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An Assessment of the Relevance of Locating the Exploitation of Raw Materials Quarries in a Framework of Sustainable Development: Use of the MACBETH Method Case of the Province of Settat

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ABSTRACT

For decades, the positioning of the sites of the extraction of materials was based, on the economic profit, (existence and abundance of the deposit, proximity of the basins of consumption) and the social aspect (number of jobs created), the environmental dimension was little or not taken into account. However, because of the negative impacts of this industry, more and more felt by the population, and in addition to the awareness of the protection of the environment, decision-makers have been forced to rethink their decision-making policies. Thus, it has become necessary to adopt sustainable management of this sector, taking into account environmental, social and economic issues. In this context, the presented work proposed the mathematical method of decision-making MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique). This approach is based on economic, social, and environmental criteria, which have been chosen concerning sustainable development issues. The selection of options reflects the geographical distribution as well as the typology of materials at the level of the study area. Then, the attractiveness of the options on each weighted criterion was evaluated following the preferences presented by the decision-makers and finally their aggregation by the MACBETH tool. The implementation of this tool made it possible to evaluate the exploitation of existing quarries at the study area level and to predict the optimization of future locations.

Keywords: MACBETH, sustainable development, criteria, locations.

INTRODUCTION

The location of the quarrying sites took into account only the economic aspect (deposit potential and the proximity of the consumption basin) and the social aspect (number of jobs generated). The environmental aspect is often considered to a limited extent or not taken into account. Certainly, this activity contributes to socio-economic development, but it has impacts and nuisance more and more felt, in addition to the rise of awareness in favor of the protection of the environment, have imposed on decision-makers the use of sustainable modes of exploitation. Thus, it has become essential to integrate the sustainable model in the management of this sector, to ensure the ecological balance, and to fight against all forms of nuisance.

In this sense, it has become essential to adopt a decision-making approach integrating the three dimensions of sustainable development (economic, social, and environmental) to strengthen the preservation of the environment.

In the same sense and view, the complexity of the decision-making problem, especially when there are many actors and several alternatives, and various points of view, which must be taken into account, leads decision-makers to adopt a multi-criteria approach to evaluate the different scenarios (Mena, 2000).

The design and implementation of the value system, on behalf of which the decision must be made, are critical steps in multi-criteria decision analysis (MCDA) (Belton and Stewart, 2002).

This system will reflect the order of attractiveness of the choice options for the decision-maker, as well as the differences in their relative attractiveness (strength of the decision-makers preferences for one option over another). Then, they are scored and ranked to generate a scale for each criterion (Von Winterfeldt and Edwards, 2007).

Indeed, the use of decision-making tools has been considerably developed in recent decades, they are becoming considerably more common and their use has become more frequent; hence, many multi-criteria methods (ELECTRE, AHP, MACBETH, PROMETHEE, etc.), have been proposed to allow decision-makers to solve decision problems, or several often contradictory points of view that must be taken into account.

In this context, the objective of this work and to apply the MACBETH multi-criteria decision-making approach, at the level of decision-making for the opening and operation of a quarry, certainly this extractive industry plays a very important role in socio-economic development, but negatively impacts the environment by various nuisances, which have been amplified in recent decades by the high demand and pressure on building materials, and non-renewable natural resources.

However, when deciding to open these quarries, the environmental dimension is often little considered, which can accentuate their negative effects on the population and the natural environment.

The proposed MACBETH approach is structured on environmental, social, and economic criteria chosen within a framework of compliance with the principles of sustainable development in order to select the sites favorable to the establishment of the quarrying.

The research methodology of this work goes through a literature review, then tools and method, and at the end the application of the approach on the territory of the province of Settat in Morocco (study area).

All this led the authors to wonder about:

1. How can quarrying be reconciled with the imperatives of sustainable socio-economic development and environmental protection?
2. What are the criteria for the selection of quarry sites?
3. How can the existing situation be evaluated and the opportunity to optimize future locations predicted?

The originality of this work lies in:

- Demonstration of the importance of the pillars of sustainable development as vectors of development and growth;
- The weighting of the pillars of sustainable development to highlight the impact of these pillars in the act of investment and as triggers for a sustainable economic dynamic.

MATERIALS AND METHODS

Presentation of the study area

The study area is located in the center of Morocco. It extends over an area of about 7220 km^2, on the Mesetian estate, in a region with very high geological diversity conducive to extraction activity. Being in the heart of the Chaouia plain, it contains a potential deposit that can be subdivided into three structural sub-domains, namely:

- The coastal Meseta area covers the western and northern parts;
- The Plateau de Settat - Ben Ahmed is a part of the Phosphate Plateau;
- The Rehamna massif constitutes the southern part (Michard A. et al. 2008, El Hassani A. 1994, Hattabi, S., et al 2020).

In addition, it is characterized by its proximity to Casablanca, which is the most important consumption basin in Morocco, especially in building materials; with its 56 careers, it presents a very adequate framework for the study, since the focus can be made on three-dimensional development (economic, social, and environmental).

Context, issue

When deciding to allow a career in a territory, the environmental dimension is often neglected, in favor of the economic and social dimensions. While this industry contributes to socio-economic dynamics, it generates negative impacts on the environment through various nuisances amplified in recent decades by the high demand and pressure on building materials, and non-renewable natural resources.

To strengthen the measures against all its forms of nuisance, it has become necessary to adopt sustainable management of this sector and to put oneself at the forefront of these prejudices and to integrate this activity into its territory, one must intervene upstream, that is to say at the level of decision-making.

Indeed, decision-making becomes multi-criteria when the problem has often several contradictory objectives, or when one wants to evaluate several options in situations where no possibility is perfect, which leads decision-makers to adopt a multi-criteria approach to evaluate the different scenarios to reconcile economic, environmental, and social aspects (Mena, 2000). The implementation of the value system, on behalf of which the decision must be made, is a crucial step in the multi-criteria decision analysis (MCDA) process (Belton and Stewart, 2002). Indeed, the emergence and use of decision-making tools, in recent decades, many multi-criteria methods (ELECTRE, AHP, MACBETH, PROMETHEE, etc.), have been proposed to allow decision-makers to find the most appropriate solution possible to solve decision problems.

Thus, in 2004, Bana e Costa, et al. opted for a decision-making approach based on the MACBETH software, to choose a future career among a set of options offered. In 2007 Hamdadou, D., et al. have developed a flexible decision-making approach designed with a GIS and multi-criteria methods, ordinal sorting and nominal sorting, the proposed MODUSMAT model integrates several variants, thus contributing best to the analysis of the context of the urban project to produce a spatial plan (land use plan) best suited. In 2009, Younsi, F. Z. et al. set up a decision-making approach that exploits GIS and georeferenced data, provided by remote sensing techniques, the latters are analyzed and aggregated by using electrei II Multi-Criteria Decision Support (AMCD) methods, to propose a land-use plan. In 2011, Tavares, G. et al. proposed a decision-making tool based on the combination of a GIS and the analytical hierarchy process (AHP) for the selection of a site for the establishment of a waste incineration plant on the island of Santiago de Cape Verde. In 2016, Evrard, presented an integrated approach for a multi-criteria evaluation of best techniques. In 2016 Bana, e Costa et al. presented an updated study of the mathematical foundations of MACBETH. They provided a reference to concrete applications and a detailed bibliography, dating back to the early 1990s. In 2016, Amellal, I. et al. (B) proposed a multi-criteria decision-making approach formed from the combination of a decision support tool and a geographic information system, while using environmental, social, and economic criteria, to assess the relevance of the location of the 12 industrial zones already existing in the Chaouia-Ouardigha region. In 2018, Patrícia A.M. Fariaa et al. combined cognitive mapping and MCDA to improve the quality of life in urban areas. In 2020, Oluwatobi Dayo-Olupona et al. proposed a multi-criteria tool for selecting technologies in open pit mines based on the fusion of the analytical hierarchy process and the enrichment method by preference classification (PROMETHEE).

The objective of this work is to propose a MACBETH multi-criteria mathematical decision-making approach, based on environmental, social, and economic criteria, which have been chosen, within a framework of compliance with the principles of sustainable development, to select sites favorable to the implementation of material extraction activities at the study area level.

To express the attractiveness between the elements, the tool uses qualitative judgments relating to their differences to produce the ratings for the options on each criterion and for the weighting of the criteria. This attractiveness can be expressed in the form of seven semantic categories: the difference in attractiveness is zero, very weak, weak, moderate, strong, very strong, and extreme. The name MACBETH comes from Measuring Attractiveness by a Categorical Based Evaluation Technique (Bana e Costa and Vansnick, 1999).

Model construction

The approach adopted to answer the posed problem is the MACBETH multi-criteria method (Figure 1) and it includes the following steps:

- identification of families of criteria and criteria;
- choice of options to be evaluated and their performance;
- Evaluation of different alternatives, as to the attractiveness on each criterion
- Weighting of criteria;
- Aggregation of criteria to rank the alternatives in ascending order.

Case study

The design of the MACBETH model begins with the choice of three families of criteria, namely Economic, Social and Environmental, which constitute the three pillars of sustainable development. Each family of criteria is made up of several criteria that are chosen with reference to the principles of this development, and that reflect the importance and concerns expressed by the evaluator.

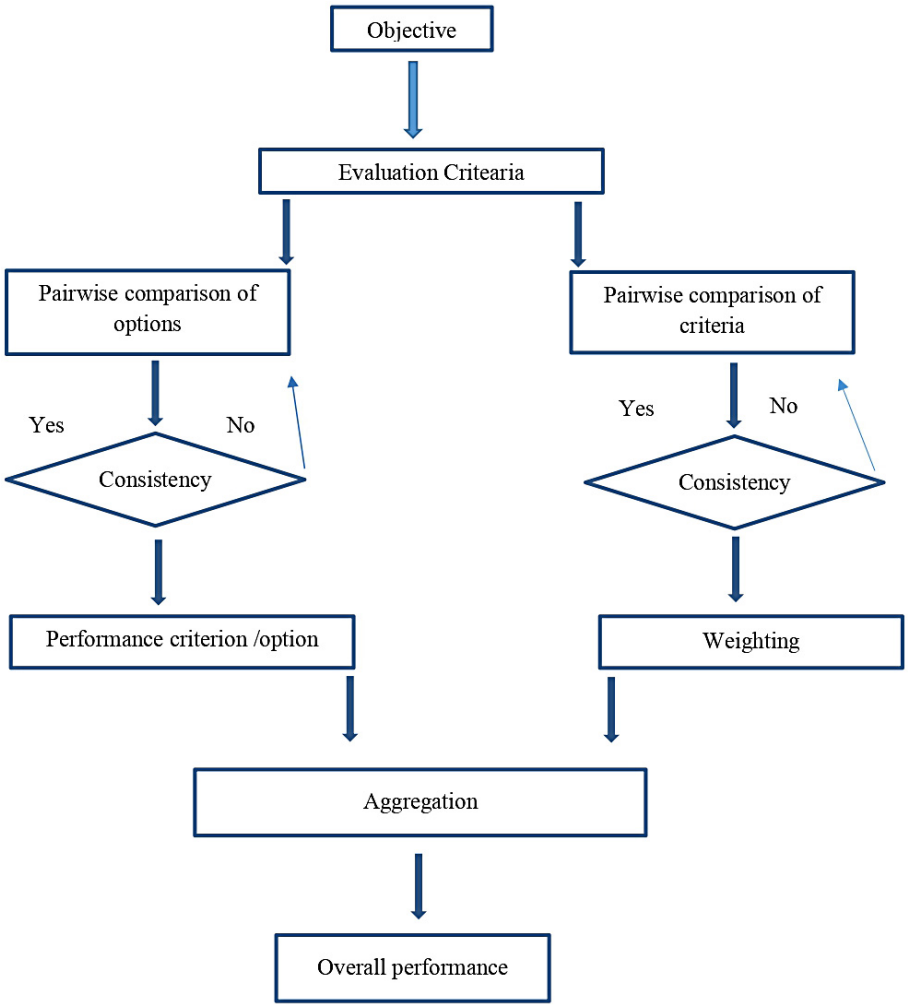


Figure 1. Description of the methodology and the steps are taken

The selection of the 16 criteria was justified by the following:

1. Economic:

- Tonne/kilometer transport unit (CR EC1): Transport impacts the cost of finished products, which explains their location near the places of consumption or the creation of small temporary and occasional quarry sites responding to a specific demand.
- Area (CR EC2): The larger the surface area of the quarry site, the more it is used. The minimum operating areas have no economic interest, since the investment of openness and the exploitation of quarries is a very heavy investment.
- Budget of local authorities (CR EC3): The poorer the local community, the more it is favored for the establishment of quarries. The contributions of these projects in a significant way in the socio-economic development of local communities.
- Investment Amount (CR EC4): The higher the investment amount, the more important is the career.
- Deposit potential, annual production, and duration (CR EC5): The importance of deposits are the main factors that allow an area to become a pole of attraction by excellence both at the regional and national level.

2. Social :

- Habitat zone (CR S6): To protect residential areas against undesirable impacts and nuisances that accompany the exploitation of quarries, a classification has been made according to the distances separating the activity and the inhabitants fewer than 10 meters are not suitable for the establishment of a quarry (legal restriction).
- Urban orientation (CR S7): To protect residential areas against the nuisances due to quarrying, safety radii have been chosen, around residential areas, as areas prohibited to the establishment of quarries.
- Monuments, tourist areas, places of worship (CR S8): Given their importance and value in order to ensure their protection classification

according to the distance with the prohibition of the establishment of quarries at a distance of fewer than 200 meters.

- Vital infrastructure (hospitals, schools, administrations, etc.) (CR S9): Facilities of general interest are an indispensable component for the well-being of the population, they are of paramount importance, hence the need to protect them with the prohibition of the establishment of quarries at a distance of fewer than 50 meters.
- Number of jobs (CR S10): These projects allow a clear improvement in the socio-economic situation of local authorities and a significant increase in the incomes of the population that work on the sites of the quarries, the greater the number of jobs the more the career is defended, They are classified according to the number of positions created.
- Waters (CR ENV11): Water is an indispensable part of life on our planet. This vital resource has been overexploited by global warming and water stress and the degradation of its quality and pollution. To protect this resource sustainably, protection perimeters are defined to prevent the risk of accidental contamination of this resource according to its size, as well as a minimum distance in which no exploitation will be authorized.

Classification according to the distances separating quarries from surface or underground water sources:

- Roads (CR ENV12): The traffic generated by the quarry operation activity has a significant additional traffic flow on the roads, and can accentuate the impact and nuisances on the road infrastructure.
- Forests (CR ENV13): Sustainable forest management is the protection of these natural resources from degradation by creating protected areas classified according to separation distances.
- Slope (CR ENV14): As all sites do not have steep slopes, the areas with a slope greater than 45° are excluded.
- Visual impact securing site rehabilitation (CR ENV15): Quarrying modifies the landscape by creating major fronts that threaten public safety, the storage of materials, and the formation of merlons, which distorts the landscape; to remedy this dysfunction the sites exploited must be rehabilitated and secured.
- Atmospheric impact (CR ENV16): The dust from quarry work will affect air quality, just as noise impact amplifies nuisances; classifications have been established according to the existence of protective barrier or not, wind direction, and distance.

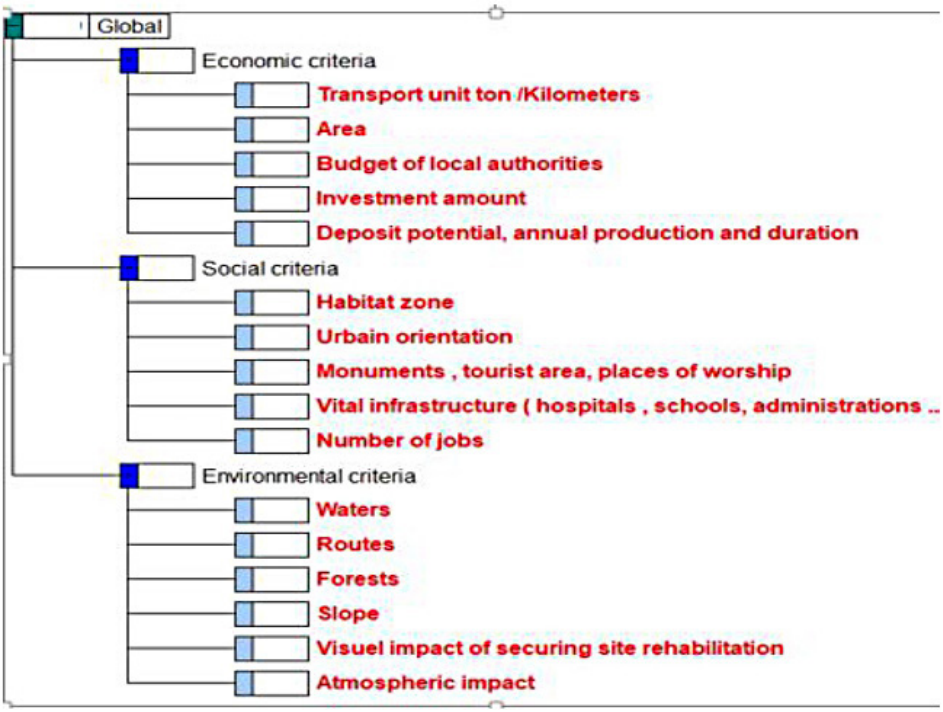


Figure 2. Value tree and career options

Then the options to be evaluated, as well as their performance were defined. The options (quarries15) were selected to be the most representative of the extraction activity not only for the local communities within the study area, but also for the types of materials extracted.

Afterwards, a tree of values was created in the MACBETH software listing the three families of criteria (economic, social, and environmental) as well as the criteria (16 criteria), and the options (15 careers). Indeed, the choice of families of criteria and options is a very decisive step in the implementation of the value system on its behalf the decision must be taken (Figure 2).

Then, these options were evaluated in the model through their qualitative or quantitative levels of performance vis-à-vis the attractiveness of alternatives on each criterion. Afterwards, the judgments were introduced into the matrix according to their importance or preference presented for decision-makers (Table 1).

They were compared in pairs according to two bases of comparison (Table 2):

- Indirect basis of comparison with a quantitative level of performance:
  - A scale of values has been created to associate each option for each criterion with a number that qualifies its attractiveness in the eyes of the evaluator on this criterion, (a rating of 1 to 5, with two levels of performance that will be used as a reference.

- Indirect basis of comparison with a qualitative level of performance:
  - A scale of values has been created to associate each option for each criterion with a number that qualifies its attractiveness in the eyes of the evaluator on this criterion

Table 1. Table of performance of the attractiveness of alternatives on each criterion

No. C	CR EC1	CR EC2	CR EC3	CR EC4	CR EC5	CR S6	CR S7	CR S8	CR S9	CR S10	CR ENV11	CR ENV12	CR ENV13	CR ENV14	CR ENV15	CR ENV16
C 1	Good	Very good	3	5	5	1	Good	Very good	5	5	1	Very good	5	5	Neutral	Acceptable
C 2	Very good	Very good	4	5	5	1	Neutral	Very good	5	5	5	Very good	5	5	Neutral	Acceptable
C 3	Very good	Very good	4	5	5	1	Weak	Very good	3	5	5	Very good	5	5	Neutral	Acceptable
C 4	Weak	Good	4	3	3	3	Good	Very good	5	4	5	Very good	5	5	Acceptable	Very good
C 5	Good	Good	4	5	5	3	Good	Very good	1	5	5	Very good	5	5	Good	Very good
C 6	Weak	Good	3	3	3	2	Good	Very good	5	4	5	Very good	5	5	Acceptable	Very good
C 7	Weak	Good	4	5	5	3	Good	Good	5	5	5	Very good	5	5	Neutral	Acceptable
C 8	Neutral	Acceptable	4	5	5	3	Good	Acceptable	5	5	5	Very good	4	1	Acceptable	Acceptable
C 9	Acceptable	Acceptable	3	5	4	5	Good	Good	5	5	1	Very good	5	5	Acceptable	Acceptable
C 10	Weak	Good	3	3	3	3	Good	Good	5	4	1	Very good	5	5	Acceptable	Acceptable
C 11	Neutral	Acceptable	5	4	3	3	Neutral	Good	4	3	4	Good	5	1	Good	Acceptable
C 12	Good	Acceptable	3	4	5	1	Good	Very good	3	5	5	Very good	5	5	Good	Very good
C 13	Very good	Acceptable	4	4	4	3	Very good	Very good	3	5	5	Good	5	5	Acceptable	Acceptable
C 14	Neutral	Acceptable	3	4	4	2	Good	Very good	5	5	2	Good	5	1	Acceptable	Acceptable
C 15	Acceptable	Acceptable	2	3	3	3	Very good	Very good	5	3	5	Very good	5	5	Good	Acceptable

Table 2. Comparison of performance levels

Indirect comparison of qualitative levels of performance				Indirect comparison of quantitative performance levels		
Family criterion	Economical	Social	Environmental	Economical	Social	Environmental
Criterion	Transport unit per tonne per duration	Urban orientation	Road	Local government budgets	Habitat area	Waters
	Area	Monuments, tourist areas, and places of worship	Visual impact, site security, and rehabilitation	Investment amount	Vital infrastructure (hospital, mosque, school, etc.)	Drills
			Atmospheric impact	Deposit potential, annual production, and duration	Number of jobs	Slope

from Very good to Weak, with two levels of performance that will be used as a reference.

To weight the criteria, qualitative judgments are introduced into the model, each of the semantic categories of the MACBETH tool can be chosen according to the preferences of the decision-maker.

In comparison cases, when the evaluator expresses his judgments (Figure 3), the software automatically checks their consistency and offers suggestions to solve their inconsistencies when they arise and owing to its functionalities, scales of ratings related to the levels of qualitative and quantitative performance are produced (Carlos A. Bana and al 2004).

RESULTS

Given the judgments introduced into the model by the decision-maker (Figure 4), the following results were produced by the software:

- A value tree was created with all scores for each of the criterion families, (Figure 4) illustrates a slight dominance of the weight of the economic criterion family with a score of 38.84, followed by the environment criterion family with a score of 32.17 and finally the social criterion family with a score of 28.99.
- An overall scale of the weights of the criteria shows that the weight of the criterion transport unit ton/kilometers is very important with a weight of 14.20, followed by the weight of the criterion area with a score of 11.40. They far exceed the weights of those of the slope (0.22), monuments, tourist areas, and places of worship (0.65) criteria (Figure 5). An overall scale representing all option scores (Figure 6):
  - Shows that the C2 option is the most attractive with a score of 113.72 and the C10, C11, and C14 options are the least attractive with scores of 60.51, 64.09, and 69.55 respectively.
  - Categorizing the scores of options, those with scores above 100 and those with scores below 100.

The profile of option C2 shows that the out of 12 criteria is greater than 100 and only one criterion is negative (Figure 7).

DISCUSSION

The MACBETH multi-criteria analysis is finalized by a hierarchy of families of criteria, criteria, and options based on their weights and importance. The final choice is based on the maximum point score of the evaluations which will influence the choice of quarry sites at the study area level. According to the results recorded, it can be observed:

- The tree of values proposed by MACBETH, shows a slight difference in weight between the three families of criteria that make up

<16>	[CR EC1]	[CR EC2]	[CR S10]	[CR ENV16]	[CR ENV11]	[CR EC4]	[CR S6]	[CR ENV12]	[CR S9]	[CR ENV13]	[CR S7]	[CR EC5]	[CR ENV15]	[CR EC3]	[CR S8]	[CR ENV14]	[toutes inf]
[CR EC1]	nulle	modérée	modérée	modérée	modérée	modérée	modérée	forte	forte	forte	tr. forte	tr. forte	tr. forte	extrême	extrême	extrême	positive
[CR EC2]		nulle	faible	mod-fort	mod-tfort	modérée	modérée	modérée	fai-mod	modérée	tfai-mod	forte	forte	tr. forte	tfai-tfort	tr. forte	positive
[CR S10]			nulle	faible	fai-mod	fai-fort	fai-mod	fai-mod	faible	tfai-mod	fai-tfort	mod-tfort	modérée	forte	fai-fort	positive	positive
[CR ENV16]				nulle	faible	tfai-mod	fai-mod	faible	fai-mod	mod-tfort	mod-tfort	mod-fort	mod-tfort	mod-tfort	fai-tfort	forte	positive
[CR ENV11]					nulle	tfai-mod	fai-mod	fai-fort	tfai-mod	mod-tfort	mod-fort	mod-tfort	mod-tfort	mod-tfort	fai-tfort	forte	positive
[CR EC4]						nulle	fai-fort	faible	fai-mod	faible	fai-tfort	modérée	modérée	forte	fai-tfort	forte	positive
[CR S6]							nulle	faible	fai-mod	faible	fai-tfort	fa-tfort	tfai-mod	fai-tfort	fai-fort	positive	positive
[CR ENV12]								nulle	tfai-mod	faible	fai-tfort	fa-tfort	fai-tfort	fai-tfort	fai-fort	fai-fort	positive
[CR S9]									nulle	faible	faible	fa-tfort	fai-fort	tfai-fort	fai-tfort	positive	positive
[CR ENV13]										nulle	faible	tfai-tfort	faible	fai-fort	fai-fort	fai-tfort	positive
[CR S7]											nulle	tfai-tfort	fai-tfort	fai-fort	modérée	positive	positive
[CR EC5]												nulle	faible	modérée	fai-tfort	modérée	positive
[CR ENV15]													nulle	fai-tfort	fai-tfort	faible	positive
[CR EC3]														nulle	faible	faible	positive
[CR S8]															nulle	faible	positive
[CR ENV14]																nulle	positive
[toutes inf]																	nulle

Figure 3. Matrix of qualitative judgments

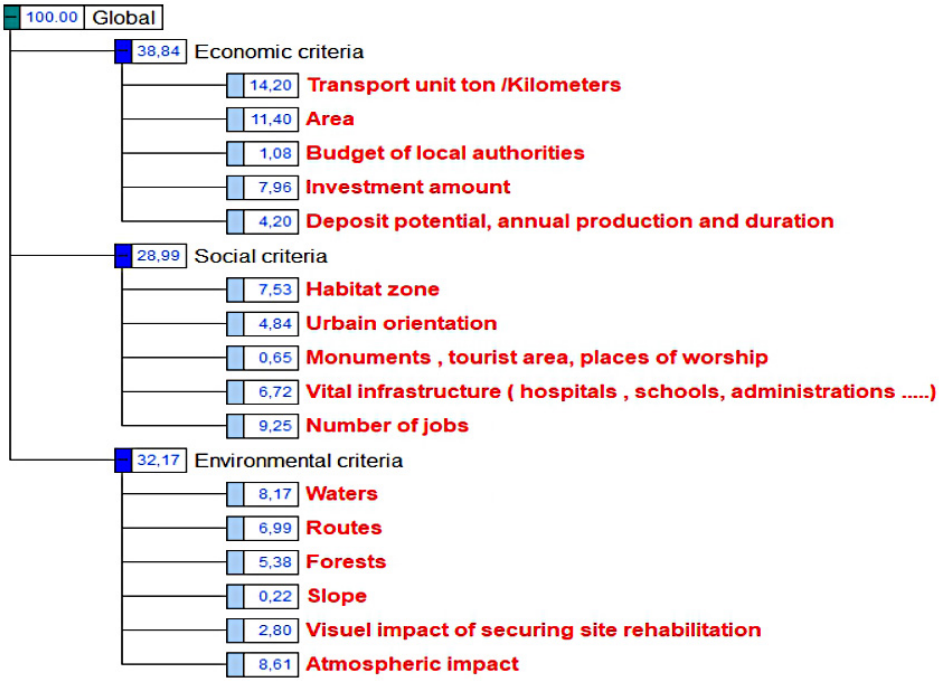
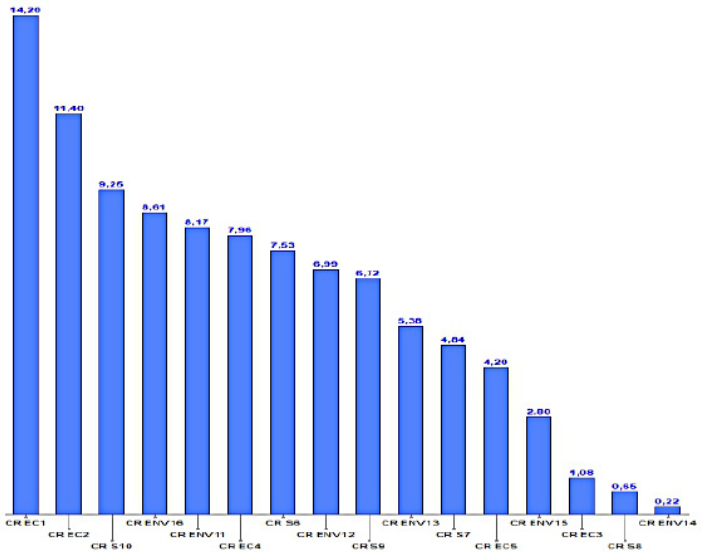


Figure 4. Value tree



	Echelle courante	MACBETH ancrée	MACBETH de base
[CR EC1]	14,20	14,20	67,62
[CR EC2]	11,40	11,40	54,29
[CR S10]	9,25	9,25	44,05
[CR ENV16]	8,61	8,61	41,00
[CR ENV11]	8,17	8,17	38,90
[CR EC4]	7,96	7,96	37,90
[CR S6]	7,53	7,53	35,86
[CR ENV12]	6,99	6,99	33,29
[CR S9]	6,72	6,72	32,00
[CR ENV13]	5,38	5,38	25,62
[CR S7]	4,84	4,84	23,05
[CR EC5]	4,20	4,20	20,00
[CR ENV15]	2,80	2,80	13,33
[CR EC3]	1,08	1,08	5,14
[CR S8]	0,65	0,65	3,10
[CR ENV14]	0,22	0,22	1,05
[toutes inf]	0,00	0,00	0,00

Figure 5. Overall scale of criteria weights

the three pillars of sustainable development, with a slight predominance of the family of economic criteria with a score of 38.84% followed by the family of environmental criteria with a score of 32.17% and finally the family of social criteria with a score of 28.99%. It can be said that it has a certain reconciliation and harmonious coexistence between the three pillars of sustainable development (Darkaoui, A., 2019, François Besancenot 2009), this can be explained by the fact that Morocco, in recent years, has established a very important legislative framework to strengthen the measures for environmental protection and pollution control, as well as to integrate sustainable development into decision-making policies and to optimize the exploitation of quarries.

- For the criterion transport unit ton / Kilometers (14.20%): The transport of extracted materials impacts the cost of the finished product. It represents a decisive character of logistics in the industrial positioning in a territory (2016 Amellal, I. et al. (A)), which

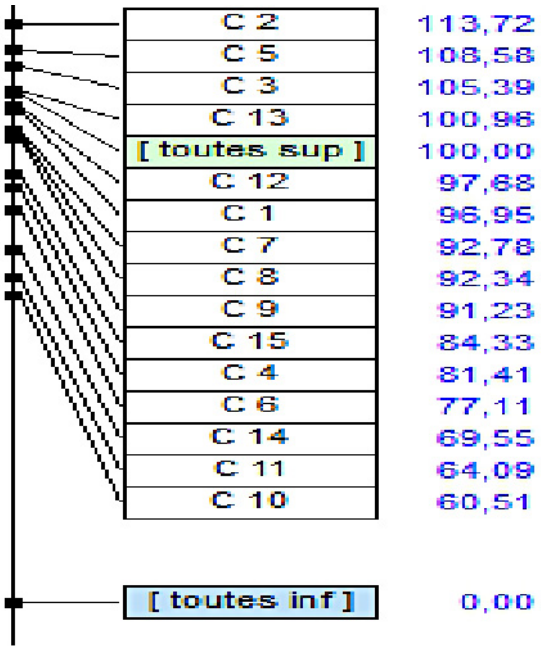


Figure 6. Overall scale of option scores

explains their location near consumption basins or the creation of small sites of temporary and occasional quarry operations responding to a punctual demand, the further one moves away from the extraction sites the higher the production cost;

- The slope criterion (0.22%): the weight of this criterion is very low given the absence of a steep slope at the level of the study area.
- The criterion monuments, tourist area, and places of worship (0.65%): the weight of this criterion is very low given the distance of all the sites of exploitation of the current quarries from the tourist sites.
- The profile of option C2 (Figure 7): this option represents one of the large cement production companies belonging to one of the major real estate groups in Morocco, the transformation of materials for this quarry is done at the site level (CR EC1), with a very large area of about 146 hectares (CR EC2), with an annual production of 800,000m^3 (CR EC5), hence the importance of their weights. This site is also very close to the inhabitants (CR S6) and the urban perimeter (CR S7) with a distance of fewer than 100 meters, hence their low weight. From the above, the exploitation of quarries can be optimized to amplify the positive impacts and eliminate or mitigate the negative impacts (Yelkouni, M et al. 2019), through the creation of employment positions for local population and the contribution to local development.

CONCLUSIONS

In this context, a MACBETH decision-making approach based on economic, environmental, and social aspects was proposed to evaluate the different existing quarries at the level of the study area, to select the sites favorable to the implementation of this type of activity.

The purpose of this work was to offer decision-makers a tool to facilitate decision-making,

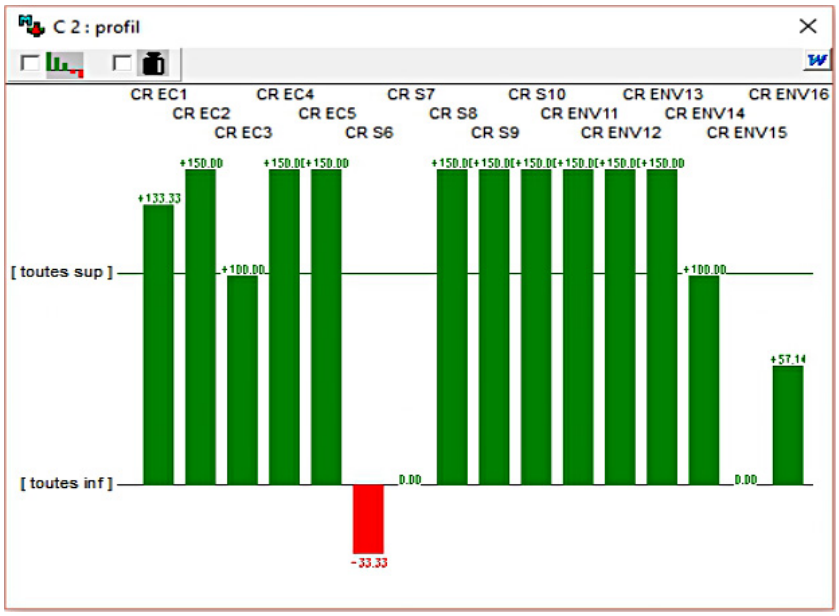


Figure 7. Profile of option C2

reduce negative repercussions, and optimize positive ones. According to the results recorded, it should be noted that there is a certain reconciliation between its three dimensions, a kind of symbiosis between activity and ecosystem.

However, this approach does not have a special representation and for more efficiency, a decision-making model based on the integration of a geographic information system with the MACBETH multi-criteria method is suggested to allow the optimization and evaluation of development projects, aiming at an improvement of prospective and sustainable development.

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