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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 ($CaCO_3$) 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

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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 ($CaCO_3$) and clay that of silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3). 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 1. *Main limestone deposits in Cameroon.*

Region	Deposit	Code	Geographic location		Area (S)	Depth (H)	% of $CaCO_3$	Estimated capacity (tons)	Ref.
			X	Y					
North	Figuil	D1	9°45'32"	13°57'32"	-	-	90	600000	[10-13]
	Bidzar	D2	14°7’	9°53’45”	320 ha	-	95	2 500000	
Littoral	Leb-Ngog	D3	10°1’38”	3°55’27”	-	-	-	-	
	Koamalep	D4	10°01’41’	3°56’00”	-	35 m	66	-	[11]
	Logbadjeck	D5	10°01'15"	3°55'55"	-	42 m	-		
	Ngol	D6	9°45’52”	4°51’00”	-	-	98	10 000000	[13, 14].
	Mungo Balangui	D7	4°30’	4°31’50”	-	-	93,5	7- 9000000	[10]
	Kompina	D8	9°35'22"	4°21'25"	-	5 m	84 à 92		
South	Mintom	D9	13°40'30"	2°10'00" and 2°40'01"	700 ha	-	98	1458 000000	[14]
South-West	Bogongo	D10	9°07	4°37’	-	-	76,32	-	[15]
	Lobé	D11	9°05'25"	4°34'25"	50 ha	7-8 m	92,5	-	[4, 10]
	Moko	D12	8°54' and 8°55'	4°50' and 4°52'	-	0,2-9 m	51	-	[4]

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= $\{a_1, a_2, a_3, \dots, a_m\}$. 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 $G = \{g_1, g_2, \dots, g_n\}$ 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 $W = \{w_1, w_2, \dots, w_n\}$. 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 $g_j(a)$ for the criterion j, in this case the difference threshold is noted $q_j(g_j(a))$, the preference threshold $p_j(g_j(a))$ and the standard deviation $\sigma_j(g_j(a))$. 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:

$$p_j = 2 \times 10\% \times \max_{i;k}(g_j(a_i) - g_j(a_k))\ ;$$

$$q_j = 10\% \times \max_{i;k}(g_j(a_i) - g_j(a_k))\ ;$$

$$\sigma_j = 3 \times 10\% \times \max_{i;k}(g_j(a_i) - g_j(a_k))$$

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 of each criterion.

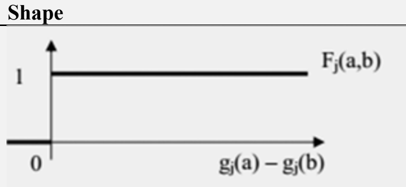
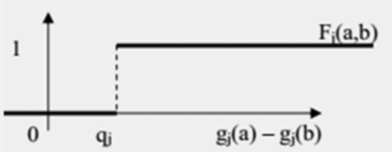
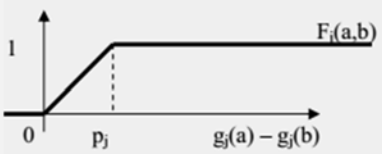
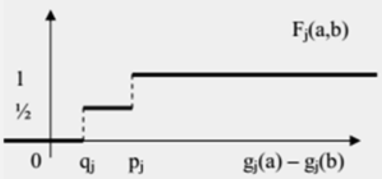
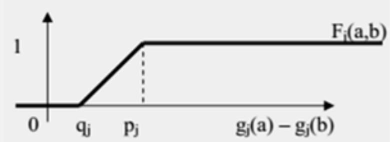
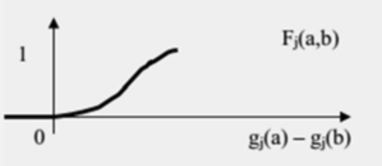
2.3. Weight Coefficient

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_i 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 2. *PROMETHEE preference function [21].*

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

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:

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

Step 3 :

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

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

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

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

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 :

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

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 splited in three levels or sub-criterion

(1) (C1): Calcium carbonate content ($CaCO_3$) generally called "carbonate titration" [3], which varies from one deposit to another. When $CaCO_3$ content ≥ 80%, the source is said to be prior; for 75%≤$CaCO_3$ content <80%, the source is acceptable and $CaCO_3$ 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.*

Region	Locality	Geographic location		Oxides							Ref.
		X	Y	S_iO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	
North	Figuil	13°57'46"	9°45'31	46.40	16.27	8.77	6.35	1.53	0.86	0.34	[24]
Centre	Etoa	11°27’	3°45’	50.11	24.80	5.42	0.48	0.46	0.67	0.04	[25]
Littoral	Bomkoul	9° 48′	4° 06′	48.01	27.41	7.34	0.06	0.31	0.31	0.02	[26]
West	Mayoum	10°59′53″	5°50′88″	63.02	25.79	0.16	<id	<id	0.87	<id	[27]
	Lembo (Mont Bana)	10°20′	5° 57′	68.10	21.60	1.04	0.03	0.062	2.57	0.093	[28]
North-West	Sabga	10°18′	6°02′	68.23	13.57	6.60	0.68	0.44	0.44	0.21	[29]

(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 millions 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 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.

Table 4. *Hydroelectric dams, thermal power plants and gas plants in Cameroon [31].*

Region	Locality	Geographic location		Waterways	Potential cement plant to be fueled	Capacity
		X	Y			
	Hydroelectric dams					
North	Lagdo	13°58'00"	8°53'00"	Bénoué	-Figuil (121km) -Bidzar (143km)	72 MW
South	Mekin	10°23’37”	2°24’09”	Dja	Mintom (15km)	15 MW
	Edéa	10°07'45"	03°48'41"	Sanaga	- Leb-Ngog (16km) - Kouamalep (15km)	276 MW
	Heavy fuel oil plant					
Littoral	Yassa-Dibamba	9°42'	4°03'		- Logbadjeck (10 km) - Ngol(158km) - Mungo Balangui (117km) - Kompina (45km)	86MW
South-West	Limbe	9°13'	4°00'		-Bogongo (116km) - Lobe (157km) - Moko (163km)	85 MW

An important step in a decision analysis is the stage where the decision maker structures the hierarchy of criteria in the decomposition of groups into sub-criteria. In the framework of this study, 7 different evaluation criteria are defined and the values of the scores are given on the basis of quantitative and qualitative measures. The scale of 1 to 10 is used for the calibration of the criteria described analytically [32]. Then their characteristics are shown in Table 5. The ranking of deposit as a function of one criterion is done by scoring. The first alternative obtains high scores on particular criteria, the second the half and the last obtain the low scores.

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

Criteria	Description	Score
C_1	80%<$CaCO_3$ content ≤ 100%	10
	75% ≤ $CaCO_3$ content <80%	5
	$CaCO_3$ content< 75%	1
C_2	A clay deposit located less than 50 km	10
	A clay deposit located between 50 and 100km	5
	A clay deposit located further than 100 km	1
C_3	Deposit capacity ≥ 72 000 000 tons	10
	48 000 000 tons ≤ Deposit capacity < 72 000 000 tons	5
	Deposit capacity <48 000 000 tons	1
C_4	Deposit Area ≥ 300 ha	10
	200 ha≤ Deposit Area < 300 ha	5
	Deposit Area < 200 ha	1
C_5	Deposit at the surface	10
	Deposit at negligible depth	5
	Underwater deposit	1
C_6	Bituminous road within 50 km	10
	Bituminous road between 50 and 100 km	5
	Bituminous road located further than 100 km	1
C_7	Deposit within 50 km of an energy production unit	10
	Deposit between 50 and 100 km from an energy production unit	5
	Deposit located more than 100 km from an energy production unit	1

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 easiness 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 6. *Estimation of criteria final weights.*

Criteria description	Weight
Chemical composition (C_1)	20
Proximity to a qualified clay source: (C_2)	15
Estimated capacity (C_3)	20
Area of the deposit (C_4)	15
Limestone extraction easiness (C_5)	15
Accessibility to the deposit(C_6)	5
Proximity with an energy source(C_7)	10

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 matrixes 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 $(F_j(a, b) = 1)$ 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 the performance of the criteria of two alternatives a and b in a criterion is lower than this threshold, they are considered as equivalent $(F_j(a, b) = 0)$ [34].

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 Figuil deposit with an outflow of 3.4, an inflow of 1 and a net flow of 2.4. The deposit of Kompina 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.

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

		Criteria						
		C1	C2	C3	C4	C5	C6	C7
Weight		20	15	20	15	15	5	10
Preferred Threshold		1.8	1.8	1.8	1.8	1.8	1.8	1.8
Threshold of indifference		0.9	0.9	0.9	0.9	0.9	0.9	0.9
Threshold of veto		2.7	2.7	2.7	2.7	2.7	2.7	2.7
Alternatives (Limestone deposits)	D1	10	10	1	1	10	10	1
	D2	10	10	1	10	10	10	1
	D3	1	5	1	1	10	1	10
	D4	1	5	1	1	5	1	10
	D5	1	10	1	1	5	5	10
	D6	10	1	1	1	10	10	1
	D7	10	1	1	1	10	10	1
	D8	10	10	1	1	5	5	10
	D9	10	1	10	10	1	10	10
	D10	1	1	1	1	10	10	1
	D11	10	1	1	1	5	1	1
	D12	1	1	1	1	5	1	1

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

Alternatives	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
Φ+	3.4	4.9	2.5	1.75	2.25	2.2	2.2	3.25	5.7	1.2	1.15	0.15
Φ-	1	0.7	2.9	3.8	3.1	1.9	1.9	1.7	2.55	3.3	3.2	4.6
Φ	2.4	4.2	-0.4	-2.05	-0.85	0.3	0.3	1.55	3.15	-2.1	-2.06	-4.45
Rank	3	1	7	10	8	5	5	4	2	11	9	12

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

Alternatives	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
Φ+	1.37	2.06	0.82	0.57	0.9	0.87	0.87	1.36	2.6	0.41	0.49	0.03
Φ-	0.46	0.32	1.21	1.47	1.22	0.8	0.8	0.57	0.94	1.45	1.23	1.87
Φ	0.9	1.73	-0.38	-0.89	-0.31	0.07	0.07	0.78	1.66	-1.04	-0.73	-1.84
Rank	3	1	8	10	7	5	5	4	2	11	9	12

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 Figuil 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 unusable. The end of the ranking is once more occupied by the Bogongo and the Moko deposits.

Table 10. *Flow matrix and classification of limestone deposits with combination of the 6 functions.*

Alternatives	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
Φ+	2.86	4.36	2.12	1.37	1.87	1.66	1.66	2.33	4.78	1.2	0.61	0.15
Φ-	0.73	0.43	2.14	3.04	2.34	1.63	1.63	1.7	2.55	2.27	2.93	3.57
Φ	2.13	3.93	-0.02	-1.67	-0.47	0.03	0.03	0.63	2.23	-1.07	-2.32	-3,42
Rank	3	1	7	10	8	5	5	4	2	9	11	12

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.

From the Excel spreadsheet, the flow histogram showing the outflow, inflow and net flow from each deposit according the application from tables 8-10 was plotted (Figure 1-3).

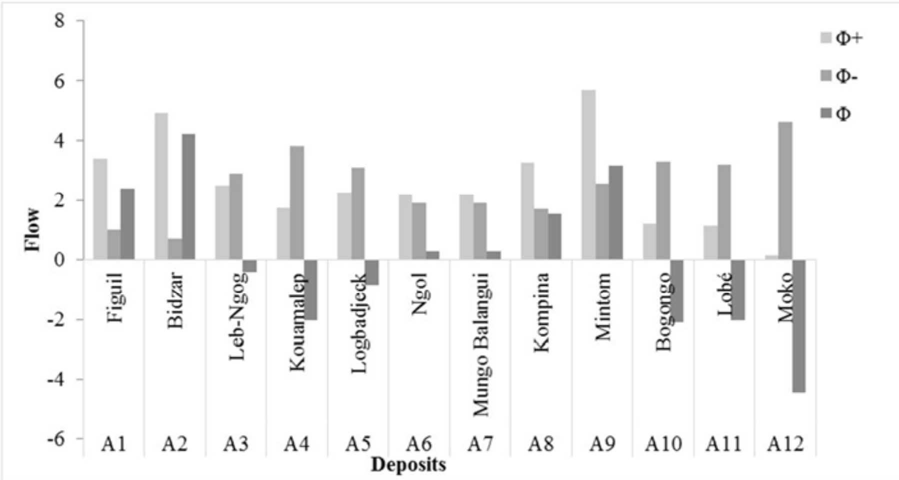


Figure 1. *Histogram of Flows of limestone deposits with Usual, U-shape, V-shape, Level and Linear functions.*

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 furfill the operating conditions.

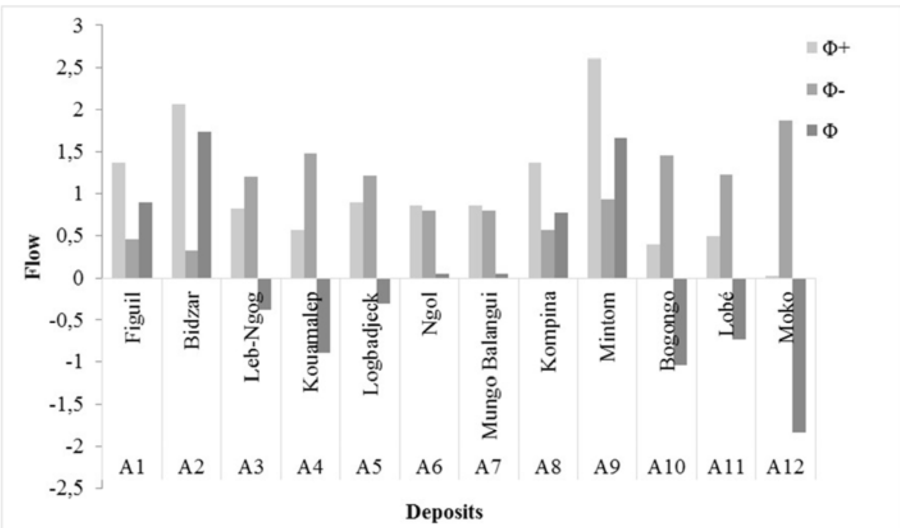


Figure 2. *Histogram of flows of limestone deposits with Gaussian function.*

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.

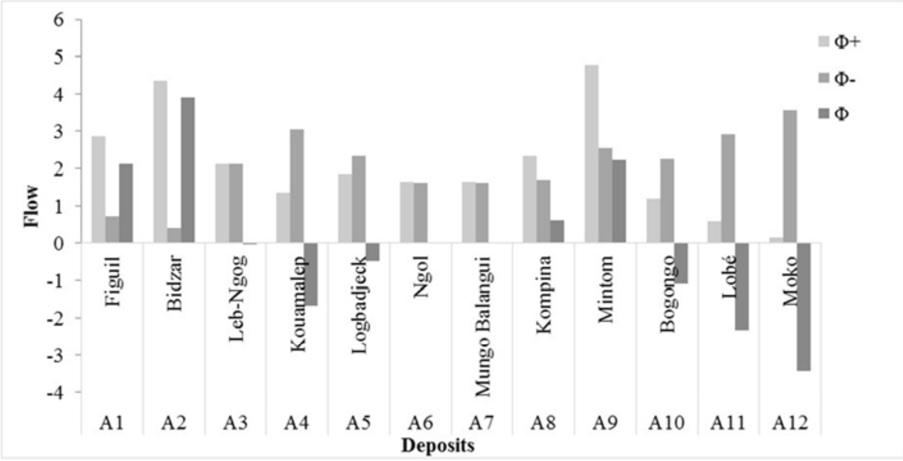


Figure 3. *Histogram of Flows of limestone deposits with combination of the 6 functions.*

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 $\Phi(a_i)$ was defined as follows: $\Phi(a_i) = \Phi^+(a_i) - \Phi^-(a_i)$.

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

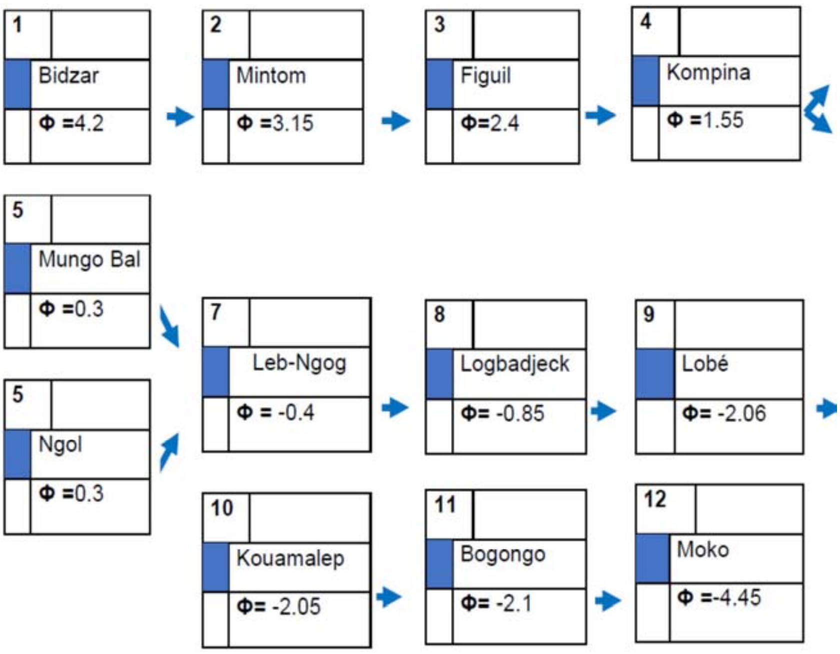


Figure 4. *Classification of limestone deposits with the Usual, U-shape, V-shape, Level and Linear functions.*

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.

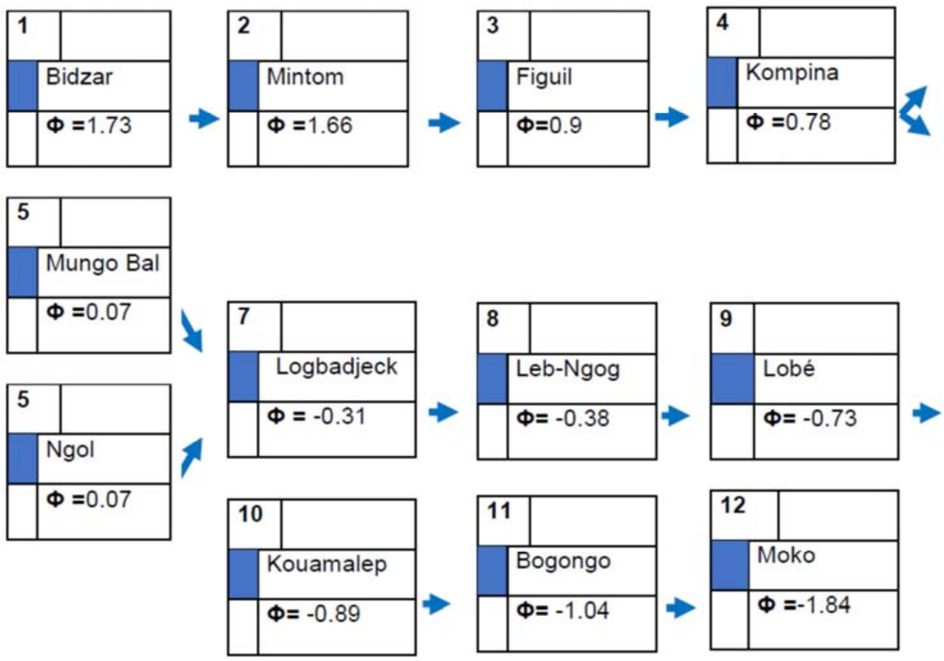


Figure 5. *Classification of limestone deposits with Gaussian function.*

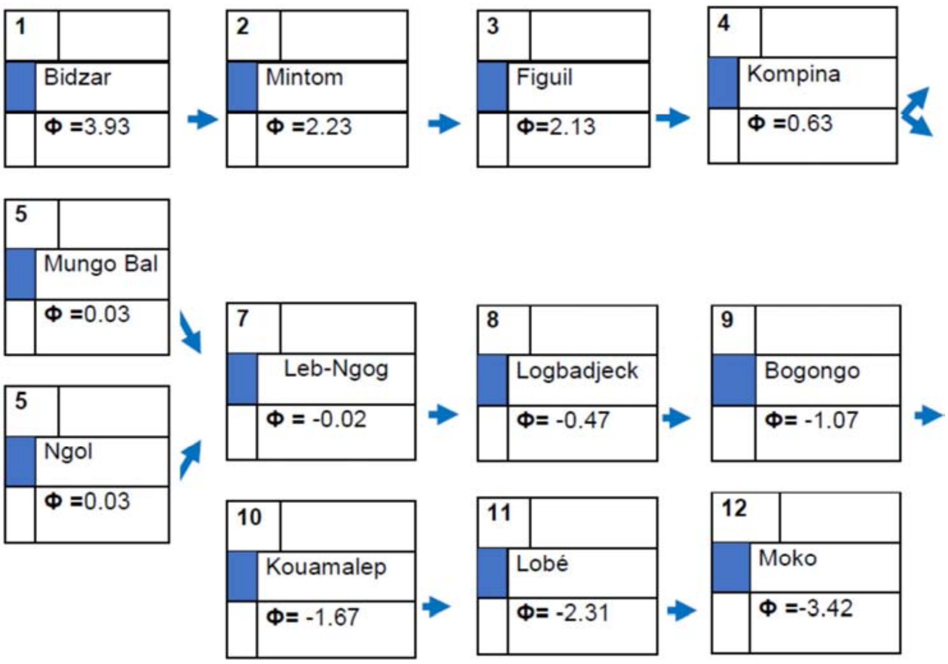


Figure 6. *Classification of limestone deposits with variation of the 6 PROMETHEE II functions.*

The upgraded chart in Figure 6 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, Bogongo, Kouamalep, Lobe and finally the Moko deposit.

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 1458,000,000 tons of raw materials with about 98% $CaCO_3$, 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 it 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 $CaCO_3$ 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 PROMETHE 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 Cameroun 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 ($CaCO_3$) 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.

References

[1] Bhattacharya A, Romani M, Stern N. Infrastructure for development: meeting the challenge, Orientation Document; Centre for climate change Economics and Policy, 2012, 20.

[2] Spencer C H. Memento rock and industrial minerals: cement materials, Ministry of Industry, Posts and Telecommunications and Foreign Trade, The company at the service of the earth, 1990, 50.

[3] Prax A. Memonto Useful Substances: Quarry Materials, Portland Clinker, office of Geological and Mining Research, Orléans Cédex; 79 SGN 148 MTX, 1979, 42.

[4] Agyingui C M, Epanty A F, Foba-Tendo J, Makoge E O, Muma P N, Kimbeng P. Preliminary investigation of some limestones and volcanic ash in the South West Province as raw matérials for the Cameroon cement industry, Afr J Build Mater 1999, 3(3):5-11.

[5] Bufardi A, Gheorghe R, Kiritsis D, Hirouchakis P. Multicriteria decision-aid approach for product end-of-life alternative selection, Int. J. Prod. Res. 42 (16); 2004, 3139-3157.

[6] Madić M, Radovanović M, Petković D, Nedić B. Multi-Criteria Analysis of Laser Cut Surface Characteristics in CO_2 Laser Cutting of Stainless Steel, Tribology in Industry. 37, 2, 2015, 236-243.

[7] Noryani M I, Sapuan S M, Mastura M T. Multi-criteria decision-making tools for material selection of natural fibre composites: A review, Journal of Mechanical Engineering and Sciences Malaysia, volume 12, issue 1, 2018, 3330-3353.

[8] Baudry G, Macharis C, Vallée T. Range-based Multi-Actor Multi-Criteria Analysis: A combined method of Multi-Actor Multi-Criteria Analysis and Monte Carlo simulation to support participatory decision making under uncertainty, Eur. J. Oper. Res., 264, 2018, 257–269.

[9] Brans J P, Mareschal B, Vincke Ph. PROMETHEE: a new family of outranking methods in multicriteria analysis, Operational Research'84, North Holland, 1984, 408-421.

[10] Regnoult J M. Synthese geologue du Cameroon, SODEXIC; Yaounde Google Scholar 1986.

[11] Gweth P N. Mineral Resources of Cameroon, SOPECAM Yaoundé, 2001, 375.

[12] Kahn H, Tassinari M M L, Ratti G. characterization of bauxite fines aiming to minimize their iron content, Minerals engineering, 2003, 1313-1315.

[13] Belinga SME. External dynamic geology of the tropical countries of the earth Africa - America - Asia. The landscapes of iron, GNOME; S.A.P, 1983, 193-206.

[14] Engon T C, Abessolo-Angue Abame M, Zo'o Zame P, Ekomane E, Bekoa E, Mvogo K, Bitom D. Morphological, physico-chemical and geochemical characterization of two weathering profiles developed on limestone from the Mintom Formation in the tropical humid zone of cameroon, Journal of African Earth Sciences, 2017, 1-16.

[15] Ndigui Billong. Optimization of the properties of materials based on lime-pozzolan binders: effect of hydrated lime, sodium hydroxide, water and sand or laterite, PhD Thesis, University of Yaounde I, 2011.

[16] Moalla Frikha H, Chabchoub H, et Marcel J M. An interactive approach for the determination of indifference thresholds in PROMETHEE. Faculty of Administration Sciences, Laval University, University campus, Québec(Qué), G1K 7P4, Canada, work Document 2007, 013:19.

[17] Macharis C, Springael J, De Brucher K, Verbeke A. Promethee and AHP: the design of operational synergies in multicriteria analysis. Strengthening PROMETHEE with ideas of AHP, European Journal of Operational Research, vol.153, n°. 2, 2004, 778-784.

[18] Lemaire S. Assisting in the selection of construction products based on their environmental and health performance, PhD Thesis: INSA of Lyon, 2006, 267.

[19] Maystre LY, Pictet J et Simos J. Méthodes multicritères ELECTRE, Lausanne : Presses Polytechniques et Universitaire Romandes, 1994, 323.

[20] Nijkamp P, Rietveld P, Voogd H M. Multicriteria Evaluation in Physical planning, Elsevier Science Publishers, Amsterdam 1990.

[21] Vincke P. Multicriteria aid to the decision, Brussels: Editions of the University of Brussels, 1989, 179.

[22] Neville A M. Properties of concrete, London: John Willey and Son, 1986, 19.

[23] Weldemar A. Cementitious materials: historical note, Material Science of Concrete I, 1987, 1-24.

[24] Yamb E, Ngwem Bayiha B, Ndigui Billong, Robertovna S I. Compatibility of Bidzar limestone and Figuil clay (Northern Cameroon) for the production of Portland clinker, International Journal of Materials Engineering and technology. Vol 15, N° 1, 2016, 63-73.

[25] Ngon Ngon G F. Morphological, geochemical and crystallographic study of laterite clays and hydromorphic clays of the Yaoundé region in tropical humid zone. Industrial trials and evaluation of their potential as building materials, Doctorate thesis. University of Yaounde I, Cameroon, 2007.

[26] Njopwouo D. Mineralogical and nanomorphological characteristics of two Cameroonian laterite zone clays and their influence on the properties of rubber-clay masterbatches, Rev. Sc. Tech. 2006, 170:223-234.

[27] Njoya D, Elimbi A, Nkoumbou C, Njoya A, Njopwouo D, Lecomte G, et al. Contribution to the physico-chemical and mineralogical study of mayoum clays (Cameroon), Aun. Chim. Sci. Mat, 2007, 55-68.

[28] Pialy P, Koumbou C, Villie F, Razafitianamaharavo A, Barres O, Pelletier M et al. Characterization for industrial applications of clays from lembo deposit, Mount Bana (Cameroon), Clay Minerals, 2008, 415-435.

[29] Wouatong A S L, Tchounang Kouonang S, Hawa Mohamed, Yerima K P, Melo Chinje U and Njopwouo D. Chemical and Mineralogical characterization of clayey deposits for traditional pottery and brickworks in the North West region of Cameroon (central Africa), British Journal of Applied science & Technology, 2015, 19-36.

[30] Institute of Energy and the Environment of the Francophonie (IEPF), the energy diagnosis of a cement plant, intergovernmental agency of the Francophonie. Technical sheet n° 1.

[31] Tchakounte J. Cameroun Tribune: Hydroelectric dams come out of the ground, Cameroon-Info.Net (page consulted on May 3, 2017), [on line], URL: http: //www.cameroon-info.net/article/cameroon-the-hydraulic-barrages-get-earth-245697.html, 2015.

[32] Szafranko E. Applicability of multi-criteria analysis methods for the choice of material and technology solutions in building structures, Mogućnost primjene metoda analize s više kriterija u izboru materijala i tehnoloških rješenja, 2017, 1935-1940.

[33] Guarini M R, Battisti F, Chiovitti A. A Methodology for the Selection of Multi-Criteria Decision Analysis Methods in Real Estate and Land Management Processes, Sustainability, 10, 2018, 507.

[34] Mergias I, Moustakas K, Papadopoulos A, Loizidou M. Multi-criteria decision aid approach for the selection of the best compromise management scheme for ELVs: The case of Cyprus, Journal of Hazardous Materials, 2007, 147:706-717.

[35] CIMENCAM, Study for the localization and potential for a cement industry in nothern Cameroon, Archive IRGM, 1965.