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Combining artificial neural networks and fuzzy analytic network process for holistic sustainable performance evaluation in the Moroccan mining industry

Farchi Chayma
Hassan First University, Faculty of Sciences and Technologies, Department of Mechanical and Electrical Engineering, Research Laboratory: IMII (Engineering, Industrial Management, and Innovation), 50 Rue Ibnou Lhaytham B.P. 577, Settat 26002, Morocco, c.farchi@uhp.ac.ma (corresponding author)
Touzi Badr
Mohammed V University, Faculty of Legal, Economic and Social Sciences - Souissi, Department of economics and management sciences, Research laboratory: LARCEPEM (interdisciplinary center for research in performance and competitiveness), Avenue des Nations Unies, Agdal, Rabat Maroc B.P:8007.N.U, Morocco, badr.touzi@um5.ac.ma
Farchi Fadwa
Hassan First University, Faculty of Sciences and Technologies, Department of Mechanical and Electrical Engineering, Research Laboratory: IMII (Engineering, Industrial Management, and Innovation), 50 Rue Ibnou Lhaytham B.P. 577, Settat 26002, Morocco, f.farchi@uhp.ac.ma
Mousrij Ahmed
Hassan First University, Faculty of Sciences and Technologies, Department of Mechanical and Electrical Engineering, Research Laboratory: IMII (Engineering, Industrial Management, and Innovation), 50 Rue Ibnou Lhaytham B.P. 577, Settat 26002, Morocco, amousrij@fsts.ac.ma

Keywords: sustainable performance evaluation, Moroccan mining industry, fuzzy analytic network process, artificial neural networks, holistic analysis.
Abstract: This article delves into the evaluation of sustainable performance in the mining industry, employing the Fuzzy Analytic Network Process (FANP) method. It specifically concentrates on examining five pivotal dimensions of sustainable development: economic, social, environmental, operational, and stakeholders. Through the application of the FANP method, a meticulous prioritized ranking is established, not only for these dimensions but also for the specific fields within each of them. This holistic approach provides a comprehensive, well-balanced assessment of sustainable performance, offering a wealth of valuable insights that can guide decision-making processes. Moreover, the method's utility extends beyond the mining sector; it is generalized into a versatile model that can be applied across different industries and research domains. This adaptability is achieved by incorporating a machine learning algorithm, with a primary focus on a multilayer perceptron. This model enables the precise determination of a company's overall multidimensional performance by quantifying various facets of performance, among other considerations. The research presented in this article serves to bridge an existing gap in integrated studies specific to the Moroccan mining industry. It provides actionable insights that can significantly enhance management practices and foster sustainable development, making it a valuable contribution to both the industry and the broader research community.

1 Introduction

The mining industry holds a pivotal role in a country's economic progress; however, it grapples with significant environmental and social issues. In light of this, the evaluation of sustainable performance has become indispensable to ensure responsible and enduring mining practices in Morocco. Despite the growing emphasis on sustainable development within the Moroccan mining sector, there's a noticeable absence of comprehensive studies that simultaneously investigate the five crucial dimensions: economic, environmental, social, operational, and stakeholders [1,2]. This deficiency underscores the necessity for a holistic approach to appraising sustainable performance in this field [3,4].

The current study seeks to bridge this gap by employing the Fuzzy Analytic Network Process (FANP) method to assess the sustainable performance of a company engaged in the Moroccan mining industry. The FANP method allows for the examination of interconnections among various dimensions and quantifies their relative significance, thereby furnishing a more thorough and well-balanced evaluation [5].

Furthermore, this approach is generalized into a versatile model that can be employed across diverse sectors or research areas. This versatility is accomplished through the use of a machine learning algorithm, primarily utilizing a multilayer perceptron. The model empowers the assessment of the company's overall multidimensional performance by quantifying various performance aspects.

This research is substantiated by an up-to-date literature review, which underscores the significance of sustainable development in the mining industry and the imperative for a comprehensive evaluation of sustainable performance. Recent references are cited to highlight the challenges and concerns related to sustainability in the context of mining.

2 Literature review

The mining industry in Morocco is a significant contributor to the country's economy, and it plays a crucial role in various sectors, including mining of minerals, phosphates, and precious metals [6]. Here is an overview of the mining industry in Morocco:

- Phosphate Mining: Morocco is one of the world's largest producers and exporters of phosphate minerals. The country possesses abundant phosphate reserves, which are essential for fertilizers and agricultural production. Phosphate mining is a major source of revenue for Morocco.
- Precious Metals: Morocco also has a rich history of mining precious metals, particularly gold and silver. The country is home to several mining projects focused on these metals, attracting both domestic and international investment.
- Diverse Mineral Resources: In addition to phosphates and precious metals, Morocco is known to have substantial deposits of other minerals, including lead, zinc, copper, and barite. The mining sector's diversification has the potential to boost economic growth.
- Economic Contribution: The mining industry contributes significantly to Morocco's GDP and provides employment opportunities, both directly and indirectly, in various regions. It is a critical sector for the country's economic development.
- Regulation and Investment: The Moroccan government has implemented policies to attract foreign investment in the mining sector. This includes offering incentives to companies willing to invest in exploration and mining projects.
- Environmental and Social Considerations: As with many mining industries worldwide, there are environmental and social challenges that need to be addressed in Morocco. Sustainable and responsible mining practices are gaining importance, as the industry seeks to balance economic development with environmental conservation and social well-being.
- Infrastructure Development: The development of infrastructure, including transportation networks, ports, and energy supply, is essential for the growth of the mining sector in Morocco. These investments facilitate the export of mined products.
- Export Markets: Morocco exports a significant portion of its mining products to international markets, making it a key player in global mineral markets.
- Research and Innovation: The Moroccan mining industry has also seen advancements in research and technology to improve efficiency and reduce the environmental impact of mining operations.

In here, we find a compelling fusion of artificial neural networks (ANN) and fuzzy analytic network process (FANP) methodologies to address the intricate challenges of sustainability in the mining sector. This innovative approach is underpinned by an expanding awareness of sustainable development [7].

These studies illustrate the potential of ANN and FANP as powerful tools for comprehensive sustainability assessment. By amalgamating ANN's data-driven capabilities and FANP's ability to handle complex decision-making processes, researchers have managed to provide a well-rounded framework for evaluating sustainable performance [8].

Crucially, the literature highlights the unique context of the Moroccan mining industry, where environmental, social, and economic dimensions intertwine. This hybrid approach offers precise insights, paving the way for actionable recommendations that can catalyze responsible practices and contribute to the long-term sustainability of the industry. It is evident from these findings that the combination of ANN and FANP methodologies is becoming increasingly indispensable in the mining sector, serving as a promising blueprint for holistic sustainable performance evaluation in Morocco and potentially in other comparable industries [9].

3 Methodology

This paragraph outlines the methodology adopted in this study, which primarily focuses on assessing the overall multidimensional performance of the mining industry. The Fuzzy Analytic Network Process (FANP) was employed in this research. To carry out the FANP analysis, the SuperDecision software was utilized. By employing FANP through the SuperDecision software, we were able to effectively evaluate the multidimensional performance of the mining industry rigorously and comprehensively. Before proceeding to the next step of generalization, an intermediate method was employed to consolidate the obtained results. This method involved the direct application of the minimal condition algorithm. In this transitional phase, the minimal condition algorithm allowed for the evaluation and verification of the dimensional and overall performance of the utilized approach. It served to confirm the relevance of the obtained results before embarking on the generalization process.

Once the validation of performance levels was completed using the minimal condition algorithm, the method was generalized by employing the multilayer perceptron. This choice was motivated by the multilayer perceptron's ability to handle more complex problems and capture non-linear relationships between variables. By incorporating the multilayer perceptron, the applicability of the method was extended to broader domains, enabling more general conclusions to be drawn from the obtained results.

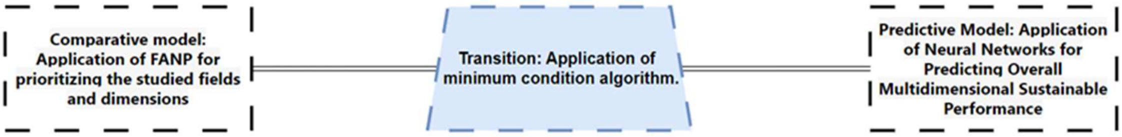

Figure 1 The main phases of the Fuzzy Analytic Network Process

The diagram depicted in Figure 1 provides a detailed representation of the approach followed in this study, starting from the Fuzzy Analytic Network Process (FANP) and extending to machine learning through the minimal condition algorithm. By following this comprehensive approach, from FANP to the minimal condition algorithm and machine learning, the study ensures a rigorous and robust analysis of sustainable performance. The diagram offers a visual representation of the step-by-step methodology adopted, facilitating a clear understanding of the research framework.

3.1 Initiation of the study

This study is mainly based on the application of the Fuzzy Analytic Network Process (FANP) method to the data of one of the largest multinational companies operating in the mining industry in Morocco. The evaluation of the company's performance was conducted using judgments from qualified experts in the field of mining. The experts were selected based on their expertise and in-depth knowledge of the company and the industry. Their judgments were collected and utilized to assess relevant criteria and sub-criteria, thereby quantifying and prioritizing the company's overall performance. This expert judgment-based approach aims to provide an accurate and informed perspective to the evaluation, leveraging the expertise and experience of professionals in the mining sector.

The study is based on the following five dimensions: economic, environmental, social, operational, and stakeholder transparency. These dimensions are considered the main pillars of sustainable development and will serve as the primary evaluation criteria. Each dimension encompasses a set of fields, which in turn will form the sub-criteria for evaluation.

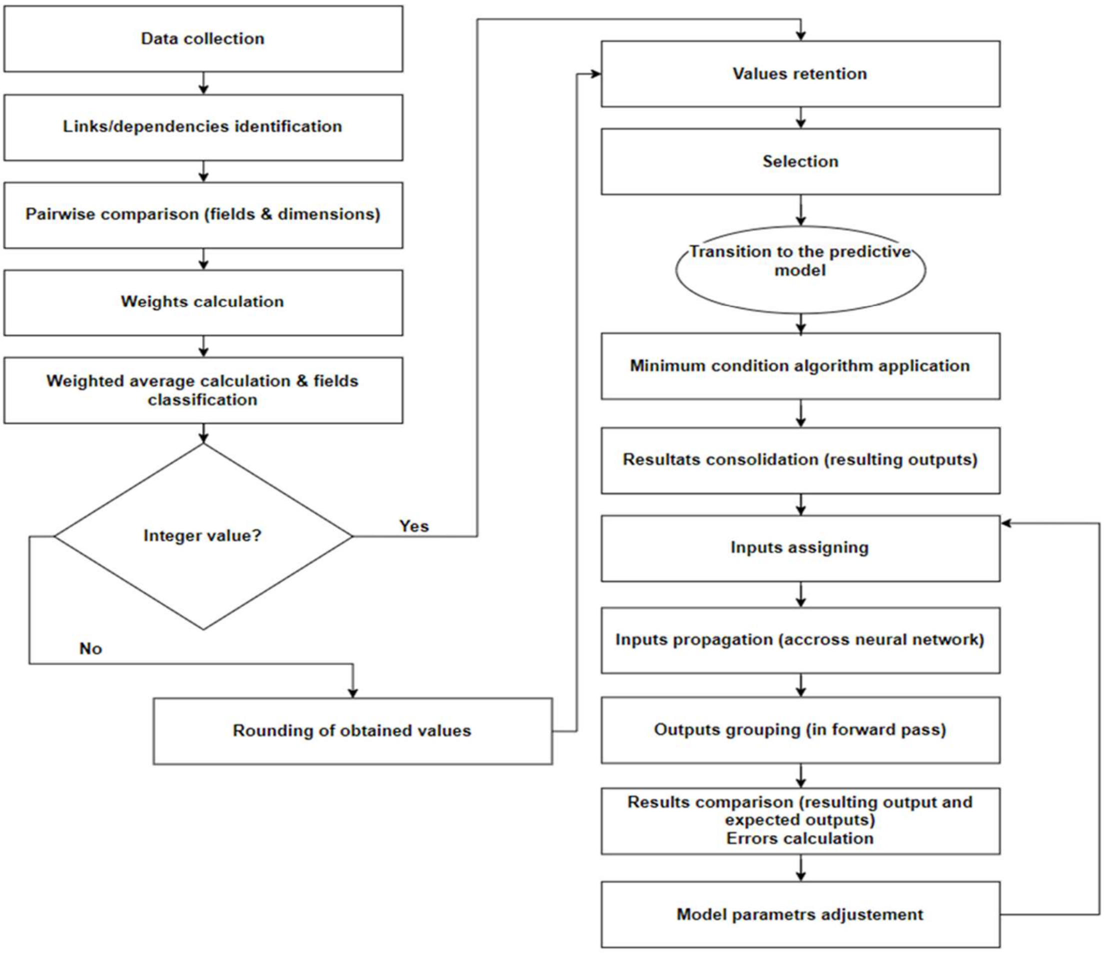

Figure 2 Diagram detailing the followed approach

1- The economic dimension focuses on assessing the mining company's financial performance and economic viability.
2- The environmental dimension aims to evaluate the company's impact on the natural environment and its commitment to sustainable practices.
3- The social dimension examines the company's social responsibility and its contribution to the well-being of local communities and stakeholders.
4- The operational dimension assesses the efficiency and effectiveness of the company's operational processes and practices.
5- The stakeholder transparency dimension focuses on the company's communication and transparency in its interactions with various stakeholders.

Considering these dimensions and their respective fields, a comprehensive evaluation framework is established based on the FANP method, allowing for a holistic assessment of the mining company's sustainable performance. This structured approach ensures that key aspects of sustainable development are adequately addressed and evaluated, providing valuable insights for decision-making and improvement initiatives.

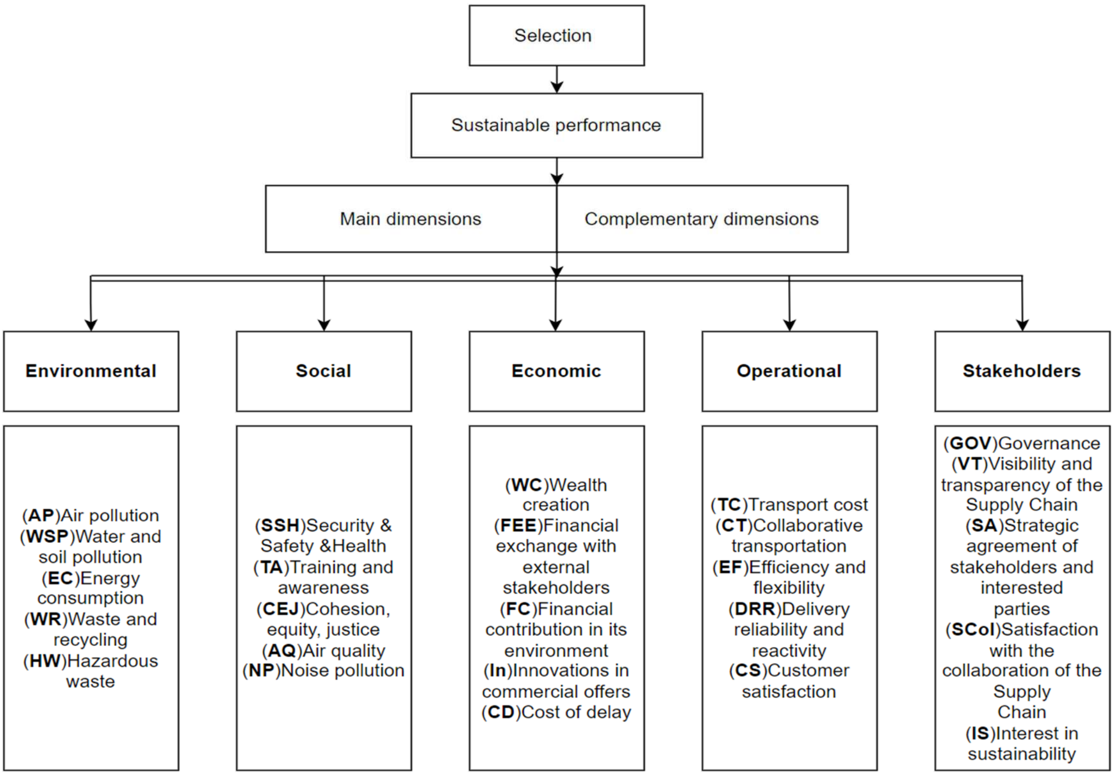

Figure 3 The framework of FANP for sustainable performance assessment

3.2 Means and methods

3.2.1 FANP-based decision-making

The Fuzzy Analytic Network Process (FANP) is a multicriteria decision-making method that effectively addresses complex problems by incorporating both dependency relationships and fuzzy judgments. Introduced by Thomas L. Saaty, 1980 [10], FANP has found widespread application in the fields of operations research and decision science. The FANP methodology revolves around the construction of an analytic network that captures the relationships among criteria, sub-criteria, and alternatives. Pairwise comparisons are conducted to assess the relative weights of network elements [11]. Fuzzy judgments are accommodated using fuzzy logic It connects ANP to fuzzy logic, a valuable technique for dealing with nondeterministic and nonlinear issues. It can represent fuzzy and qualitative knowledge, and so can reason like a human [12], allowing for the modeling of uncertainties and imprecisions within the decision-making process. The FANP method provides quantitative outputs for prioritizing criteria, evaluating performance, and making informed decisions.

3.2.2 Weighted sum and weighted average

Weighted sum and weighted average are two mathematical computations employed to combine a set of values by assigning weights to each value [13]. Although both methods involve the allocation of weights to individual values [14], the selection between the two methods depends on the specific context and the intended purpose of the calculation as they diverge in the manner in which these weighted values are consolidated [15]. In a weighted sum, each value is multiplied by its corresponding weight and subsequently added together [16,17] This yields the aggregate of the weighted values. Mathematically, it can be represented as (1):

$$Weighted\ Sum = (Value1 * Weight1) + (Value2 * Weight2) + ... + (ValueN * WeightN) \tag{1}$$

The weighted sum produces a comprehensive value that encompasses the cumulative contribution of each value, accounting for its assigned weight.

While in a weighted average, each value is multiplied by its weight, and the sum of the weighted values is divided by the sum of the weights. Mathematically, it can be expressed as (2):

$$Weighted\ average = \frac{((Value1 * Weight1) + (Value2 * Weight2) + ... + (ValueN * WeightN))}{(Weight1 + Weight2 + ... + WeightN)} \tag{2}$$

The weighted average generates a representative value that incorporates both the values and their respective weights. This approach is beneficial when calculating an average that acknowledges the importance or significance of each value [15].

3.2.3 Presentation of the "Minimum condition algorithm"

The minimum condition algorithm, as described earlier, is utilized in our performance measurement system to calculate the overall multidimensional sustainable performance value. This algorithm assigns the minimum value of the fields within each dimension to determine the performance level of that dimension. The steps involved in the algorithm can be summarized as Figure 4.

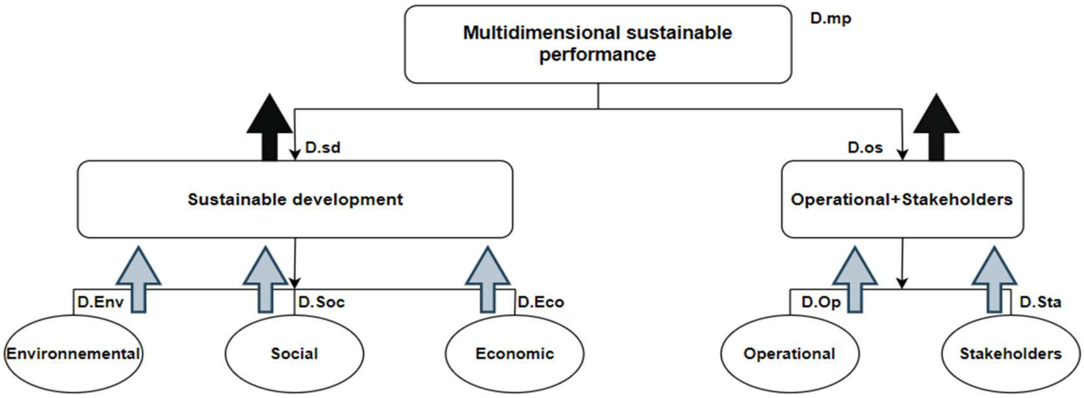

Figure 4 Performance calculation levels

1. Field Performance Determination: Assign a score ranging from 1 to 9 to each field within every dimension.
2. Dimension Scoring: Determine the score for each dimension by considering the minimum scores of the fields within that dimension. The performance of the dimension is equivalent to the minimum value among its fields.
3. Comparison of Dimensional Performance:
4. Sustainable Development Performance (D.sd): Determine the minimum dimensional performance value among economic, environmental, and social dimensions. D.sd = Min (economic dimensional performance, environmental dimensional performance, social dimensional performance)
5. Operational Performance + Stakeholders (D.os): Determine the minimum dimensional performance value among operational and stakeholder dimensions. D.os = Min (operational dimensional performance, stakeholder dimensional performance).
6. Performance Level Determination for D.sd and D.os.
7. Calculation of Sustainable Multidimensional Performance (D.mp): D.mp = Min performance level (D.sd, D.os).

The output values are derived directly from the application of the minimum condition algorithm, which assumes that a global performance level (output) is only achieved when all the inputs are validated.

The minimum condition algorithm comprises three main performance levels, adopting a scale from 1 to 9. Consequently, the output performance level is determined by the lowest score assigned to the dimensions as mentioned in Figure 5.

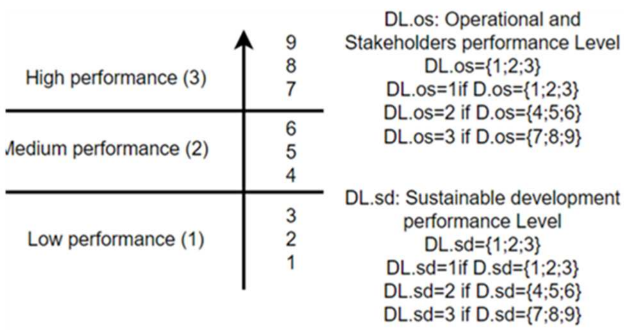

Figure 5 Multidimensional performance measurement scale

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3.2.4 Artificial neural network

ANN is a data processing archetype that is triggered in such a way that the information in the human brain is processed by a biological nervous system. It is made up of a large number of highly interconnected processing components, which are neurons that work together to solve certain issues. For chores requiring precise and rapid mathematical calculations, the computer surpasses organic brain systems. Artificial neural systems ensure the production of innovative information processing networks. Its computation falls somewhere in the middle between artificial intelligence and engineering [18].

Neural networks, specifically multilayer perceptron's, are a branch of artificial intelligence that model non-linear mappings. They consist of interconnected nodes with weighted connections and non-linear activation functions. By combining these functions, they approximate complex relationships [19]. Used in many fields, the application of ANNs has seen a lot of success in a number of different areas of specialization, including.

The multilayer perceptron is a feed-forward network with multiple layers, where the input layer serves as a conduit for data transmission.

4 Practical case

4.1 Application FANP

In this case study, experts utilized the Fuzzy Analytic Network Process (FANP) with the assistance of the user-friendly SuperDecisions software [20,21].

software integrates advanced methodologies to enhance decision-making processes across different domains [22]. Through pairwise comparisons, a group of carefully selected experts with expertise in sustainable performance assessment identified the interactions between various dimensions and fields. These interactions shed light on the intricate relationships within the evaluated system. Notably, direct interactions among the fields specified in the provided table were identified by the experts [23].

The SuperDecisions software visually presents the interactions through a model represented in Figure 6. The model consists of five clusters, each representing a specific dimension. Within each cluster, nodes are assigned to represent the fields under study. This visual representation provides a clear and organized depiction of the relationships between dimensions and the specific fields being assessed. The clustering structure facilitates the categorization and grouping of interconnected fields, enabling a comprehensive analysis of the entire system.

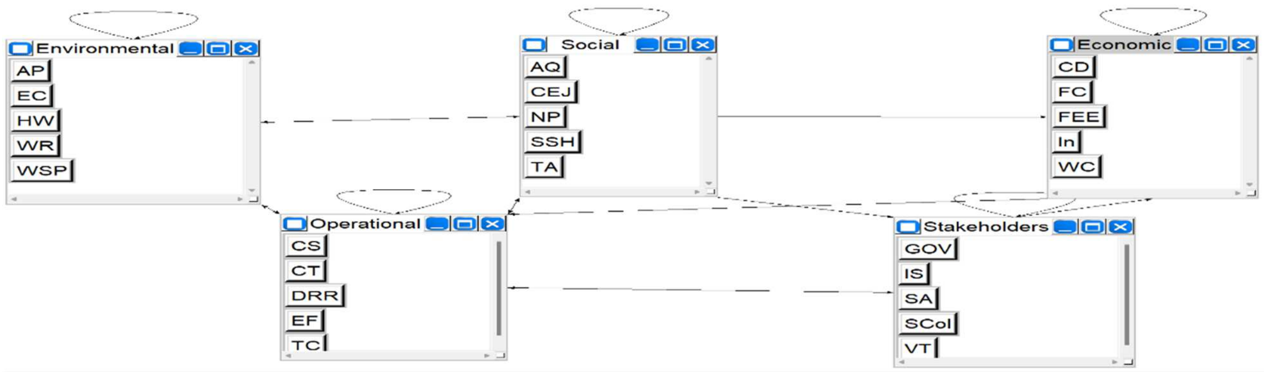


Figure 6 Selection network

In FANP evaluation, values 1, 3, 5, 7, and 9 (Table 1) are frequently employed to convey the degrees of importance or preference for criteria or alternatives. These values are linked with descriptive language to aid in the quantification of decision-makers uncertain or imprecise judgments. Here is a general interpretation of the typical connotations associated with these values which has been used in pairwise comparison.

Table 1 Pairwise evaluation scale

Importance	Explanation
1	Signifies minimal importance or extremely low preference. This implies that the criterion is deemed insignificantly important or inferior when compared to the majority of other criteria.
3	Represents moderate importance or moderate preference. This suggests that the criterion holds a certain level of significance or a moderately preferred position among the other criteria.
5	Indicates an intermediate level of importance or a neutral preference. This means that the criterion is considered to possess a medium degree of importance or a neutral preference when compared to other criteria.
7	Denotes a high level of importance or a strong preference. This indicates that the criterion is regarded as having substantial importance or a significantly higher preference relative to the other criteria.
9	Reflects an extremely high level of importance or preference. This signifies that the criterion is viewed as critically important or holds an exceptionally high preference when compared to other criteria.
2,4,6,8	Even scores reflect intermediate values.

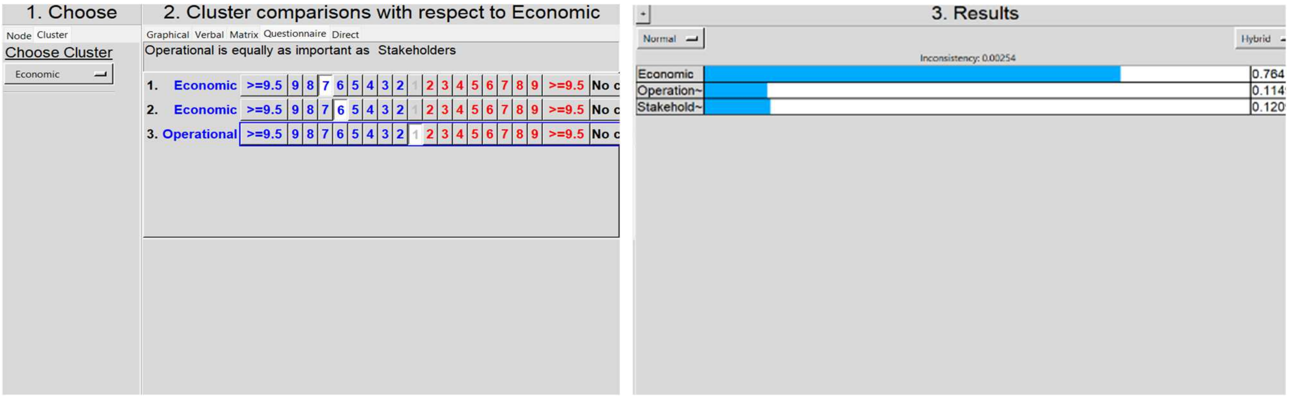


Figure 7 Pairwise comparison example

a- Dimensions and fields prioritization

The Fuzzy Analytic Network Process (FANP) is utilized in this study to prioritize fields by assigning weights. The primary goal is to quantify and rank the elements involved in the decision-making process, allowing for a more informed approach. Weight prioritization becomes crucial when multiple criteria are considered, as it helps identify the most impactful or relevant ones. By doing so, it enables a focus on the key aspects and prevents subjective or equal evaluation of all criteria.

Once the analytic network is constructed to represent the relationships between criteria and sub-criteria (or dimensions and fields), causal links are established, either as cause-effect or dependency connections. These links capture the associations between dimensions and fields, to which weights are assigned based on their significance. This assignment is done through pairwise comparison analysis, where two criteria are compared at a time to determine their relative importance compared to others. The resulting weights are then used to calculate weighted weights for each criterion and sub-criterion associated with the dimensions. These weighted weights indicate the relative importance of each criterion within the context of sustainability being studied. The Figure 8 below visually represents the relative importance (weights) of sub-criteria and main criteria based on the pairwise comparisons conducted.

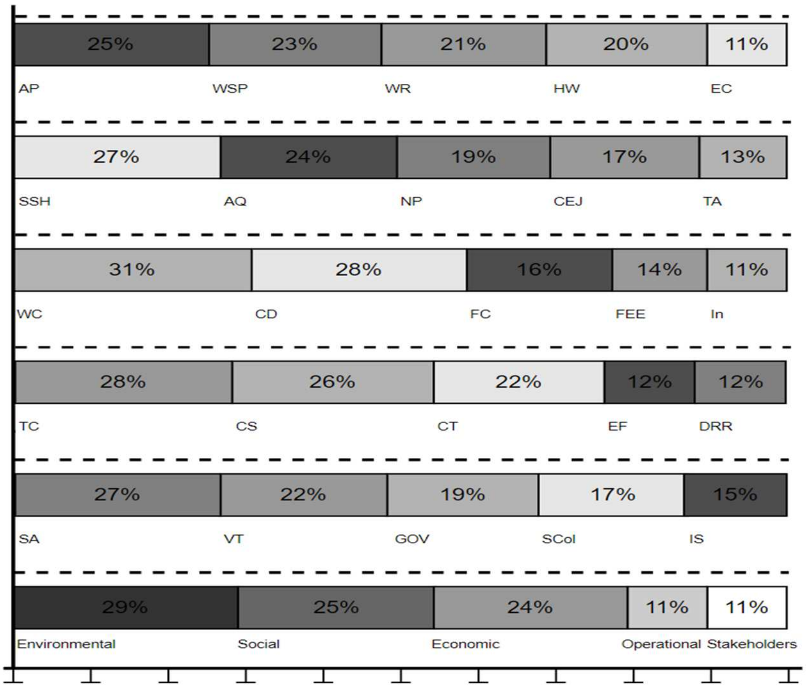


Figure 8 The relative importance (weights) for main criteria and sub-criteria

b- Sustainable performance calculation

By applying weighted weights [24], the calculation of sustainable performance involves aggregating the measurements of criteria and sub-criteria linked to each dimension. This computation can be accomplished through techniques like the weighted sum or weighted average of scores. The weighted average is particularly valuable as it provides a consolidated metric that considers the relative distribution of weights by dividing the weighted sum by the sum of weights (Table 2). In this approach, the weighted average is utilized to determine the sustainable performance of dimensions. By incorporating the weighted weights, it becomes possible to calculate sustainable performance by amalgamating the measurements of criteria.

Table 2 Example of weighted average results

Dimensions	Fields	Weights	Fields performances	Weighted weights	Weighted average
Environmental	AP	0.25	5	1.25	4.37
	WSP	0.23	4	0.92	
	WR	0.21	5	1.05	
	HW	0.20	3	0.6	
	EC	0.11	5	0.55	
Social	SSH	0.27	5	1.35	4.14
	AQ	0.24	4	0.96	
	NP	0.19	4	0.76	
	CEJ	0.17	4	0.68	
	TA	0.13	3	0.39	
Economic	WC	0.31	5	1.55	4.89
	CD	0.28	5	1.4	
	FC	0.16	5	0.8	
	FEE	0.14	5	0.7	
	In	0.11	4	0.44	
Operational	TC	0.28	3	0.84	3.68
	CS	0.26	5	1.3	
	CT	0.22	4	0.88	
	EF	0.12	4	0.48	
	DRR	0.12	4	0.18	
Stakeholders	SA	0.27	5	1.35	4.53
	VT	0.22	5	1.1	
	GOV	0.19	5	0.95	
	SCol	0.17	4	0.68	
	IS	0.15	3	0.45	

Through the utilization of the weighted average, we were able to perform calculations that yielded weighted aggregates. These aggregates served as valuable indicators of the relative performances exhibited by the fields under consideration in this evaluation. The weighted average method takes into account the assigned weights of each field and combines them with their respective performance measures. This approach allows for a comprehensive assessment that considers the varying degrees of importance assigned to each field. By obtaining these weighted aggregates, we gain a deeper understanding of how the different fields compare in terms of their performance within the evaluated context.

4.2 Minimal condition algorithm and artificial neural network

Before proceeding to the next steps, we performed rounding of the weighted scores [24]. Different methods are used to round real values to integers in sustainable performance measurement. In this context, we will adopt the classical approach of rounding the weighted scores. This method involves rounding the real values to the nearest integer using conventional rounding rules, such as rounding up or rounding down.

According to the minimum condition algorithm, the performance level of a higher-level (D.sd, D.os, or D.mp) relies primarily on the minimum performance value among the dimensions (D.Eco, D.Soc, D.Env, D.Op, and D.Sta) contained within that same level or the oversize level being studied (D.os, D.sd). By applying this algorithm, we quantified the performances of D.sd and D.op, and based on these two measures, calculated the overall multidimensional sustainable performance, D.mp.

The resulting data underwent analysis using a machine learning algorithm to investigate the relationship between the various sustainable performance values of the dimensions and the overall sustainable performance value for each scenario. This learning process was carried out using a neural network, specifically a multilayer perceptron, with a database comprising over 200,000 observations from the mining company's performance indicator monitoring systems.

The Table 3 below provides an example of scenarios illustrating the transition from the rounded weighted average to the value of D.mp.

Table 3 Scenarios' examples

Scenario 1			Scenario 2			Scenario 3			Scenario 4		
D.Env= 8			D.Env= 8			D.Env= 8			D.Env= 9		
D. Soc= 9	D.sd=2		D. Soc= 9	D.sd=3		D. Soc=	D.sd=2		D. Soc= 9	D.sd=3	
D.Eco=6		D.mp=2	D.Eco=7		D.mp=3	D. .Eco=8		D.mp=2	D.Eco=9		D.mp=3
D.Op=8	D.os=2		D.Op=8	D.os=3		D.Op=8	D.os=3		D.Op=9	D.os=3	
D.Sta=6			D.Sta=8			D.Sta=8			D.Sta=9		

The elements found in the initial columns of each scenario correspond to the inputs of the ANN model, whereas the elements in the final columns represent the outputs of the model. This structure is designed to capture the relationship between the input variables and the resulting predictions or outcomes generated by the ANN model. The input variables, located in the first columns, serve as the initial information provided to the model, while the output variables, located in the final columns, represent the model's predicted or calculated values based on the given inputs.

4.3 Outcomes of the contribution

The article makes two significant contributions. First, it introduces a method for prioritizing dimensions by assigning weights to them and their respective fields based on their relative impact on overall performance assessment. This approach underscores the substantial influence of the environmental aspect among the various dimensions, underscoring its pivotal role in determining sustainable performance. Dimension prioritization enhances our understanding of the relative significance of different factors in the evaluation of overall performance.

Secondly, the article presents a predictive model employing an Artificial Neural Network (ANN). This model achieves an impressive accuracy rate of 94% with minimal error margins, as evidenced by a negligible Root Mean Square Error (RMSE). By training on the weighted calculations, the ANN model learns the intricate relationships between dimensions, fields, and overall performance, enabling it to provide highly accurate predictions.

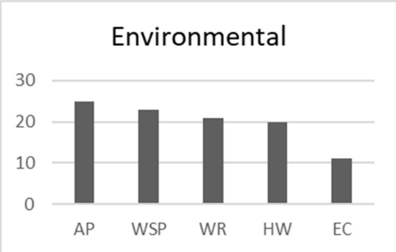
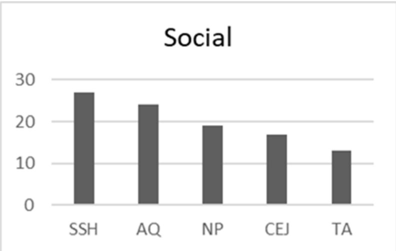
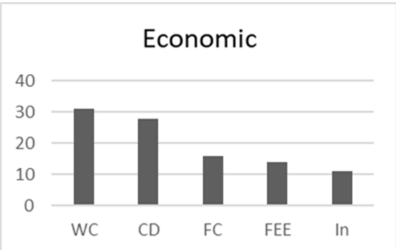
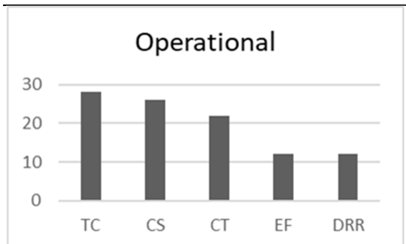
The integration of dimension prioritization and the ANN-based prediction model in this combined approach offers an innovative and efficient method for assessing and predicting multidimensional performance. It not only enhances our comprehension and measurement of sustainable performance in practical applications but also supports decision-making processes and advances progress toward sustainability objectives.

5 Discussion of results

The prioritization of weights assigned to individual fields within the dimensions during the assessment of sustainable performance within a Moroccan mining industry company has emerged as a pivotal step in this endeavor. This weight assignment process has not only facilitated the quantification and ranking of the dimensions and their respective fields but has also yielded a wealth of invaluable insights concerning their relative importance. These insights, in turn, serve as guiding beacons for driving improvement initiatives and informing crucial decision-making processes.

The allocation of weights to fields within each dimension has been transformative in the evaluation process, offering a profound and comprehensive understanding of the intricate web of their relative significance within the broader framework of sustainable performance. It provides stakeholders with a nuanced map, illuminating the areas that exert the most substantial influence on the overarching performance landscape. This, in essence, empowers stakeholders to channel their attention and allocate resources judiciously, concentrating their efforts where they can make the most significant impact on the company's overall sustainable performance. It not only refines the focus but also underscores the power of data-driven decision-making in the pursuit of sustainability goals within the Moroccan mining industry.

Table 4 Relative comparison

Dimensions	Descriptions
	Issues related to air, water, and soil pollution often have significant consequences for the environment. The mining industry can generate emissions of air pollutants, discharge contaminated wastewater, and produce solid waste that can negatively impact surrounding ecosystems. Therefore, in the evaluation of sustainable performance, greater importance may be placed on these dimensions to ensure proper management of environmental impacts. Waste management and recycling are crucial issues in the mining industry. Waste can contain toxic or hazardous substances that require proper management to prevent negative impacts on human health and the environment. Regarding energy consumption, the mining industry is often energy-intensive, requiring a significant amount of energy for mineral extraction, processing, and transportation. Reducing energy consumption can contribute to a more sustainable performance by lowering greenhouse gas emissions and minimizing the company's carbon footprint.
	The higher importance given to SSH and AQ among these fields in the social dimension of sustainable development can be explained by several factors. Firstly, SSH is a major concern in many industries, including the mining industry, as it relates to worker safety, prevention of accidents and occupational illnesses, and adherence to health and hygiene standards. These aspects are essential for ensuring a safe and healthy work environment, as well as protecting the lives and well-being of employees. Similarly, AQ plays a crucial role in sustainable development as air quality directly impacts human health and the environment. The mining industry can generate air emissions such as fine particles and pollutants that have detrimental effects on air quality. Therefore, placing high importance on monitoring and improving air quality contributes to the protection of the health of surrounding communities and the preservation of the environment.
	Overall, the high importance given to WC and CD underscores the significance of wealth creation and cost management in driving economic sustainability and long-term success for mining industry companies. WC reflects here the fundamental objective of the businesses, which is to generate wealth and economic value. It encompasses various aspects such as revenue generation, profitability, and economic growth. Prioritizing WC indicates the emphasis placed on maximizing financial performance and ensuring sustainable economic development. The CD is another critical field as it directly affects the financial aspects of a company. The cost of delay refers to the potential losses or negative consequences that may arise from delays in project execution. Managing and minimizing the cost of delay is crucial for maintaining efficiency, competitiveness, and financial success. By prioritizing CD, companies aim to optimize their resource allocation, mitigate risks, and enhance their overall economic performance.
 	By emphasizing TC and SA, the evaluation of sustainable performance acknowledges the importance of efficient transport cost management, which contributes to operational efficiency, cost reduction, and enhanced competitiveness of the company. Additionally, strategic collaboration with stakeholders ensures a harmonious relationship, social acceptance, and sustainable management of mining projects. This focus aims to achieve optimal operational performance and sustainable development in the mining industry.

The Table 4 above represents the prioritization of fields detailing the dimensions in the evaluation of sustainable performance for a Moroccan mining industry company. The fields are depicted in descending order of their relative importance. This ranking provides a visual representation of the significance of each field in contributing to overall performance.

Furthermore, the results demonstrate a strong and consistent performance of the predictive model, making it a reliable framework for calculating and quantifying multidimensional performance. These findings attest to the model's ability to provide accurate and dependable predictions, rendering it applicable to a wide range of studies, domains, and sectors. With its adaptive nature, the model can be adjusted and customized to fit specific contexts using appropriate performance indicators.

The adaptability of the model allows for its application to diverse case studies, offering increased flexibility and relevance in evaluating multidimensional performance. For instance, in the mining industry, performance indicators such as waste management, energy efficiency, and carbon footprint can be incorporated into the model to assess the sustainability of mining operations.

By utilizing the adaptive predictive model, practitioners and researchers can benefit from a valuable tool for evaluating, comparing, and enhancing multidimensional performance across various contexts. This enables a more personalized and targeted approach, promoting better management of sustainable performance and informed decision-making in diverse industrial sectors and fields of study.

6 Conclusion

The mining industry in Morocco is not only a major contributor to the national economy but also a key global player in the extraction of minerals, phosphates, and precious metals. Its influence reaches across various sectors, and as the industry evolves, it places increasing importance on sustainable and responsible mining practices. The government's support, investment in infrastructure, and commitment to innovation ensure that Morocco remains at the forefront of the global mining landscape.

In this paper, we have focused on this topic in order to study it closely and make decisions based on the results obtained.

In summary, the application of the Fuzzy Analytic Network Process (FANP) method has proven to be highly effective in our study, enabling us to systematically rank and prioritize the five dimensions of sustainable development we examined. The order of priority, as determined by our analysis, is as follows: environmental (29%), social (25%), economic (24%), operational, and stakeholders (11%). This prioritization is a valuable outcome, shedding light on the relative significance of each dimension within the framework of evaluating sustainable performance in the Moroccan mining industry.

Furthermore, our study delved deeper by pinpointing specific subcategories or fields within each dimension, offering a comprehensive understanding of areas that require targeted attention and improvement. By quantifying and highlighting the relative importance of these individual fields, stakeholders and decision-makers are equipped with a clear roadmap, allowing them to channel their efforts towards addressing the most critical aspects of sustainable performance.

Additionally, we calculated the dimensional performance aggregates by employing weighted averages, duly considering the significance assigned to each dimension. This approach permits a thorough assessment of the overall sustainable performance, incorporating the varying degrees of importance assigned to each dimension. It offers a holistic perspective on the company’s sustainable performance, taking into account the nuanced interplay between three dimensions.

Moreover, the predictive model we have developed presents a direct and easily interpretable means of estimating the overall performance value, delivering a generalized gauge of the company's performance level. This predictive tool facilitates quick and informed decision-making and is instrumental in providing a snapshot of the company's performance.

The implications of these results and findings are substantial, offering a robust framework for decision-making and improvement initiatives within the Moroccan mining industry. By paying attention to the priority dimensions and specific fields we've identified, companies are well-positioned to elevate their sustainable performance, advocate responsible practices, and make significant contributions to the long-term sustainability of the environment, society, and the economy.

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