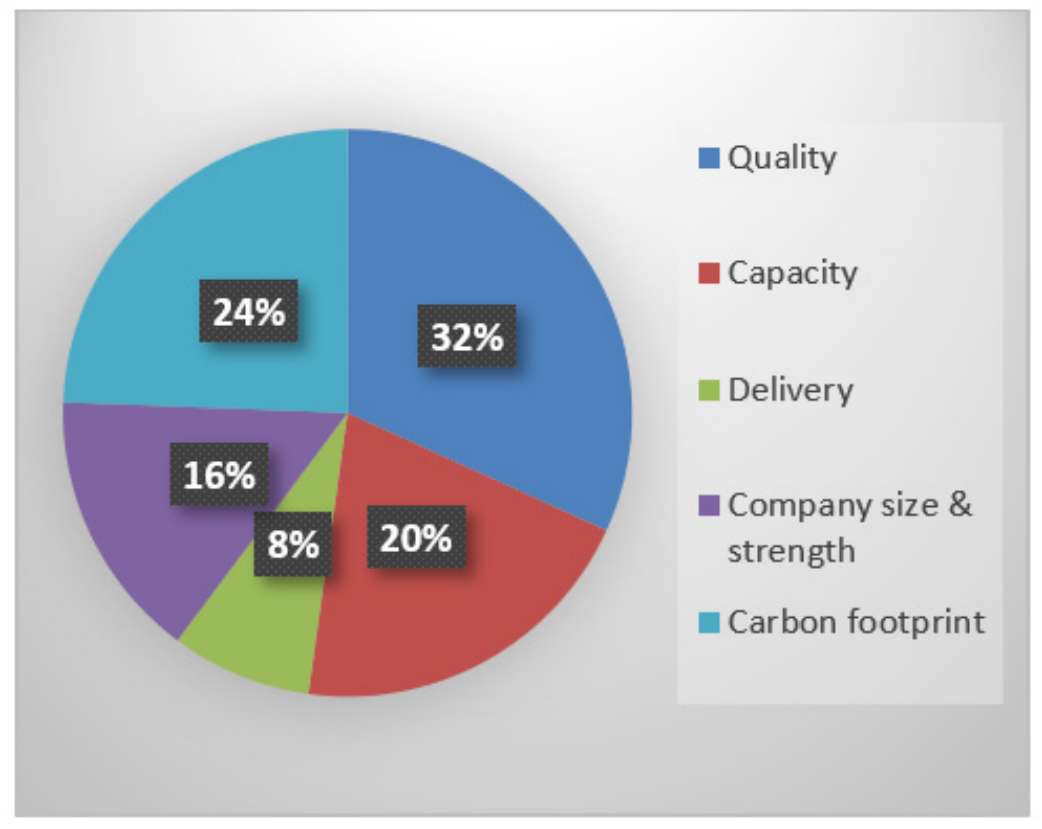

Figure 8: Criteria weights with respect to objectives.

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Qualitative Aspect:

- Document analysis: Analyse company documents such as procurement policies and sustainability reports to understand the current approach to supplier selection and any existing sustainability initiatives.
- Case study
- Literature Review

Data collection involves multiple stages:

i. Literature review: Extensive research was done to review existing literature on sustainability in supply chains, supplier selection criteria in mining, AHP methodology and other strategic decision-making tools (eg MCA etc).

ii. Case study: Debswana Diamond Company is the chosen case study organisation due to its significant contribution to the mining industry as well as its commitment to carbon neutrality. Data is collected by signing a Non-disclosure agreement (NDA) in order to gain access to company documents like procurement policies and supplier technical evaluation criteria.

Strategic decision making tool calculations

AHP outline:

- Defining the problem and desired solution
- Structuring of the hierarchy
- Constructing the pairwise comparison matrices
- Pairwise judgments completed using the fundamental scale
- Transferring the judgements into matrices
- Perform steps c, d and e for all pairwise comparisons
- Use and synthesis method to produce eigenvectors and priorities for each matrix to then calculate final priorities [24] (Figure 2).

The research problem is identifying the best possible supplier in mining according to a set of selection criteria that includes emissions using AHP. The machinery suppliers compared in this case study are Komatsu, Hitachi and Caterpillar, which are the major machinery suppliers for Debswana.

The five supplier selection criteria used for this analysis were derived from the literature review carried out, as well as the company's internal documents, such as the procurement policy and evaluation criteria Debswana currently uses. The criteria selected for this research are quality, capacity, delivery, company size and strength and carbon footprint (CO_2e emissions). For example, some of the company data collected through company reports that aided in the analysis is illustrated, found in the findings section.

Thomas L Saaty [24] developed a 1-9 point scale that would then be used to reflect qualitative information in mathematics. The scale consists of nine levels, each representing a degree of preference or importance assigned to a particular option. The levels are:

- Equal significance (1): This indicates that two factors contribute equally to an objective
- Moderate significance (3): At this level, one option is slightly favoured over another
- Significant importance (5): This level signifies that one option is strongly favoured over another.
- Very significant importance (7): Here, one option is very significantly preferred over the other.
- Utmost importance (9): This level shows a substancial and clear difference in importance of one over another.
- Intermediate values (2, 4, 6, 8): At this level, compromise is required.
- Reciprocal values (1/2, 1/3, ¼ ,1/5, 1/6, 1/7, 1/8, 1/9): These values indicate a reverse preference

Matrices would be formed after using the Likert scale to show the relative importance of each pairwise comparison. In addition to the likert scale and literature review, suppliers named were critically analysed. Some of the data found included the NPS scores. NPS is a Net Promoter Score, a market research metric companies use to measure customer satisfaction and loyalty [26]. Raileanu [26] gave the below defined responses to give the researcher/reader context of the results.

Promoters (9-10): Loyal customers who will most likely recommend the business or product to a new customer.

Passives (7-8): Although satisfied, they may only sometimes stay loyal and switch to another brand if presented with better offers.

Detractors (1-6): Unhappy customers that could spread negative feedback through word of mouth and may affect business reputation.

To conduct a thorough comparison of the companies, we took a close look at their NPS scores obtained from Comparably (n.d.) [27]. Caterpillar [28] received a product quality rating of 4 out of 5, while Komatsu received a rating of 3.5 out of 5. When it comes to pricing, Caterpillar outperformed Komatsu with a rating of 4 compared to Komatsu's 3.8. In addition, Caterpillar also received positive feedback for their exceptional customer service by achieving a rating of 4.1 out of 5 whilst Komatsu got 3.8 out of 5.

Furthermore, the NPS scores of Hitachi Vs Komatsu were also taken into account. Hitachi earned a quality rating of 4 out of 5, while Komatsu received a rating of 3.5 out of 5. As for pricing, both companies received a rating of 3.8 out of 5. When it comes to

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customer service, most customers gave both companies a rating of 3.8 out of 5.

A matrix is then formed, as seen in the calculation in Equation 1.

$$A = \left(a_{ij}\right) = \left(\begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix}\right) \quad (1)$$

Equation 1. AHP Matrix Calculation

A is an n x n square matrix where the diagonal elements are the self-comparison of the attributes (criteria). Therefore diagonal elements aij=1 where i=j and i,j=1,2, …., n

Additionally, the off-diagonal corresponding elements are reciprocal.

Calculating the weight vector

The weight vector, the normalized weight eigenvector represents the weight of the criteria calculated in step 2. The combination of the geometric mean method and normalisation technique is used to determine the normalised weight vector of the criteria. The sum of the normalised weight vector must equal to 1.

The normalised weight column vector, denote the importance degree or weight for the i attribute or criteria.

Table 1 & 2 illustrate the calculations done in the Excel sheet submitted alongside this research after the matrix was squared, allowing the reader to fully understand the step.

With the many different criteria, there are other expected or wanted outcomes. For some attributes, for example, cost, the decision maker would want a low-cost supplier, whereas when it comes to quality, they would want a high-quality supplier. To tackle these issues the researcher would normalise the attributes so that they can be measured in empirical form. The normalised matrices would then be developed in a similar method described in step 1 when the matrices were developed.

Another matrix would be developed and suppliers would be compared against each other in order to calculate the final priority matrix. This matrix would determine which supplier would be the best possible supplier according to a set of criteria that incorporates emissions. The priority score matrix is a m x 1-dimensional column matrix that holds the overall score for each alternative.

Ethics and Limitations

A preliminary ethics form was filled out to evaluate the risks associated with the study. A low-risk form and a non-disclosure agreement with Debswana were signed to ensure that their data would only be used in this research and not tarnish the name of the company. The lack of substantial research within the context of mining in terms of sustainable procurement led to this study needing more research and work for comparison and gaps. Due to the economic value and position of Debswana, some documents were inaccessible as they were classified as high profile.

Findings and Discussion

The five supplier selection criteria for this study are Quality, Capacity, Delivery, Company size and strength and Carbon footprint. Supplier company reports were compiled and analysed to aid in the calculation of the matrix and weightings. The Excel sheet containing the calculations illustrated below and company data has been submitted alongside this report. The manufacturer's profiles illustrated in Table 3 were compiled to aid in the decision-making. Thorough research was done to compile the list to ensure accuracy and consistency in the calculations that would follow, aiming to minimise bias in decision-making processes. The first objective of this study was achieved through the literature review conducted. This section seeks to achieve objectives 2 and 3 stated (Table 4).

Quality

Many researchers have defined quality however most of them have different opinions as they had different circumstances. Tuchman [29] defined quality as excellence; conformance to specifications Shewhart [30]; Levitt [31], whilst Ryall and Kruithof [32] described it as meeting customer expectations. Quality pairwise comparison was formulated using the Likert scale in addition to customer ratings of the three suppliers concerning the quality of machinery. In the Debswana technical evaluation criteria, the company had five different evaluation criteria, the quality of which was linked to their proposed method and strategy (technical approach 2), to form a matrix suitable for the business. The quality criteria include factors like durability and how often machines are in for maintenance. A matrix was then formulated, as seen in Table 5.

The matrix illustrated in Table 5 was then normalised to achieve the normalised weights in order of priority. The calculations are demonstrated in Table 1 and 2. The final normalised weights for Criteria 1 are depicted in Table 6.

The results show that Caterpillar is the most suitable supplier in terms of criteria 1 to quality, whilst Komatsu was the least preferred supplier. A graph was then deduced from the results in Table 6 to illustrate the weightings with respect to criteria one. This is seen in Figure 3.

Capacity

One of Debswana's evaluation criteria incorporated technical capacity, which led to this attribute being one of the criteria. This aspect was used interchangeably with flexibility. To assess this aspect, the company's number of locations was considered. The locations shown are inclusive of sales and manufacturing sites. This would allow Debswana to analyse whether the suppliers in question would be able to fulfil orders for different kinds of machinery and provide maintenance if in-house engineers need support. The pairwise comparison matrix is seen in Table 7.

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Table 1: Weights calculated in Excel.

24	28.5
25	4.292
26	15.567
27	0

Table 2: Normalisation of weights in Excel.

28.5	=A24/A27
4.292	
15.567	
48.359	

Table 3: Companies data Sources: Komatsu, Caterpillar, Hitachi (2023).

Factors	Caterpillar	Komatsu	Hitachi
Market Cap ($Billion)	176.73	183.89	75.79
Employees	113000	76551	322530
Revenue ($ Billion)	67.1	23.4	65.98
Locations	>500	251	52
Scope 1 emissions (kt-CO2e)	740	113	490
Scope 2 emissions (kt-CO2e)	1540	350	1080
Scope 3 emissions (kt-CO2e)	613000	34721	267670

Table 4: Criteria 1 pairwise comparison.

Supplier A	Score	Supplier B	Score	Explanation
Caterpillar	6	Komatsu	1	Strong plus favour Caterpillar. The NPS scored CAT 4/5 while Komatsu scored 3.5/5
Caterpillar	2	Hitachi	1	Weak favour CAT. They both scored 4/5 on NPS however CAT had more promoters than Hitachi
Komatsu	1	Hitachi	4	Moderate plus favour Hitachi. Hitachi scored higher than Komatsu on NPS rating.

Table 5: Criteria 1 Matrix - from Excel spreadsheet calculations.

	Caterpillar	Komatsu	Hitachi
Caterpillar	1	6	2
Komatsu	1/6	1	1/4
Hitachi	1/2	4	1

Table 6: Criteria 1 weights priorities.

	Normalised Sums	Weight
Caterpillar	28.5	0.589
Komatsu	4.292	0.089
Hitachi	15.567	0.322
Total	48.359	1

Table 7: Criteria 2 pairwise comparison matrix.

Supplier A	Score	Supplier B	Score	Explanation
Caterpillar	3	Komatsu	1	Moderate favour CAT. The number of locations CAT has is almost twice the number of locations globally for Komatsu.
Caterpillar	7	Hitachi	1	Very strong favour CAT. The number of locations is almost more than 7 times of Hitachi
Komatsu	5	Hitachi	1	Strong favour Komatsu. Komatsu locations are almost 5 times that of Hitachi.

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Table 8: Criteria 2: Resulting matrix from pairwise comparisons (excel calculations).

	Caterpillar	Komatsu	Hitachi
Caterpillar	1	3	7
Komatsu	1/3	1	5
Hitachi	1/7	1/5	1

Table 9: Criteria 2 Priorities.

	Weights
Caterpillar	0.65
Komatsu	0.276
Hitachi	0.074
Total	1

Table 10: Criteria 3 pairwise comparison.

Supplier A	Score	Supplier B	Score	Explanation
Caterpillar	3	Komatsu	1	Moderate favour CAT. The customer ratings for CAT customer service were 4.1/5 whilst Komatsu 3.8/5. The difference was not very large as they both also had more than 200 locations
Caterpillar	5	Hitachi	1	Strong favour CAT. CAT locations are almost 5 times that of Hitachi and the customer ratings were 4.1/5 for CAT and 3.8/5 for Hitachi
Komatsu	3	Hitachi	1	Moderate favour Komatsu. The customer ratings for Komatsu and Hitachi customer service were both 3.8/5. However, Komatsu has more locations globally than Hitachi

Table 11: Criteria 3 Resulting matrix.

	Caterpillar	Komatsu	Hitachi
Caterpillar	1	3	5
Komatsu	1/3	1	3
Hitachi	1/5	1/3	1

Table 12: Criteria 3 priorities.

	Weights
Caterpillar	0.639
Komatsu	0.257
Hitachi	0.104
Total	1

Table 13: Criteria 4 Pairwise comparison.

Supplier A	Score	Supplier B	Score	Explanation
Caterpillar	3	Komatsu	1	Moderately favour CAT. The employee difference is not too high and however CAT had substantial revenue more than Komatsu
Caterpillar	1	Hitachi	4	Moderate plus favour Hitachi. Hitachi has a relatively higher number of employees than CAT although the revenue difference is not too high.
Komatsu	1	Hitachi	7	Very strong favour Hitachi. The number of employees and revenue is substantially higher for Hitachi than Komatsu.

Table 14: Criteria 4 Resulting matrix.

	Caterpillar	Komatsu	Hitachi
Caterpillar	1	3	1/4
Komatsu	1/3	1	1/7
Hitachi	4	7	1

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Table 15: Criteria 4 Resulting Priorities.

	Weights
Caterpillar	0.275
Komatsu	0.076
Hitachi	0.649
Total	1

Table 16: Criteria 5 pairwise comparison.

Supplier A	Score	Supplier B	Score	Explanation
Caterpillar	1	Komatsu	7	Very strong favour Komatsu. The CO2e emissions in total for scope 1,2 and 3 were significantly lower for Komatsu compared to Caterpillar
Caterpillar	1	Hitachi	3	Moderate favour Hitachi. Scope 1,2 and 3 emissions for Hitachi almost half of CAT emissions.
Komatsu	4	Hitachi	1	Moderate plus favour Komatsu. Komatsu Scope 1,2 and 3 emissions were more than half lower than of Hitachi.

Table 17: Criteria 5 Resulting matrix.

	Caterpillar	Komatsu	Hitachi
Caterpillar	1	1/7	1/3
Komatsu	7	1	4
Hitachi	3	1/4	1

Table 18: Criteria 5 Resulting Priorities.

	Weights
Caterpillar	0.083
Komatsu	0.707
Hitachi	0.21
Total	1

Table 19: Criteria 6 with respect to the objective pairwise comparison.

Criteria	Score	Criteria	Score
Quality	2	Capacity	1
Quality	2	Delivery	1
Quality	3	Company size & strength	1
Quality	2	Carbon footprint	1
Capacity	3	Delivery	1
Capacity	1	Company size & strength	2
Capacity	1	Carbon footprint	3
Delivery	1	Company size & strength	2
Delivery	1	Carbon footprint	3
Company size & strength	1	Carbon footprint	2

Table 20: Resulting pairwise matrix.

	Quality	Capacity	Delivery	Company size & strength	Carbon Footprint
Quality	1	2	2	3	2
Capacity	1/2	1	3	1/2	1/3
Delivery	1/2	1/3	1	1/2	1/3
Company size & strength	1/3	2	2	1	1/2
Carbon footprint	1/2	3	3	2	1

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Table 21: Resulting Priorities.

Normalised sums	Weight	Weight percentage
Quality	0.318	31.80%
Capacity	0.204	20.40%
Delivery	0.08	8.00%
Company size & strength	0.154	15.40%
Carbon footprint	0.244	24.40%

Table 22: Final priorities calculation results from Excel sheet.

Criterion (x)	Criteria Priority	Y(Alternative)	A (priorities of all manufacturers)	B (criteria priority)	C (final priorities) (A x B)
1. Quality	0.318	Caterpillar	0.589	0.318	0.1873
		Komatsu	0.089	0.318	0.0283
		Hitachi	0.322	0.318	0.1024
2.Capacity	0.204	Caterpillar	0.65	0.204	0.1326
		Komatsu	0.276	0.204	0.0563
		Hitachi	0.074	0.204	0.0151
3.Delivery	0.08	Caterpillar	0.639	0.08	0.0511
		Komatsu	0.257	0.08	0.0206
		Hitachi	0.104	0.08	0.0083
4.Company size and strength	0.154	Caterpillar	0.275	0.154	0.0424
		Komatsu	0.076	0.154	0.0117
		Hitachi	0.649	0.154	0.0999
5. Carbon footprint	0.244	Caterpillar	0.083	0.244	0.0203
		Komatsu	0.707	0.244	0.1725
		Hitachi	0.21	0.244	0.0512

Table 23: Final priorities.

Total priorities	Weights
Caterpillar	0.4336
Komatsu	0.2894
Hitachi	0.277
	1

This was then transferred to a matrix, as seen in criteria one, in order to calculate the eigenvectors and final priorities in regard to this criteria. The results in Table 5 illustrate the comparison of capabilities in terms of flexibility or capacity of the suppliers using Saaty's scale to give a consistent analysis. The matrix formulated is illustrated in Table 8.

This matrix was then squared as stated in criteria one to the final synthesised eigenvectors. The weights results are shown in Table 9 and illustrated in a graph in Figure 4 respectively. This denotes that Caterpillar is the better supplier for this criteria selection, and Hitachi is the least preferred supplier.

Delivery

Whether a supplier can deliver on time as well as their proposed turnaround time is crucial to the operation of any business. This is also seen by Debswana requiring a proposed Gannt chart from suppliers to be included as part of the selection process. To analyse this aspect, the company's customer service ratings were considered as this could give Debswana an unbiased overview of the company's service, as sometimes Gantt charts are biased. Some companies manipulate Gantt charts to favour them in the selection process. Additionally, the locations were also considered as if the company does not have sites near the mining

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towns, it may take a substantial amount of time for Debswana to acquire the machinery, especially considering the size of mining equipment and machinery. Companies with sites in or near Botswana would be beneficial as the turnaround time may be shorter, unlike acquiring machinery halfway across the globe. The pairwise comparison is depicted in Table 10, whilst the resulting matrix is shown in Table 11.

Similar steps carried out for criteria 1 and 2 were conducted to derive the resulting priorities. According to the results in Table 12, the most suitable supplier in terms of Delivery would be Caterpillar, followed by Komatsu and Hitachi. A graph was deduced from these results and illustrated in Figure 5.

Company Size and Strength

The company's size and strength may influence its ability to fulfil a project and give context, especially regarding issues such as sustainability. To analyse this aspect, the value of company revenue and employees was taken into account. A high level of confidence in a company is required to validate a project over millions of Botswana Pula, the local currency. This is also seen in the company technical evaluation criteria, which stated the need to denote all company management roles as well as evidence of projects of high magnitude. In most cases, companies that have been in the industry longer and have the paperwork to validate their profits are awarded high-value projects as there is more security that the project will be completed than start-up companies still finding their feet. Table 13 and Table 14 illustrate the pairwise comparison and resulting matrix, respectively.

As seen in previous criteria analysed, the same steps were carried out to achieve the results seen in Table 15, which shows the resulting priorities and, consequently, the graph in Figure 6. The results show that in regard to company size and strength, Hitachi was the best suitable supplier with 0.649, whislt Komatsu was the least suitable at 0.076.

Carbon Footprint

This metric is one of the attributes that most companies do not include in their supplier selection criteria. Furthermore, this is also seen in the Debswana technical evaluation criteria as there is no inclusion of this aspect. Additionally, the analysis would help them fulfil and show commitment to the amendment of the sourcing policy to incorporate emissions goals. To measure criteria 5, scope 1, 2 and 3 emissions were analysed from the 2023 supplier's sustainability reports.

- **Scope 1 emissions:** Includes all direct emissions from activites on site or under the organisations control. For example, onsite air conditioning leaks and fuel combustion [33].
- **Scope 2 emissions:** Indirect emissions by the organisation through the purchase and use of electricity [33].
- **Scope 3 emissions:** Greenhouse gas (GHG) emissions from upstream and downstream value chains [34].

The sustainability reports information is shown in the company data compiled list in Table 3. Additionally, the pairwise comparison and its resulting matrix are shown in Table 16 and Table 17 respectively.

The exact process explained in the methodology and shown in the other criteria analysis was carried out. Thus, the resulting priorities were obtained, as shown in Table 18. The results denote that Komatsu, at 0.707 [35], was the most suitable supplier in the context of carbon footprint, whilst Caterpillar was the least suitable supplier at 0.083. Figure 7 contains a graph to illustrate these results.

Calculating Priorities with Respect to the Objective

To provide an in-depth analysis before combining each individual results obtained, a final pairwise matrix was formulated with respect to the research objective. The exact process described in the methodology was followed; however, in this case, the criteria itself was compared against each other, meaning there were ten pairwise comparisons. This was done because the criteria are not assumed to have equal weighting when selecting a supplier. Furthermore, evidence is seen in the criteria currently used by Debswana as they have different weightings for the other aspects. As it stands, the technical approach-proposed method or strategy has the highest weighting, which is 30%, whereas the technical ability and capacity have equal weightings of 25%. The lowest weighing aspects in the selection are the Tendered programme and delivery schedule, as well as the SHE program, at 10% each. To achieve consistency in this research, the fundamental scale described in the methodology was also used in the pairwise comparison for this analysis. The final pairwise comparison is illustrated in Table 19.

All criteria analysed are essential; however, some may be slightly more important than others, which is why it is essential to calculate the weightings. When looking at the first two pair comparisons, these have similar reasoning. The ability to provide durable machinery and equipment that won't have a lot of breakdowns is slightly more important than the portfolio or availability of required equipment. It can be available but not durable, which is why quality was rated more important than capacity for this research. In the same light, a supplier may be able to deliver an order with a shorter turnaround time; however, the quality may be compromised, and therefore, quality is considered more important than delivery. Company size and strength can help measure whether a supplier can take on a substantial strategic project; however, if the quality is compromised, this could bring safety and health hazards, especially in the mining context.

Furthermore, for that reason, quality was deemed more important than company size and strength. Regarding the quality

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vs carbon footprint, when selecting a supplier, whether they are carbon compliant in today's world is a crucial component to consider; however, it may not be the highest weighing criteria to consider. Over the years, the critical function of the supply chain has been to ensure that the material acquired is of the best or lowest cost without compromising the quality. Although carbon footprint is essential, it is not more important than quality. Similar reasonings were used to justify the ratios attached for the rest of the pairwise comparisons on the table. The resulting pairwise comparison matrix is illustrated in Table 20 [36,37].

The same steps were also carried out for criteria 1-5 in this analysis, resulting in the weightings obtained in Figure 8. The weight percentage results were depicted (Table 21).

Figure 8 shows that from the calculations made for this research, quality would be the most critical criteria to consider with the aim of achieving the objectives stated. This is followed by carbon footprint being the second most critical criteria to consider which many companies overlook. The least critical criteria from this analysis would be Delivery. Even when taking the Debswana technical evaluation criteria into consideration, it was scored at 10%, which was the lowest weight they had alongside the SHE program. The steps described in the methodology for calculating the final priorities are carried out to attain the results shown in Table 22.

The priority of each manufacturer concerning each criteria was multiplied by the priority of the criteria in relation to the objective. The sum of these totals for these manufacturers was then calculated to attain the priorities. Thus, the highest value according to the Analytic Hierarchy Process implemented would be the best suitable supplier according to the set supplier selection criteria that incorporate emissions. The priority results are depicted in Table 23 [38,39].

Analysis and Evaluation of Results

Caterpillar's score of 0.4336 significantly surpassed that of Komatsu, which stood at 0.2894, thus indicating pronounced superiority and advocating it as the best suitable supplier. Of the set five criteria, Caterpillar was dominant in most but not all; of the five, it was the preferred supplier in three aspects. From the first criteria (quality) outcome, Caterpillar obtained 0.589, whilst the second runner-up was Hitachi, which scored 0.322. This was a significant difference of 0.267, which set Caterpillar ahead of its competitors. Additionally, this was highly beneficial as this was also the highest weighing criteria with respect to the objective. In the second criteria (capacity) it was also the most preferred supplier by calculation as it attained 0.65 whilst the second highest was Komatsu this time with a weight of 0.276. The difference was also substantial as it was 0.374, again setting the company far ahead. However, the second most critical criteria, carbon footprint, did not favour Caterpillar. Although it did not perform well in this aspect, it was considered that it had a relatively significant number of locations as compared to its competitors, which could have led to the substantial difference in Co2e emissions reported. According to the results in Table 18, Komatsu was the most suitable supplier as it attained 0.707, whilst the second most preferred supplier was Hitachi, with 0.21.

Furthermore, these results are a fair explanation of Komatsu being the second most suitable supplier as it scored a substantial weighting in this research's second most critical criteria. The difference of 0.497 compared to the second-highest supplier was significant, coupled with its coming second in two out of four of the rest of the criteria. To illustrate these essential differences, graphs were deduced from the results found. The results to illustrate Caterpillar's significant lead in the highest weighing criteria with respect to the objective are shown in Figure 6. Additionally, the results to depict the substantial lead Komatsu had concerning the second most critical criteria to the objective are shown in Figure 7.

According to the prioritisation derived from the AHP analysis, the recommended order for the most suitable supplier for Debswana in this thesis would be as follows (from most suitable to least suitable): Caterpillar in first place, followed by Komatsu in second place and Hitachi in third place. Consequently, using Saaty's Analytic Hierarchy Process method for strategic analysis, Caterpillar emerges as the most suitable mining machinery and equipment supplier for Debswana. On the other hand, Hitachi ranks as the least favoured option based on the analysis.

Conclusions & Recommendations

Conclusion

The AHP model has demonstrated its effectiveness in simplifying a complex strategic decision into manageable pairwise comparisons and subsequently synthesising them into a singular, unambiguous recommendation. In this instance, a substantiated recommendation has been derived incorporating various factors and considerations concerning selecting the most suitable supplier according to a set criterion that incorporates emissions. However, it wouldn't be a just and fair analysis if the weaknesses identified were not discussed.

In the context of this dissertation, it is imperative to acknowledge that while striving for objectivity and factual accuracy, there is an inherent element of subjectivity. This subjectivity stems from the pairwise comparisons primarily relying on one individual's discernment. Although there was adherence to Saaty's fundamental scale, the judgements still have an element of subjectivity. To enhance the robustness and credibility of the model, it is recommended that a sample of individuals engage in pairwise comparisons with the averages obtained and used for priority synthesis. Furthermore, although the intricate decision-making process has been simplified into manageable

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pairwise comparisons, the assessment may be challenging as there are numerous sub-factors, such as cost-effectiveness. This analysis maintains a comprehensive perspective aligned with the company's goals and aims from the company documents.

Recommendations

This study offers insightful information for Debswana and the mining industry regarding restructuring and evaluating the supplier selection criteria, which have neglected the environmental or, rather, emissions aspect. They support the creation of a new framework that could become a benchmark for other mining companies. The suggested weighting for the technical evaluation of Debswana based on the results illustrated in Figure 8 is as follows :

- Technical Approach- Proposed Method or Strategy (Quality)- 32%
- Carbon footprint/emissions (Including SHE program) – 24%
- Technical Capacity – 20%
- Technical Ability (Company size and strength) – 15%
- Tendered programme and Delivery schedule (Delivery) – 8%

Future work

Furthermore, these results open up new investigations and directions for this topic in the mining industry. Most companies would prefer the most cost-effective supplier, disregarding the emissions and, to a greater extent, the environmental aspect; therefore, to implement integrating sustainability as a supplier selection criteria, stakeholders would need to be educated on more initiatives implemented to encourage the monitoring and inclusion of sustainability, not just emissions in procurement. Sensitising Debswana suppliers on carbon footprint data collection would be a stepping stone towards achieving carbon neutrality goals, as most may be unaware of how to record and monitor the data. Future research could also include looking into the 19 ESG attributes altogether to further develop the framework and decarbonisation strategies.

In conclusion, some of the ways Debswana can embed sustainability within the carbon footprint scope in procurement, in addition to the revaluation of the technical evaluation criteria, are as follows:

- Working with the highest GHG emitters
- Assess the carbon literacy and maturity of suppliers
- Provide incentives to encourage suppliers to participate
- Explicitly state the expectations to convince them to sign a pledge and commit to carbon neutrality

Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

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