Optimizing the Choice of Limestone Deposits for the Production of Portland Cement in Cameroon

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Abstract: Despite the presence of raw materials (limestone and clay) deposits for Portland cement production, the major part of cement sold in Cameroon is from crushed imported clinker. This contributes to high cost of this material and reduction of local employment. In this study and based on existing data, a multi-criteria analysis tool was developed and applied to guide decision in the choice of limestone deposits in Cameroon for the production of Portland cement. The criteria evaluated were: calcium carbonate (CaCO₃) content of limestone, proximity of the limestone deposit to a qualified clay source, estimate of its capacity, area covered by the limestone deposit, extraction of limestone easiness, accessibility to the limestone deposit and the proximity of the limestone deposit to a source of energy. The study is conducted on twelve limestone deposits identified by previous studies around the country. The PROMETHEE II methodology used made it possible to highlight the best deposits with respect to the criteria set. The results showed in terms of preference that, the Bidzar and Mintom deposits respectively in the North and South Regions are the two best deposits to be considered for the local production of Portland cement. Their exploitation will more promote purely local cement industry in Cameroon.

Keywords: Cameroon, Limestone Deposits, Portland Cement Production, Multi-criteria Analysis, Promethee II

1. Introduction

Cameroon, like all other developing countries, is experiencing considerable growth in terms of infrastructure development in recent years [1]. This is leading to a growing demand for building materials, of which Portland cement is a major component. This cement is the main binder used in construction for the manufacture of concrete, mortars and plaster. It is obtained after firing at about 1450°C a mixture of 80% limestone and 20% clay to obtain Portland clinker which is then crushed with other admixtures such as gypsum and pozzolans to obtain the final cement. Four over five Portland cement plants located in Cameroon are crushing imported clinker with negative consequences on the cost of finished products and local jobs. Physicochemical characteristics of the raw materials for Portland clinker production have been presented by several authors [2, 3]. For clinker composition, limestone is the source of calcium carbonate (CaCO₃) and clay that of silica (SiO₂), alumina (Al₂O₃) and iron oxide (Fe₂O₃). Deposits of limestone and clay are scattered throughout the whole territory of Cameroon. Only on the basis of their physicochemical characteristics and the capacity of deposits, previous work has stated that Cameroonian limestone could be suitable for the production of Portland clinker [4]. However, these two criteria are not the only ones to be considered in order to actually set up a cement industry. To manufacture a ton of clinker, 1.55 to 1.60 tons of raw materials, mainly consisted
of limestone is required. This justifies the proximity of the cement plant to the limestone source, to avoid long distance transportation of this raw material [2]. Since the mixture is heated to about 1450°C, a source of energy is necessary around the production area [2]. Other criteria such as the proximity of the limestone deposit to a qualified clay deposit, the extraction easiness of the resource and the accessibility to the deposit are also to be taken in consideration.

The objective of the present study is to provide optimized guiding data for the sustainable production of Portland cement in Cameroon, using the multi-criteria approach.

2. Method

In recent years, several multi-criteria decision making techniques (MCDA) have been suggested to select the best materials for a particular application [5-8]. The selection of the most appropriate MCDA method is performed by comparing the property framework characterizing each MCDA method with the qualifications that the method must possess (the expected properties), depending on the decision problem to be solved and taking into account both the exogenous and endogenous variables. The weighting of the variables (optional action): A set of variables (representing the criteria) and their potential qualifications. In the present study, the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) II multi-criteria synthesis improvement method was chosen [9].

2.1. Materials

Table 1 indicates the main limestone deposits in Cameroon. They are located in South-west, South, Littoral and North Regions.

<table>
<thead>
<tr>
<th>Region</th>
<th>Deposit</th>
<th>Code</th>
<th>Geographic location</th>
<th>Area (S)</th>
<th>Depth (H)</th>
<th>% of CaCO₃</th>
<th>Estimated capacity (tons)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>Figuil</td>
<td>D1</td>
<td>9°45'32&quot; X 13°57'32&quot; Y</td>
<td>320 ha</td>
<td>35 m</td>
<td>90</td>
<td>600000</td>
<td>[10-13]</td>
</tr>
<tr>
<td></td>
<td>Bidzar</td>
<td>D2</td>
<td>14°7' X 9°53'45&quot;</td>
<td>-</td>
<td>-</td>
<td>95</td>
<td>2 500000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Leb-Ngog</td>
<td>D3</td>
<td>10°1’38&quot; X 3°55'27&quot;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Koanalep</td>
<td>D4</td>
<td>10°0'1’41&quot; X 3°56'00&quot;</td>
<td>-</td>
<td>35 m</td>
<td>66</td>
<td>-</td>
<td>[11]</td>
</tr>
<tr>
<td></td>
<td>Logbadjeck</td>
<td>D5</td>
<td>10°0’1’15&quot; X 3°55'55&quot;</td>
<td>-</td>
<td>42 m</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ngol</td>
<td>D6</td>
<td>9°45'52&quot; X 4°51'00&quot;</td>
<td>-</td>
<td>-</td>
<td>98</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mungo Balangui</td>
<td>D7</td>
<td>4°30' X 4°31'50&quot;</td>
<td>-</td>
<td>-</td>
<td>93,5</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kompina</td>
<td>D8</td>
<td>9°35'22&quot; X 4°21'25&quot;</td>
<td>-</td>
<td>5 m</td>
<td>-</td>
<td>10 000000</td>
<td>[13, 14]</td>
</tr>
<tr>
<td>Littoral</td>
<td>Mintom</td>
<td>D9</td>
<td>13°40'30&quot; X 2°10'00&quot; and 2°40'01&quot;</td>
<td>700 ha</td>
<td>-</td>
<td>98</td>
<td>1458 000000</td>
<td>[14]</td>
</tr>
<tr>
<td></td>
<td>Bogongo</td>
<td>D10</td>
<td>9°0'7 X 4°3'7&quot;</td>
<td>-</td>
<td>-</td>
<td>76,32</td>
<td>-</td>
<td>[15]</td>
</tr>
<tr>
<td>South</td>
<td>Lobé</td>
<td>D11</td>
<td>9°05'25&quot; X 4°34'25&quot;</td>
<td>50 ha</td>
<td>7-8 m</td>
<td>92,5</td>
<td>-</td>
<td>[4, 10]</td>
</tr>
<tr>
<td></td>
<td>Moko</td>
<td>D12</td>
<td>8°54' X 4°50' and 8°55' X 4°52'</td>
<td>0,2-9 m</td>
<td>51</td>
<td>-</td>
<td>-</td>
<td>[4]</td>
</tr>
</tbody>
</table>

2.2. PROMETHEE II Multi-criteria Method

In this study, the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) II multi-criteria synthesis improvement method [9] have been chosen because it relies on the elementary mechanism which is the two-to-two comparison of actions according to each criterion. It is based on the weighting of threshold criteria and produces a ranking of actions, [16]. PROMETHEE II makes a judicious comparison of two alternatives in each criterion in order to determine the partial binary relations presenting the preferences of the alternatives «a» on the alternative «b» [9, 17]. After considering a set of actions A= {a₁, a₂, a₃, ..., aₘ}, it classifies these actions by comparing them in pairs. Each action is compared to others on the basis of the criteria considered. The evaluation of the actions is carried out by a real function. For each criterion, the set G = {g₁, g₂, ..., gₙ} containing the evaluation of the action on all the criteria is defined. The importance of the criteria in decision-making is evaluated by a set of weights W = {w₁, w₂, ..., wₙ}. For this method, the difference, preference and veto thresholds depend on the evaluation of the action for each criterion. For an action a, evaluated by gᵢ(a) for the criterion j, in this case the difference threshold is noted qᵢ(gᵢ(a)), the preference threshold pᵢ(gᵢ(a)) and the standard deviation σᵢ(gᵢ(a)). These thresholds depend on the evaluations of the actions according to each criterion; they can vary in an interval from 10 to 20% around their initial value in order to take account of uncertainty relating to the data [18].

Taking into account an uncertainty of 10%, the following proposal can be made:

\[ pᵢ = 2 \times 10\% \times \max_{aₖ} (gᵢ(aₖ) - gᵢ(aₗ)) \]

\[ qᵢ = 10\% \times \max_{aₖ} (gᵢ(aₖ) - gᵢ(aₗ)) \]

\[ σᵢ = 3 \times 10\% \times \max_{aₖ} (gᵢ(aₖ) - gᵢ(aₗ)) \]

The value of the preference function is either 0 or 1 and it is defined separately for each criterion [16]. These evaluations mainly involve quantitative data and require two types of additive information, namely: relative import information which is the weight of the criterion considered and information of the preference function used when comparing the contributions of the alternatives for each criterion.
2.3. Weight Coefficient

The weight measures the relative importance of the criteria as seen by the decision maker. This measure is not always easily determined by the decision maker in many situations. Methods for evaluating the weights of the criteria [19] are developed to overcome this difficulty. The weighing of the criteria therefore corresponds to the attribution of a weight to each chosen criterion which can be determined by several methods among which: the weighted analysis, the weighted vote, the entropy method and the hierarchization criteria [20]. In this study, the entropy method is retained because the weight reflects the experience of the decision-makers and their insights.

2.4. Preference Function

The PROMETHEE methods are based on an extension of the notion of criterion by the introduction of a function expressing the Preference $F_j(a, b)$ the decision-maker have for an action $a_1$ with respect to another action $a$. For each criterion, the decision-maker is called to choose one of the six curve shapes represented in table 2. The parameters relating to each curve represent indifference and / or preference thresholds.

<table>
<thead>
<tr>
<th>Function</th>
<th>Expressions</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usual</td>
<td>$-\text{Immediate \ strict preference; }$ $-\text{No parameters to be determined.}$ $F_j(a, b) = \begin{cases} 1 \text{ if } g_j(a) &gt; g_j(b) \ 0 \text{ if } g_j(a) \leq g_j(b) \end{cases}$</td>
<td></td>
</tr>
<tr>
<td>U-shape</td>
<td>$-\text{There is an indifference threshold (quasi-criterion) that must be set.}$ $F_j(a, b) = \begin{cases} 1 \text{ if } g_j(a) - g_j(b) &gt; q_j \ 0 \text{ if } g_j(a) - g_j(b) \leq q_j \end{cases}$</td>
<td></td>
</tr>
<tr>
<td>V-shape</td>
<td>$-\text{The preference grows up to a preference threshold that must be set.}$  $F_j(a, b) = \begin{cases} 1 \text{ if } g_j(a) - g_j(b) &gt; p_j \ \frac{g_j(a) - g_j(b)}{p_j} \text{ if } 0 &lt; g_j(a) - g_j(b) \leq p_j \ 0 \text{ if } g_j(a) - g_j(b) \leq 0 \end{cases}$</td>
<td></td>
</tr>
<tr>
<td>Level</td>
<td>$-\text{There is an indifference threshold and a threshold of preference to be fixed (pseudo criterion); between the two, the preference is average.}$ $F_j(a, b) = \begin{cases} 1 \text{ if } g_j(a) - g_j(b) &gt; p_j \ \frac{2}{2} \text{ if } q_j &lt; g_j(a) - g_j(b) \leq p_j \ 0 \text{ if } g_j(a) - g_j(b) \leq q_j \end{cases}$</td>
<td></td>
</tr>
<tr>
<td>Linear</td>
<td>$-\text{There is an indifference threshold and a preference threshold to be set; between the two the preference is increasing.}$ $F_j(a, b) = \begin{cases} 1 \text{ if } g_j(a) - g_j(b) &gt; p_j \ \frac{g_j(a) - g_j(b) - q_j}{p_j - q_j} \text{ if } q_j &lt; g_j(a) - g_j(b) \leq p_j \ 0 \text{ if } g_j(a) - g_j(b) \leq q_j \end{cases}$</td>
<td></td>
</tr>
<tr>
<td>Gaussian</td>
<td>$-\text{The preference grows according to a Gaussian law whose standard deviation must be fixed.}$ $F_j(a, b) = 1 - \exp\left(-\frac{(g_j(a) - g_j(b))^2}{2\sigma^2}\right)$ (with $\sigma = \text{standard deviation}$)</td>
<td></td>
</tr>
</tbody>
</table>

2.5. Implementation of the PROMETHEE II Method

The PROMETHEE II method is implemented as follows:

Step 1 : For each criterion, one of the six forms of curves proposed above, and the parameters associated with it are chosen.

Step 2 : For each pair of shares $(a_i, a_k)$, the preferably global matrix (degree of over classing) is calculated as follows:

$$P(a_i, a_k) = \frac{\sum_{j=1}^{n} w_j \times F_j(a_i, a_k)}{\sum_{j=1}^{n} w_j}$$  (1)

Step 3 : The outgoing ($\Phi^+(a_i)$) and the incoming ($\Phi^-(a_i)$) flows for
each action $a_i$ are calculated as follows:

$$\Phi^+(a_i) = \sum_{a_k \in A} a_k \geq a_i P(a_i, a_k)$$ (2)

Positive flow that expresses the strength of $a_i$: outgoing flow;

$$\Phi^-(a_i) = \sum_{a_k \in A} a_k \leq a_i P(a_i, a_k)$$ (3)

Negative flow which expresses the weakness of $a_i$: incoming flow.

Step 4: Arranging shares in descending order of net flows $\Phi(a_i)$ defined as follows:

$$\Phi(a_i) = \Phi^+(a_i) - \Phi^-(a_i)$$ (4)

At the end, PROMETHEE II provides a total pre-order.

2.6. Evaluation of Criteria

Seven criteria (Ci) used in the present study are detailed below. Each criterion is split in three levels or sub-criterion

(1) (C1): Calcium carbonate content ($\text{CaCO}_3$) generally called "carbonate titration" [3], which varies from one deposit to another. When $\text{CaCO}_3$ content $\geq 80\%$, the source is said to be prior; for $75\% \leq \text{CaCO}_3$ content $< 80\%$, the source is acceptable and $\text{CaCO}_3$ content $< 75\%$, the source is unqualified [22, 23].

(2) (C2): Proximity of the limestone deposit to a qualified clay source. According to Spencer [2], the capacity of the clay source must be one-fifth of that of the limestone deposit. Its proximity to the limestone deposit reduces the costs of transporting this material. Based on previous studies, six major clay deposits have been identified for the production of Portland clinker (Table 3). The minimum distances between the limestone deposits and those of clays were estimated using the map of roads in Cameroon. Thus deposits located within 50 km of the limestone deposit are prior, those between 50 and 100 km are acceptable and those at more than 100 km, the transportation cost will be high.

Table 3. Qualified clay deposits in Cameroon for the production of Portland clinker.

<table>
<thead>
<tr>
<th>Region</th>
<th>Locality</th>
<th>Geographic location</th>
<th>Oxides</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>Figuil</td>
<td>13°57′46″</td>
<td>$\text{X}$, $\text{Y}$</td>
<td>$\text{SO}_2$, $\text{Al}_2\text{O}_3$, $\text{Fe}_2\text{O}_3$, $\text{CaO}$, $\text{MgO}$, $\text{K}_2\text{O}$, $\text{Na}_2\text{O}$</td>
</tr>
<tr>
<td>Centre</td>
<td>Etoa</td>
<td>11°27′</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Littoral</td>
<td>Bomkoul</td>
<td>9°48′</td>
<td></td>
<td></td>
</tr>
<tr>
<td>West</td>
<td>Mayoun</td>
<td>10°59′53″</td>
<td></td>
<td></td>
</tr>
<tr>
<td>North-West</td>
<td>Sabga</td>
<td>10°18′</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(3) (C3): Estimated capacity of the deposit: the potential must be exploitable for at least 30 years [30]. The qualification of the limestone deposit must be made according to the demand for cement [2]. In the case of Cameroon, the demand for cement is estimated at 3 million tons / year. Considering that, the production of Portland clinker requires $80\%$ of limestone, a deposit capacity equal or more than 72 million tons of limestone will be preferable. Otherwise between 48 millions and 17 millions tons would be acceptable but, less than 48 millions would not allow a return in investment.

(4) (C4): The area of the limestone deposit: that area is also a major criterion in the choice of limestone deposits. It must be greater than 300 ha [2]. Between 200 and 300 ha, the deposit can be acceptable in function of the depth of the layer of the ore. An area of less than 200 ha is negligible.

(5) (C5): Limestone extraction easiness: it depends if the deposit is open, deep or under water. This situation may affect the extraction of the material and the position or the activation of explosives. In this case, surfaced limestone is preferable, followed by deposits with material at negligible depth. Deposits underwater are less preferable.

(6) (C6) Accessibility to the limestone deposit: the paved road and the presence of the bridges on the watercourse facilitate access to the site to allow the exploitation and transportation of the material. The ideal would be that, the limestone deposit is close to a paved road for less than 50 km, between 50 and 100 km would be acceptable but more than 100 km, accessibility would be very difficult.

(7) (C7) Proximity of the limestone deposit to a source of energy production: energy cannot be neglected because the production of cement is energy intensive. The electricity consumption is between 70 and 160 kWh/ton of cement and this energy represents between 30 to 40% of the production cost of the cement. The main fuels used for firing clinker are: petroleum, coke, coal and lignin, some wastes, heavy fuel oil and gas [31]. In the context of Cameroon, the sources of energy selected are: hydroelectric and thermal power plants. Table 4 shows the energy sources and their minimum costs of transporting this material.

Table 4 shows the energy sources and their minimum distances from the limestone deposits. Distance of 50 km from the energy source would be ideal, between 50 and 100 km would be acceptable and at more than this distance, energy availability would be considered difficult.

Ref.
2.7. Criteria Weight Coefficients

In this work, all the criteria are weighted according to their degree of importance, by the weight coefficient by criterion and sub criterion. The determination of the weight of a criterion (table 6) was based on:

i. The experience observed in the application of this decision support tool;
ii. The specific data of each deposit obtained by the documentary analysis of the work carried out in this field, observations and existing infrastructures in the country;
iii. Opinions and suggestions of some actors in the field of industry, research and decision-making in the field of Portland cement [33].

The weights were distributed in such a way that: the chemical composition of the raw materials and the estimated capacity was attributed 20%, the proximity to a qualified clay source, the area of the deposit and the limestone extraction easeiness 15%, the accessibility 5% and proximity of an energy source 10%. The sum of the weight is 100% and the final coefficient retained is that obtained after multiplication of the weight of the criterion by the weight of the group [35] which is presented in Table 6. PROMETHEE II fully classifies alternatives from best to worst using the net flow. The analysis of the sensitivity of the results can be done according to the change of "weight" and "thresholds".

### Table 5. Calibration of the 7 criteria in the (1-10) scale.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$</td>
<td>80% $\leq$ CaCO$_3$ content $\leq$ 100%</td>
<td>10</td>
</tr>
<tr>
<td>$C_1$</td>
<td>75% $\leq$ CaCO$_3$ content &lt; 80%</td>
<td>8</td>
</tr>
<tr>
<td>$C_1$</td>
<td>CaCO$_3$ content &lt; 75%</td>
<td>6</td>
</tr>
<tr>
<td>$C_2$</td>
<td>A clay deposit located less than 50 km</td>
<td>5</td>
</tr>
<tr>
<td>$C_2$</td>
<td>A clay deposit located between 50 and 100 km</td>
<td>4</td>
</tr>
<tr>
<td>$C_2$</td>
<td>A clay deposit located further than 100 km</td>
<td>3</td>
</tr>
<tr>
<td>$C_3$</td>
<td>Deposit capacity $\geq$ 72 000 000 tons</td>
<td>5</td>
</tr>
<tr>
<td>$C_3$</td>
<td>Deposit capacity &lt; 72 000 000 tons</td>
<td>4</td>
</tr>
<tr>
<td>$C_4$</td>
<td>Deposit Area $\geq$ 300 ha</td>
<td>5</td>
</tr>
<tr>
<td>$C_4$</td>
<td>Deposit Area &lt; 300 ha</td>
<td>4</td>
</tr>
<tr>
<td>$C_5$</td>
<td>Deposit at the surface</td>
<td>3</td>
</tr>
<tr>
<td>$C_5$</td>
<td>Deposit at negligible depth</td>
<td>2</td>
</tr>
<tr>
<td>$C_6$</td>
<td>Underwater deposit</td>
<td>1</td>
</tr>
<tr>
<td>$C_6$</td>
<td>Limestone extraction easeiness</td>
<td>20</td>
</tr>
<tr>
<td>$C_7$</td>
<td>Proximity to a qualified clay source: (C$_2$)</td>
<td>15</td>
</tr>
<tr>
<td>$C_7$</td>
<td>Estimated capacity (C$_3$)</td>
<td>10</td>
</tr>
<tr>
<td>$C_7$</td>
<td>Area of the deposit (C$_4$)</td>
<td>15</td>
</tr>
<tr>
<td>$C_7$</td>
<td>Limestone extraction easeiness (C$_5$)</td>
<td>5</td>
</tr>
<tr>
<td>$C_7$</td>
<td>Accessibility to the deposit(C$_6$)</td>
<td>10</td>
</tr>
<tr>
<td>$C_7$</td>
<td>Proximity with an energy source(C$_7$)</td>
<td>10</td>
</tr>
</tbody>
</table>

### Table 6. Estimation of criteria final weights.

<table>
<thead>
<tr>
<th>Criteria description</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical composition (C$_1$)</td>
<td>20</td>
</tr>
<tr>
<td>Proximity to a qualified clay source: (C$_2$)</td>
<td>15</td>
</tr>
<tr>
<td>Estimated capacity (C$_3$)</td>
<td>20</td>
</tr>
<tr>
<td>Area of the deposit (C$_4$)</td>
<td>15</td>
</tr>
<tr>
<td>Limestone extraction easeiness (C$_5$)</td>
<td>15</td>
</tr>
<tr>
<td>Accessibility to the deposit(C$_6$)</td>
<td>5</td>
</tr>
<tr>
<td>Proximity with an energy source(C$_7$)</td>
<td>10</td>
</tr>
</tbody>
</table>

2.8. Application of the Method and Presentation of Results

Table 7 served as a content template in the "performances.xls" file and summarized the indifference and preference criteria. It presented the 1.8 preference threshold, the 0.9 indifference threshold and the 2.7 veto threshold, as well as the performance of the scores for each deposit in each criterion.

The first application consisted of the Usual, U-shape, V-shape, Level and Linear functions individually and by calculating each time the flows to classify the deposits in table 8. This presented a complete ranking of alternatives,
from best to worst based on their net flow. The second application consisted of varying only the Gaussian function and the results are shown in Table 9. The last application combined all the six functions of the PROMETHEE II method, calculated the flows and gave the ranking presented in Table 10. From the algorithm obtained, a Matlab program was realized which imported the performances edited in the Excel file. It collected for each resource, the evaluations of each criterion. The preference scales of criteria must be either increasing (value to be maximized) or decreasing (value to be minimized). At the end, it calculated the matrices of global preference, the flow vectors entering, leaving and finally the net flow.

The preference threshold is set at 20% of the difference between the highest score and the lowest one, while, the indifference threshold is set at 10% of the same difference. The preference threshold indicated that the strict preference (F\(a,b = 1\)) of the alternatives a on b is only observed if the difference in performance is greater than this threshold. At the indifference threshold, if the difference in performance is greater than this threshold. The preference scales of criteria must be either equivalent (\(F\(a,b = 0\)) [34].

### Table 7. Performances for the classification of limestone deposits.

<table>
<thead>
<tr>
<th>Alternatives (Limestone deposits)</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
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<tbody>
<tr>
<td>Weight</td>
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<td>15</td>
<td>20</td>
<td>15</td>
<td>15</td>
<td>5</td>
<td>10</td>
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<tr>
<td>Preferred Threshold</td>
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<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
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<td>Threshold of indifference</td>
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<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Threshold of veto</td>
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<td></td>
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<td>10</td>
<td>1</td>
</tr>
<tr>
<td>D2</td>
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<td>10</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>D3</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
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</tr>
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<td>10</td>
<td>1</td>
</tr>
<tr>
<td>D7</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>D8</td>
<td>10</td>
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<td>10</td>
</tr>
<tr>
<td>D9</td>
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<td>1</td>
<td>1</td>
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<tr>
<td>D10</td>
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<td>10</td>
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<td>D11</td>
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<td>1</td>
</tr>
<tr>
<td>D12</td>
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<td>1</td>
<td>1</td>
<td>5</td>
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</tr>
</tbody>
</table>

### Table 8. Flow matrix and classification of limestone deposits with variation of Usual, U-shape, V-shape, Level, and Linear functions.

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>D5</th>
<th>D6</th>
<th>D7</th>
<th>D8</th>
<th>D9</th>
<th>D10</th>
<th>D11</th>
<th>D12</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Phi^+)</td>
<td>3.4</td>
<td>4.9</td>
<td>2.5</td>
<td>1.75</td>
<td>2.25</td>
<td>2.22</td>
<td>2.23</td>
<td>3.25</td>
<td>5.7</td>
<td>1.2</td>
<td>1.15</td>
<td>0.15</td>
</tr>
<tr>
<td>(\Phi^-)</td>
<td>0.1</td>
<td>0.7</td>
<td>2.9</td>
<td>2.9</td>
<td>3.1</td>
<td>1.9</td>
<td>1.9</td>
<td>1.7</td>
<td>2.55</td>
<td>3.3</td>
<td>3.2</td>
<td>4.6</td>
</tr>
<tr>
<td>(\Phi)</td>
<td>2.4</td>
<td>4.2</td>
<td>-0.4</td>
<td>-2.05</td>
<td>-0.85</td>
<td>0.3</td>
<td>0.3</td>
<td>1.55</td>
<td>3.15</td>
<td>-2.1</td>
<td>-2.06</td>
<td>-4.45</td>
</tr>
<tr>
<td>Rank</td>
<td>3</td>
<td>1</td>
<td>7</td>
<td>10</td>
<td>8</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>11</td>
<td>9</td>
<td>12</td>
</tr>
</tbody>
</table>

### Table 9. Flow matrix and classification of limestone deposits with Gaussian function.

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>D5</th>
<th>D6</th>
<th>D7</th>
<th>D8</th>
<th>D9</th>
<th>D10</th>
<th>D11</th>
<th>D12</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Phi^+)</td>
<td>2.75</td>
<td>2.06</td>
<td>0.82</td>
<td>0.57</td>
<td>0.9</td>
<td>0.87</td>
<td>0.87</td>
<td>1.36</td>
<td>2.6</td>
<td>0.41</td>
<td>0.49</td>
<td>0.03</td>
</tr>
<tr>
<td>(\Phi^-)</td>
<td>0.46</td>
<td>0.32</td>
<td>2.12</td>
<td>1.47</td>
<td>0.12</td>
<td>1.22</td>
<td>0.8</td>
<td>0.8</td>
<td>0.57</td>
<td>0.94</td>
<td>1.45</td>
<td>1.23</td>
</tr>
<tr>
<td>(\Phi)</td>
<td>0.9</td>
<td>1.73</td>
<td>-0.38</td>
<td>-0.89</td>
<td>-0.31</td>
<td>0.07</td>
<td>0.07</td>
<td>0.78</td>
<td>1.66</td>
<td>-1.04</td>
<td>-0.73</td>
<td>-1.84</td>
</tr>
<tr>
<td>Rank</td>
<td>3</td>
<td>1</td>
<td>8</td>
<td>10</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>11</td>
<td>9</td>
<td>12</td>
</tr>
</tbody>
</table>

The results presented in Table 9 show that the Bidzar deposit is at the top of the rankings with an outflow of 2.06, an inflow of 0.32 and a net flow of 1.73 followed by the Mintom deposit with an outflow of 2.6, a flow of entering 0.94 and a net flow of 1.66. Ranked third was the Fiqilu deposit with an outflow of 1.37, an inflow of 0.46 and a net flow of 0.9. From the 7th position, the net flows also become negative, which shows that from this rank the deposits become

### 3. Results

#### 3.1. Performances and Flow Matrix

The results presented in Table 8 show that the Bidzar deposit is at the top of the rankings with an outflow of 4.9, an inflow of 0.7 and a net flow of 4.2 followed by the Mintom deposit with an outflow of 5.7, an inflow of 2.55 and a net flow of 3.15. The third rank was for the Fiqilu deposit with an outflow of 3.4, an inflow of 1 and a net flow of 2.4. The deposit of Komina is at the 4th rank. In the 5th rank are the Ngol and Mungo Balangui deposits with the same flows that are 2.2 as outflow, 1.9 as inflow and 0.3 as net flow. At the 7th rank, the net flow becomes negative, which shows that from this rank the deposits become unusable because the inflow is greater than the outflow. The unfavorable criteria are superior to the favorable operating criteria. The end of the ranking was occupied by the Bogongo deposit (11th position) deposit with an outflow of 1.2, an inflow of 3.3 and a negative net flow of 2.1 and finally the Moko deposit (12th position) with an outflow of 0.15, an inflow 4.6 and a negative net flow of 4.45.

The results presented in Table 9 show that the Bidzar deposit is at the top of the rankings with an outflow of 2.06, an inflow of 0.32 and a net flow of 1.73 followed by the Mintom deposit with an outflow of 2.6, a flow of entering 0.94 and a
The results presented in Table 10 show once more that the Bidzar deposit comes at the top of the rankings with an outflow of 4.36, an inflow of 0.43 and a net flow of 3.93 followed by the Mintom deposit with an outflow of 4.78, an inflow of 2.55 and a net flow of 2.23. In the third rank is the Figuil deposit with an outflow of 2.86, an inflow of 0.73 and a net flow of 2.13. The 5th position is occupied by the Ngol and Mungo Balangui deposits with the same outflow of 1.66, an inflow of 1.63 and net flow of 0.03. From the 7th position, the net flow also becomes negative. The end of classification is occupied this time by the Lobé deposit in 11th position with an outflow of 0.61, an inflow of 2.93 and a negative net flow of 2.32 and finally the Moko deposit with an outflow of 0.15, an inflow of 3.57 and a negative net flow of 3.42.

The results presented in Figure 1 show the high outflow for the Mintom deposit followed by Bidzar and the high inflow for the Moko deposit with a very low outflow justifying the fact that deposits with negative net flows do not fulfill the operating conditions.
The results presented in Figure 2 show the outflow almost half high from the value of Figure 1 for the Mintom deposit followed by Bidzar with a low inflow. The high inflow for the Moko deposit and an outflow almost equal to the net flow justify the fact that deposits with inflows greater than outflows do not fulfill the conditions of exploitation.

![Figure 3](image3.png)

*Figure 3. Histogram of Flows of limestone deposits with combination of the 6 functions.*

The results presented in Figure 3 show that the flow values of this figure are comparable to those of the Figure 1. Some deposits such as Kouamalep and Lobe have increased their inflow and are losing their positions.

### 3.2. Final Arrangement

The final arrangement consisted of ordering the actions in descending order of the scores $\Phi_a$ was defined as follows:

$$\Phi_a = \Phi^+(a) - \Phi^-(a).$$

Using Tables 8-10, the upgrade charts below from best to worst deposit was build.

![Figure 4](image4.png)

*Figure 4. Classification of limestone deposits with the Usual, U-shape, V-shape, Level and Linear functions.*

The upgraded chart in Figure 4 shows the ranking of the best to worst deposits as follows: the first is the Bidzar deposit, then Mintom, Figuil, Kompina, Mungo Balangui and Ngol at the same rank, Leb-Ngog, Logbadjeck, Lobe, Kouamalep, Bogongo, and finally the Moko deposit.

The over-classification graph of Figure 5 has the same classification as that of the graph of Figure 4, but with generally low net flow values.
4. Discussion of Results

The results show that:

1. The criteria with quantitative evaluation are prior the easiest to use for an aggregation. However, they present the problem of unit uniformity and require standardization at the level of the sub-criteria;

2. Qualitative criteria are tricky to manage and require the decision-maker's subjective intervention to score the actions on a discrete scale large enough to account for all the possible sensitivity aspects of the decision maker (for example, a scale from 0 to 10);

3. The PROMETHEE II method is easy and comprehensible for the user. It makes it possible to establish a net classification. Compared to the other methods of outclassing of synthesis, each solution has a
row which is clear.

(4) The results obtained after having varied each type of
criteria individually and simultaneously are
satisfactory. The order was identical from the first to
the sixth place. It proved that the PROMETHEE II
method is adapted to the analysis with a good stability
of results.

(5) The present method has established that each deposit
has a rank of its own. The values presented in figures 4
to 6 quantify the degree to which each field
outperforms (positive value) or is outperformed
(negative value) by others:

i. From the over-classification graphs (Fig. 4-5), it can
be seen that the applications with the first 5
functions of the PROMETHEE II method and the
Gaussian function give the net ranking of the
limestone deposits in Cameroon compared to the
combination of 6 functions that maintain the same
ranking of the first 6 deposits in which the deposits
of Bogongo and Kouamalep have outperformed the
Lobé deposit with a slight increase in flows as
shown in Fig. 6. The Moko deposit occupied the last
rank. The classification retained being the following:

ii. The best deposit is that of Bidzar. This deposit is
already being exploited by the first pure local
cement company producing 180,000 tons of clinker
per year [35]. This fact validated the precision of the
method;

iii. The Mintom deposit, which is estimated at
14,580,000 tons of raw materials with about 98%
CaCO₃, ranked second. This position of the deposit is
mostly due to the fact that the deposit is under the
river Dja [10] making it difficult to exploit despite its
important volume;

iv. The third is the Figuil deposit, which is not far from
Bidzar and could be exploited for cement production
by the local cement company in addition to the
Bidzar deposit;

v. The Kompina deposit is fourth and it is not yet
exploited like that of Mungo, Balangui and Ngol at
the same rank. Limestone deposits of Leb-Ngog,
Logbadjeck, Lobe, Kouamalep, Bogongo and Moko
obtained low ranks because of their low percentage
in CaCO₃ varies between 35 and 51%. The deposits
of Mungo Balangui and Ngol were ex-aequo in all
the various classifications showing similar
evaluation performance in the decision of investment
in cement production with these deposits;

vi. With only the matrix of evaluations, it could have
not be easy to have the idea about the best
alternative showing that the PROMETHEE II method
formalizes well the desired aggregation;

vii. The PROMETHEE II method with the Gaussian
function allowed a complete classification of
alternatives from the best to the worst according to
the net flows [34]. The change in the weight of the
criteria makes it possible to highlight the results of

the comparisons of the deposits. It showed that the
deposits of Bidzar and Mintom achieved the best
compromise between the criteria for the industrial
production of Portland clinker in Cameroon and they
are therefore the two best choices for that
investment.

5. Conclusion

This study was devoted to the application of the multi-
criteria selection tool for the optimization of the choice of
limestone deposits for the production of Portland clinker in
Cameroon. Data mining on about 12 limestone deposits and 6
important clay deposits in Cameroon were done. The
classification of limestone deposits was made on the basis of
comparisons of alternatives taking into account the chemical
characteristics of the raw material and the conditions of the
deposit which allowed the definition of a set of selection
criteria that was applied to each limestone deposit. These
criteria were: calcium carbonate (CaCO₃) content of
limestones, proximity of the limestone deposit to a qualified
clay source, estimate of its capacity, area covered by the
limestone deposit, extraction of limestone easiness,
accessibility to the limestone deposit and the proximity of the
limestone deposit to a source of energy. The multi-criteria
decision approach used was based on the PROMETHEE II
method. The application consisted firstly to vary individually
the functions: Usual, U-shape, V-shape, Level and Linear
function. Secondly, to fix only the Gaussian function and
finally to combine the 6 functions of PROMETHEE II
method. The calculation of the flows and the complete
ranking of the alternatives from best to worst according to
their net flow were done for each application. A program
created in Matlab software imported the performances edited
in the Microsoft Excel file, calculated the global preference
matrixes, the flow vectors entering or leaving and the net
flow. The ranking of potential actions on 12 deposits of
limestone in decreasing order has been made. At the end of
the investigation, it can be concluded that the Bidzar deposit
is at the forefront of the deposits making it possible to
achieve the best compromise between the criteria for the
production of Portland clinker in Cameroon followed of by
the Mintom deposit, despite the fact that it is the largest
deposit in term of raw materials volume when data on
deposits are considered individually. The tool was subjected
to a sensibility analysis (by varying the weights) to test its
consistency, stability and reliability. The optimized data
obtained in the present study could help investors and
decision makers in the choice of limestone deposits necessary
for the sustainable production of Portland clinker in
Cameroon.

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