Hybird Fuzzy Decision Making Framework for Environmental Impact Assessment, Tangier, Morocco

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Abstract- The purpose of this paper is to implement a methodology based on stakeholder's judgment with assistance of fuzzy Multi-Criteria Decision Analysis (MCDA) methods to assess the environmental impact. Fuzzy Analytic Hierarchy Process (FAHP) is used as a multi-level decision-making tool taking into consideration human evaluation; it captures the vagueness in ordinal judgments obtained from stakeholder's filled questionnaires and translates them into priorities which are not vague. Fuzzy ELECTRE III, known as the elimination and choice translating reality method is employed to opt for a solution to mitigate the assessed impacts. Soil, underground, surface water, underground water, air, aquatic ecology, terrestrial ecology, public health, view, economy are the ten sub-criteria used in environmental impact assessment, they are subject to the appreciations of six stakeholders groups which represent the main decision makers (DM): neighbors, enterprises, keys actors, state departments, medias and research institutions. The set of alternatives comprises the creation of a new landfill site, creation of a new ringroad, installation of a recycling unit, installation of a lixiviat unit, installation of a biogas unit and soil stabilization. The use of combined Stakeholder's analysis, Fuzzy AHP and Fuzzy ELECTRE III are the distinguishing features of this paper, they form an integrated decision aiding framework that constitutes its novelty. It is applied on the linguistic judgments values to assess the environmental impact. This work proposes an integrated decision-making approach applied in the case study of the urban waste landfill of Tangier city in north Morocco.

Keywords- Environmental Impact Assessment (EIA); Fuzzy AHP; Fuzzy ELECTRE III; Stakeholders

I. Introduction

Municipal solid waste management (MSWM) encompasses the functions of collection, transfer, resource recovery, recycling and treatment. The primary target of MSWM is to protect the health of the population, promote environmental quality, develop sustainability and provide support to economic productivity. Waste management is a problem for most countries around the world because of the increasing volume of waste material and the paucity of places to deposit [1]. It has been a threat to environment and public health.

The aim of this paper is to succeed in implementing a decision framework based on fuzzy methods for the goal of assessing the environmental impacts; the result established a three time process articulated around stakeholders, Fuzzy Analytic Hierarchy Process (FAHP) and Fuzzy ELECTRE III.

In a first articulation, stakeholders concerned with environmental issues caused by the landfill of the city of Tangier were assisted into rationalizing their judgments and evaluations of the criteria involved in this matter by use of Fuzzy Analytic Hierarchy Process (FAHP) ; FAHP, which is the second articulation, is a Multi-Criteria Decision Analysis (MCDA) method devised to couple AHP's ability of organizing and analyzing a complex decision-making situation it acknowledges the psychological nature of humans in decision-making, a nature that is characterized by qualitative understanding that is better represented by fuzzy set theory rather than conventional set theory.

The third and last articulation is Fuzzy ELECTRE III which was adopted to easily convert linguistic preferences into fuzzy numbers for choosing the best action from a set of actions, its modeling of preferences with outranking relations is a complex algorithm trusted to render more reliable rankings than other MCDA procedures. A sensitivity analysis is conducted to evaluate the robustness of the rankings obtained; it is the last step of the framework and is based on testing the outranking process on several criteria weight combinations.

II. Literature Review

Currently, it is generally agreed that better decisions are implemented with less conflict and more success when they are driven by stakeholders [2]. The stakeholder analysis theory was born in the '60s as a tool for supporting management processes. It constitutes an approach for understanding a system by identifying the key actors, and assessing their respective interest in that system. There is a rich body of literature on approaches defining stakeholders [3]. Stakeholders can include “any group or individual who can affect or is affected by the achievement of the organization’s objectives” [4]. Many applications of stakeholder analysis can be found in several fields of study, including business management, international relations, policy development, participatory research and natural resource management [5,6,7,8]. As an analytical tool, the stakeholders theory has been applied many times in the context of project management [9] while the works in the domain of environmental decision-making are less consolidated. Stakeholder's analysis is powerful because the role of various stakeholders has been recognized as an influential factor in whether a technology succeeds or fails [10]. Rosso et al. speak of five steps to respect in decision-making processes involving stakeholders management, they form a continuous and iterative procedure : 1) Identification of all relevant stakeholders, 2) Documentation of stakeholders needs, 3) Analysis and assessement of stakeholders influence/interest, 4) Management of stakeholders expectations, 5) Design of actions, 6) Revision of the status and repetition of the procedure [3].

Hwang and Yoon (1981) have classified the MCDM methods into two categories: multi-objective decision making (MODM) and multi-attribute decision making (MADM) [11]. MODM has been widely studied by means of mathematical programming methods with well-formulated theoretical frameworks [12]. MODM methods have decision variable values that are determined in a continuous or integer domain with either an infinitive or a large number of alternative choices, the best of which should satisfy the DM constraints and preference priorities. MADM methods, on the other hand, have been used to solve problems with discrete decision spaces and a predetermined or a limited number of alternative choices. The MADM solution process requires inter and intra-attribute comparisons and involves implicit or explicit tradeoffs (Hwang and Yoon, 1981) [11]. Several methods have been proposed for solving MADM problems (i.e., Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS), Preference Ranking Organization Method (PROMETHEE) and (ELECTRE).

The AHP method breaks down a complex multi-criteria decision problem into a hierarchy and is based on a pair-wise comparison of the importance of different criteria and sub-criteria [13]. Each item (criterion, sub-criterion or alternative) would then be further divided into an appropriate level of detail. Once the hierarchy has been structured, decision makers judge the importance of each criterion in pair-wise comparisons, structured in matrices. The judgment is performed from the perspective of the direct upper level criterion [14]. AHP is a subjective method. Saaty suggested the AHP as a decision making tool to resolve unstructured problems [13]. Chang’s approach, which is utilized in this work [15], introduced the use of triangular fuzzy numbers for pairwise comparison scale of fuzzy AHP, and the use of the extent analysis method for the synthetic extent value Si of the pairwise comparison.

The ELECTRE (ELimination Et Choix Traduisant la REalité) method originated from Roy in the late 1960s. The ELECTRE method is based on the study of outranking relations and uses concordance and discordance indexes to analyze the outranking relations among the alternatives. Concordance and discordance indexes can be viewed as measurements of satisfaction and dissatisfaction that a decision-maker chooses one alternative over the other [16]. Fuzzy ELECTRE III was designed to deal with the impreciseness in data with the aim of reflecting the decision maker’s preferences when criteria are conflicting each other, it introduces the concept of pseudo-criteria and is based on outranking relations which simulate the fuzziness in comparison of alternatives and results from concordance, discordance and credibility indices [17,18]; the matrix of alternatives performances is based on linguistic evaluations equated with triangular fuzzy numbers. ELECTRE III was successfully implemented in vendor selection [19], group decision support [20], value engineering [21], mineral prospectivity mapping [22] and waste management [23,24] and environmental impact assessment [25]. ELECTRE III will use it in our work to rank the solutions addressing the current problems detected by the environmental analysis.

The Technique for Order Preference by Similarity to an ideal Solution (TOPSIS) is a widely accepted MCDM technique which is based on the concept that the ideal alternative has the best level for all attributes considered, whereas the negative-ideal is the one with all the worst attribute values. It defines solutions as the points that are simultaneously farthest from the negative-ideal point and closest to the ideal point. TOPSIS also provides an understandable structure and adaptable model calculation procedure. TOPSIS has the ability of taking various criteria with different units into account simultaneously. In fuzzy TOPSIS, qualitative data can be converted to fuzzy numbers which are then used in the calculations [26].

The central principle of PROMETHEE is based on the pairwise comparison of alternatives along each attribute that is to be maximized or minimized. The implementation of PROMETHEE requires relevant information concerning the weights and the preference function of the attributes. Structuring the decision problem and determining the weights are great weaknesses of PROMETHEE. The PROMETHEE method also suffers from the rank reversal problem. This means that, in some cases, the ranking of the alternatives can be reversed when a new alternative is introduced [12].

For the weight criteria step, Fuzzy AHP is quite well-proven to be applied for this purpose, which ensures the application at this case. Also, due to the considerable number of criteria evaluated by decision makers, is important to measure the consistency of the evaluation, and Fuzzy AHP allows it [42].

The choice for Fuzzy ELECTRE at this case study is justified by several reasons:

- It is a common applied method not only in solid The Fuzzy ELECTRE approach has a long history of successful practical applications in waste management [25] [43] [44] [45] [46]. These applications have paid special attention to the economic, technical, normative, social, political and environmental aspects of waste management decision processes and have provided great insight in related complex problems involving conflict analysis and resolution among different stakeholders and interest groups. With ELECTRE, the DMs are able to take into account economic and social attributes, in an effort to interlace local acceptance and financial viability of waste management problems [46]
- Applicable even when there is missing information [42].
- Applicable even when there are incomparable alternatives [42]
- Applicable even when incorporation of uncertainties is required [42].

III. Study Area

Positioned at (467000km, 571500km) in the Conical Conformal Lambert Zone I (the coordinate system of Morocco), Tangier's public landfill was put under use in 1970, it is located in the South East of the city, at 5 km from its center, on the Road "R.N.2" heading to the city of Tetouan.

Fig 1. Map of location of the landfill site

The landfill is limited in the South by a clay carrier and in the South West by an industrial neighborhood distant by 1km. In the West, at few hundreds of meters: a residential agglomeration is exposed to it. Only the Southern limit is actually limited with a fence, the remaining limits are accessible to the public.

Geologically its terrain is located on hills characterized by impermeable constitution based on Schist, Clay and marlstone, this advantage is disturbed by the presence of faults exposing the underground waters, at least two faults pass right through the site.

The hydrographic network is composed of two rivers surrounding the landfill: "Mghougha" and "M'laleh". These rivers are subject to lixiviat impact which flows along with their waters in the bay of Tangier. Also, the lixiviat can infiltrates the sub-surface waters but since no aquifer is directly located on the study area, the effect on underground waters is minimized while the danger for wells remains alarming.

Household wastes represent the prime contributor to the landfill with 83% of wastes coming from homes, this category of waste is composed from vegetal and animal organic substances (65%) causing odor pollution, especially knowing the wind blows from the landfill in the direction of Tangier one (1) day each five (5). Other categories of waste, both from households and industrial origins, are papers, plastic, tissues, metals, etc.

IV. Methodology

A. Stakeholders

A list of all potential groups of stakeholders was made, based on expert consultations according to the definition of Freeman (1984) [4]. The initial list was then rearranged to identify similar stakeholders that can be regrouped.

The list was sent back to the experts for validation. Finally, six large groups of respondents were formed based on their relation with the landfill and their knowledge.

Once the stakeholders are defined (fig. 4.), a questionnaire was conceived where each participant was asked to rate the importance of the impact caused by an environmental factor/criterion.

The factors/criteria were established by experts before being handed to stakeholders for evaluation; they consist of three major clusters: environmental pollution, ecological alteration and socioeconomic disturbance. The environmental pollution contains five indicators: soil, underground, surface water, underground water and air; the ecological alteration contains two indicators: aquatic and terrestrial; the socioeconomic disturbance includes three indicators: public health, view and economic. The evaluation of acceptability of impacts related to these indicators is based on judgment of diverse stakeholders and is intended to provide a human appraisal of the importance of the impact for each criterion.

B. Fuzzy AHP

In most of the real-world problems, some of the decision data can be precisely assessed while others cannot.

Humans are unsuccessful in making quantitative predictions, whereas they are comparatively efficient in qualitative forecasting [29].

Essentially, the uncertainty in the preference judgments gives rise to uncertainty in the ranking of alternatives as well as difficulty in determining consistency of preferences [30].

Zadeh (1965) has introduced the fuzzy set theory to deal with the uncertainty caused by imprecision and vagueness of data. Fuzzy set theory unlike other theories is capable of representing vague data. The theory also allows mathematical operators and programming be applied to the fuzzy domain. A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function, which assigns to each object a grade of membership ranging between zero and one [31]. In this work, we use triangular fuzzy numbers to represent a fuzzy number such that $F = \{X, \mu_F(x), X \in \mathbb{R}\}$, where X takes its value in $\mathbb{R}$, $-\infty \le x \le +\infty$ and $\mu_F(x) \in [0,1]$. A fuzzy number is denoted by $M = (a,b,c)$.

With $a \le b \le c$, the triangular membership functions:

$$\mu_{F(x)} = \begin{cases} 0 & x < a \\ \frac{x-a}{b-a} & a < x < b \\ \frac{c-x}{c-b} & b < x < c \\ 0 & x > c \end{cases} \qquad (1)$$

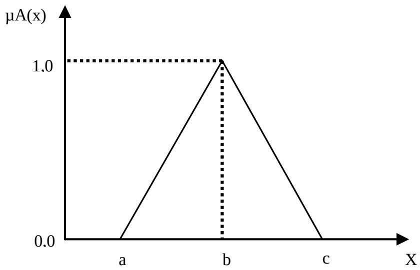

Fig 2. Fuzzy triangular number (a graphical representation)

The procedure of fuzzy AHP is presented as follows.

Step 1: Compare the scores of performance by using fuzzy numbers $(\breve{1},\breve{3},\breve{5},\breve{7},\breve{9})$, each fuzzy number $\breve{a}$ is the TFN $(a-1, a, a+1)$.

Step 2: Construct the fuzzy comparison matrix $\breve{A}(a_{ij})$ as follows:

$$\breve{A} = \begin{bmatrix} \breve{1} & \breve{a}_{12} & \cdots & \breve{a}_{1n} \\ \breve{a}_{21} & \breve{1} & \cdots & \breve{a}_{2n} \\ \cdots & & & \cdots \\ \breve{a}_{n1} & \breve{a}_{n2} & \cdots & \breve{1} \end{bmatrix} \quad (2) \qquad (2)$$

$$a_{ij} \begin{cases} 1 & i = j \\ \breve{1},\breve{3},\breve{5},\breve{7},\breve{9} \text{ or } \breve{1}^{-1},\breve{3}^{-1},\breve{5}^{-1},\breve{7}^{-1},\breve{9}^{-1} & i \ne j \end{cases}$$

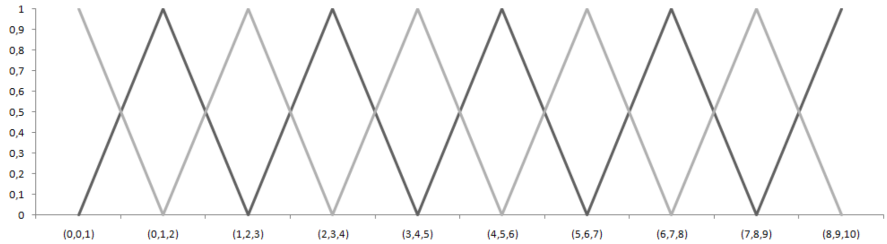

Fig 3. Triangular Fuzzy numbers used in the comparison matrix

Step 3: row sums (R_i) of the matrix $\breve{A}$:

$$R_i = \sum_{j=1}^{n} \breve{a}_{ij} \qquad (3) \tag{3}$$

R_i is a TFN, the sum in fuzzy sets is as follows:

$$R_i = \sum_{j=1}^{n} \breve{a}_{ij} = \sum_{j=1}^{n} (a_{ij}^{l}, a_{ij}^{m}, a_{ij}^{u}) = (\sum_{j=1}^{n} a_{ij}^{l}, \sum_{j=1}^{n} a_{ij}^{m}, \sum_{j=1}^{n} a_{ij}^{u})$$

$$R_i = (l_i, m_i, u_i)$$

Step 4: matrix sum (A):

$$A = \sum_{i=1}^{n} \sum_{j=1}^{n} \breve{a}_{ij} \qquad (4) \tag{4}$$

Step 5: the fuzzy synthetic extent for a criterion i is defined as per the equation :

$$S_i = R_i \times A^{-1} \tag{5}$$

The fuzzy arithmetic operations implied in this equation are carried in this fashion:

$$S_i = R_i \times A^{-1} = (l_i, m_i, u_i) \times \left(\left(\frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij}^{u}}, \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij}^{m}}, \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij}^{l}} \right) \right)$$

$$= \left(\frac{l_i}{\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij}^{u}}, \frac{m_i}{\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij}^{m}}, \frac{u_i}{\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij}^{l}} \right)$$

Step 6: the weight of a criterion i is:

$$W_i = \min V(S_i \geq S_k) \ where\ k = 1, \dots, n; k \neq i \tag{6}$$

V is the degree of possibility of S_i being greater than S_k ; it's a function comparing fuzzy TFNs:

$$V(S_i \geq S_k) = \begin{cases} 1 & if\ S_i \geq S_k \\ 0 & if\ l_k \geq m_i \\ \dfrac{l_k - u_i}{(m_i - u_i) - (m_k - l_k)} & otherwise \end{cases} \tag{7}$$

Step 7: if desired, the normalized weight of a criterion i is:

$$W'_i = \frac{W_i}{\sum_{i=1}^{n} W_i} \tag{8}$$

C. Fuzzy ELECTRE III

An important drawback of ELECTRE is the need for precise measurement of the performance ratings and criteria weights [33]. However, in many real-world problems, importance weights and performance ratings cannot be measured precisely as some DMs may express their judgments using linguistic terms such as low, medium or high [33]. The fuzzy set theory is ideally suited for handling these ambiguities encountered in solving MADM problems. Fuzzy logic – together with fuzzy arithmetic – could be used to develop procedures for treating vague and ambiguous information which is frequently expressed with linguistic variables and whose inaccuracy is not particularly due to the variability of the measures, but to the uncertainties inherent in the available information. Since Zadeh (1965) introduced fuzzy set theory, and Bellman and Zadeh (1970) described the decision making method in fuzzy environments, an increasing number of studies have dealt with uncertain fuzzy problems by applying fuzzy set theory [34,35].

In this article, we adopted the ELECTRE III method based on fuzzy sets, the method defines the concept of pseudo-criteria and resorts to weights (which will be collected from the FAHP method), the workflow is as shown in figure 4.

For a criterion j being considered, three thresholds q , p and v are defined that help compare the performances of two alternatives a and b [23] the comparison is an outranking relation R , aRb means “a outranks b” or “a is at least as good as b”, in fact [19]:

- If aRb and bRa , a is indifferent to b ,
- If aRb and NOT bRa , a is preferred to b ,
- If NOT aRb and NOT bRa then a is incomparable to b ,

The thresholds help evaluate these three cases of comparison with equations indicating either concordance or discordance.

The concordance index estimates for each pair of alternatives a and b the general comparison for all criteria, it is calculated as per (Eq. 9):

$$C(a,b) = \frac{1}{W}\sum_{j=1}^{n} w_j c_j(a,b) \tag{9}$$

Where $c_j(a,b)$ is defined as per (Eq. 10):

$$\begin{cases} 1 \; if \; q_j \geq g_j(a) - g_j(b) \\ 0 \; if \; p_j \leq g_j(b) - g_j(a) \\ \dfrac{g_j(a) - g_j(b) + p_j}{p_j - q_j} \; otherwise \end{cases} \tag{10}$$

The p and q are the preference and indifference thresholds, g_k is the performance function for a criterion k , thus, $g_k(a)$ would be the performance of alternative a for the criterion k .

The discordance index uses the veto threshold v to possibly overrule an outranking relation as measured by the concordance index, it is possible that an alternative a outranks b globally but still suffers an outranking from b for a particular set of criteria by an intolerable margin.

The discordance index is calculated as per (Eq. 11):

$$Dj(a,b) = \begin{cases} 0 \; if \; g_j(b) - g_j(a) \leq p_j \\ 1 \; if \; v_j \leq g_j(b) - g_j(a) \\ \dfrac{g_j(b) - g_j(a) - p_j}{v_j - p_j} \; otherwise \end{cases} \tag{11}$$

The degree of credibility of an outranking is determined by S function shown in (Eq. 12):

$$S(a,b) = \begin{cases} C(a,b) if \; \forall j \; D_j(a,b) \leq C(a,b) \\ C(a,b) \displaystyle\prod_{j \in \delta(a,b)} \frac{1 - D_j(a,b)}{1 - C(a,b)} \end{cases} \tag{12}$$

Where δ is the set of indices j where $D_j(a,b) > c_j(a,b)$.

Notice that if there’s only one criterion for which b outranks a whilst a outranks b in general, the credibility of “a outranks b” is lesser than $C(a,b)$, should $D_j(a,b) = 1$, we have: $S(a,b) = 0$ (i.e: "a outranks b" is a zero-credible statement”).

The distillation is a two phase process, it starts by descending ranking where the best rated alternatives are selected first then from worst to worst, an ascending ranking selects the worst alternatives and finishes with the best, the algorithm for these rankings uses the qualification score:

Step 1: Set $\lambda_{\max}$ such as $\lambda_{\max} = \max_{a,b\in A}\{S(a,b)\}$,

Step 2: A cutoff level of outranking $\lambda = \max_{\{S(a,b)<\lambda_{\max}-s(\lambda_{\max})\}}\{S(a,b)\}$, with $s(\lambda_{\max}) = \alpha - \beta\lambda_{\max}$.

Step 3: for each alternative a determine its $\lambda - strength$, i.e: the number of alternatives b with $S(a,b) > \lambda$, $strengh_{\lambda}(a) = Card(J), J = \{b \in A, S(a,b) > \lambda\}$

Step 4: for each alternatives a determine its $\lambda - weakness$, i.e: the number of alternatives b with $(1-s(\lambda))\times S(a,b) > S(b,a)$

$weakness_{\lambda}(a) = Card(J'), J' = \{b \in A, (1-s(\lambda))\times S(a,b) > S(b,a)\}$

Step 5: for each alternative determine its qualification Q which is:

$Q(a) = strength_{\lambda}(a) - weakness_{\lambda}(a)$

Step 6: the set of alternatives with largest (lowest) qualification is called the first distillate (D1) for the descending (ascending) distillation,

Step 7: If D1 has more than one alternative, repeat the process on the set D1 until all alternatives have been classified. If there is a single alternative, than this is the most preferred one. Then continue with the original set of alternatives minus the set D1, repeating until all alternatives have been classified.

For the final ranking there are several ways for combining both orders. The most frequent is the intersection of two outranking relations: aRb (a outranks b according to R) if and only if a outranks or is in the same class as b according to the orders corresponding to both relationships.

D. The Integrated Framework

The stakeholders analysis commences with experts suggesting each a list of stakeholders they think should be involved in the environmental assessment process, once the contribution of each expert is done, a set of all possible stakeholders is formed by aggregation of all these contributions, the exhaustive aggregated list is then subject to a selection process run by the experts. Ultimately, a set of selected stakeholders is extracted, and then it is hierarchized. All these steps constitutes the stakeholders analysis, a process aiming to recognize stakeholders capable of understanding the problem and assessing its gravity, in the form of verbal judgments, the identification of the problem and its performances are the work of experts. The verbal judgment of impact are transformed into triangular fuzzy numbers, these, coupled with the criteria that are extracted from the problem identification are run into Fuzzy AHP for weight extraction, thus, each criterion is endowed with a weight. Once the weights are determined, the alternatives and performances of alternatives resulting from the identification of the problem are run into the Fuzzy ELECTRE III process which ranks the alternatives. In more practical terms, the process is developed on these following steps:

Step 1: Stakeholders judges the severity of the impact on a Saaty-like scale; the question was how to convert these judgments from a quasi-verbal form into a numerical form; with FAHP, such conversion was possible. The stakeholders are handed forms and asked to express verbally their assessment of the environmental impact, each stakeholder emits factorial judgments of the impacts which are be aggregated into a general judgment, just as the global impact of the landfill is the aggregation of several environmental factors impacts. In this way, the FAHP weights express the contribution of an environmental factor (criterion) to the overall impact.

The values express fuzzy magnitudes of impact’s importance as estimated by stakeholders; the impact is declined in the defined ten criteria.

Step 2: formulating the pair-wise comparison matrix: the criteria are compared in view of their corresponding stakeholder’s score. The fuzzy AHP method calculation are run under Matlab 7.12.0 (R2011a), we obtain these weights per stakeholder per criterion and then deduce averaged values for criteria weights accounting equally all stakeholders.

Step 3: A list of waste management alternatives is established, the list includes: 1) planification and construction of a new landfill site, 2) a new ringroad, 3) a recycling unit, 4) a unit of lixiviat treatment, 5) biogas unit, 6) stabilization of landfill.

Planification and construction of new landfill site: this solution consists in changing the current landfill site and choosing a new waste disposal area, this choice must be sustainable and reduce the exposure of environment to the harms. MCDM and GIS can be applied to select the new site [36,37].

New ringroad: will reduce the transportation flux in the city roads leading to the landfill, thus increasing the air quality.

Recycling unit: represents an advanced feature in the management of waste disposals and can return economic and environmental benefits.

Unit of lixiviat treatement: The lixiviat of a dump is a used and complexe water generated the from a humid content [38], characterized by extremes of pH, biochemical oxygen demand and heavy metals: a combination of the chemical/physical and biological treatement is needed to maximize the efficiency of landfill leachate treatment [39].

Biogaz unit: Landfill biogas emissions contain mainly carbon dioxide and methane. In particular, the methane concentration can be higher than 50% by volume. This means that the calorific value of sanitary landfill biogas can be higher than 18,000 kJ/N m3; utilizing this gas to produce energy can reduce the landfill impact on the environment and represent a source for renewable energy [40].

Stabilization of landfill site's soil: mechanically stabilized earth (MSE) embankments, granular or sand compaction piles, vertical drains, and the lime/cement deep mixing method can present a means to prevent landfill's landslides.

Step 4 : To fill the performance matrix of the ELECTRE III method, we hand the matrix to the decision makers and ask them to use the ranking system in table 1. This system is an ordinal scale for the criteria, both discreet and qualitative [41].

TABLE I
The equivalence system used to convert verbal assessment into TFN

Verbal evaluation	**Description**	**TFN**
VUE	Very Uneffective	(0,1,2)
UE	Uneffective	(2,3,4)
ME	Moderatly Effective	(4,5,6)
E	Effective	(6,7,8)
VE	Very Effective	(8,9,10)

Since each verbal judgment {VUE, UE, ME, E, VE} is represented with a TFN, they can be replaced by these fuzzy numbers which are afterwards defuzzied as per (Eq -13):

$$\mathrm{DTFN}((l,m,u)) = \sqrt[3]{l^2 + m^2 + u^2} / \sqrt[3]{3} \qquad (13)$$

According to this formula, the TFN are defuzzied into values as shown in table 2.

TABLE II
Deffuzification table

TFN	**Defuzzied TFN**
(0,1,2)	1,29099445
(2,3,4)	3,10912635
(4,5,6)	5,06622805
(6,7,8)	7,04745817
(8,9,10)	9,03696114

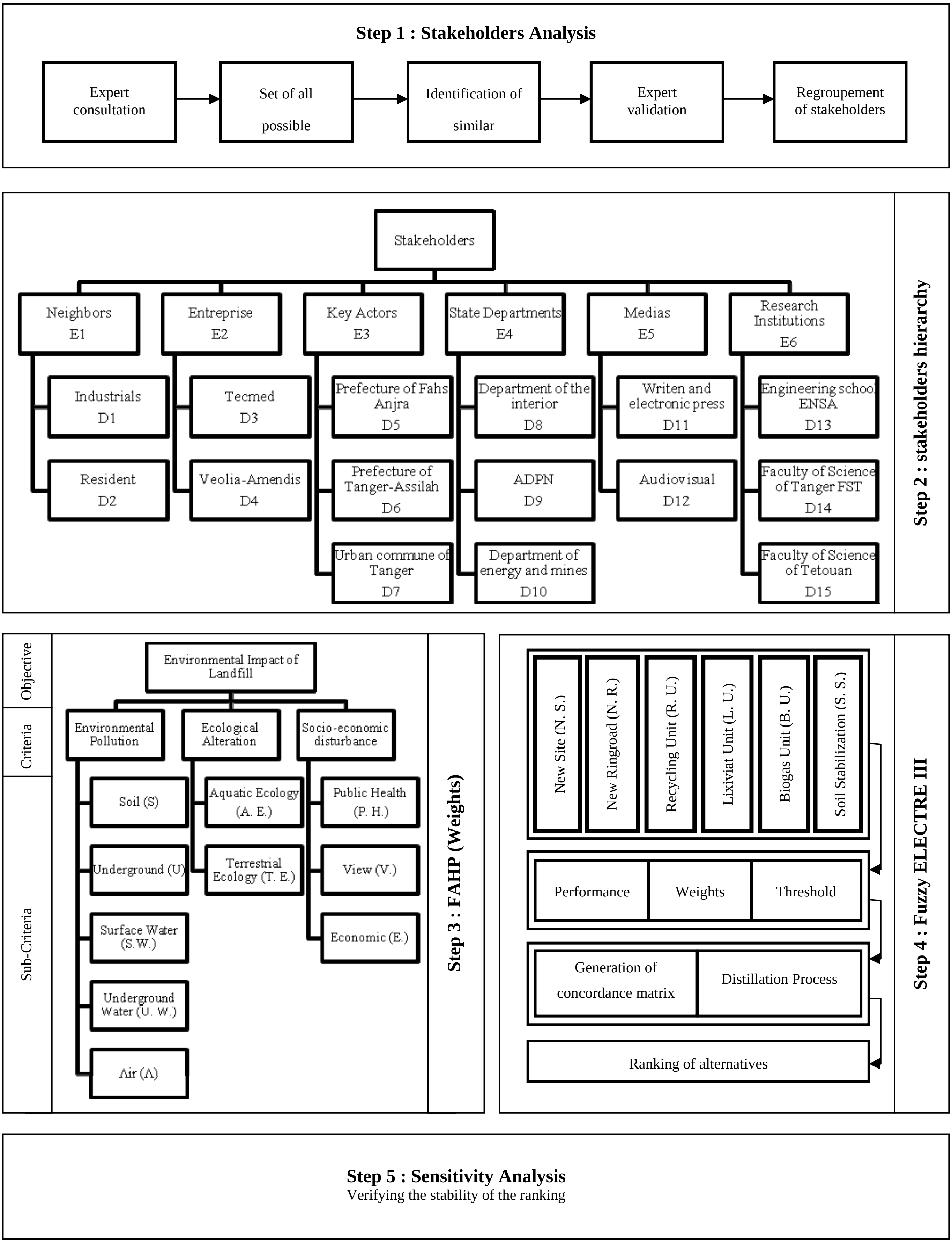

Fig 4. General schema of the adopted method

ELECTRE III hands the following outputs: an aggregated concordance matrix (Table 8.), an aggregated discordance matrix (Table 9.), a matrix of credibility (Table 10.), and rankings (figure 7, figure 8, Table 11.).

V. Results and Discussion

Table 3 shows the importance scores for the criteria as given by the stakeholders; it displays the ordinal judgments a stakeholder attribute to a criterion. As per this table, we can already notice that the judgments are severe, in fact, the weights that the Fuzzy AHP will be extracting cannot express the severity of judgments but only the difference between criteria, in table 3, we see that a great many deal of values are superior to five (i.e: $\breve{5}, \breve{7}, \breve{9}$). In fact, only 23 cells in table 3 hold a value of either $\breve{1}$ or $\breve{3}$, whereas the remainder of 135 cells (112 cells) is a high value (82,96%). Indeed, if we take out the neutral judgment (i.e: $\breve{5}$), the number of cells with a high value ($\breve{7}$, $\breve{9}$) amounts to 87, thus representing 64,44% of overall stated judgments.

TABLE III
The ordinal judgment values of the severity of impact as assessed by stakeholders

Stakeholder		U.	T. E.	U.W.	V.	A.	A. E.	S. W.	P. H.	S.	E.
E1	D1	$\breve{1}$	$\breve{5}$	$\breve{3}$	$\breve{9}$	$\breve{9}$	$\breve{1}$	$\breve{5}$	$\breve{9}$	$\breve{3}$	$\breve{7}$
	D2	$\breve{1}$	$\breve{3}$	$\breve{3}$	$\breve{9}$	$\breve{9}$	$\breve{1}$	$\breve{5}$	$\breve{9}$	$\breve{3}$	$\breve{3}$
E2	D3	$\breve{1}$	$\breve{3}$	$\breve{3}$	$\breve{1}$	$\breve{5}$	$\breve{1}$	$\breve{5}$	$\breve{9}$	$\breve{9}$	$\breve{7}$
	D4	$\breve{7}$	$\breve{7}$	$\breve{9}$	$\breve{9}$	$\breve{9}$	$\breve{3}$	$\breve{1}$	$\breve{9}$	$\breve{9}$	$\breve{3}$
E3	D5	$\breve{5}$	$\breve{7}$	$\breve{7}$	$\breve{7}$	$\breve{7}$	$\breve{7}$	$\breve{7}$	$\breve{5}$	$\breve{5}$	$\breve{5}$
	D6	$\breve{5}$	$\breve{7}$	$\breve{5}$	$\breve{7}$	$\breve{7}$	$\breve{5}$	$\breve{7}$	$\breve{9}$	$\breve{7}$	$\breve{7}$
	D7	$\breve{7}$	$\breve{9}$	$\breve{7}$	$\breve{7}$	$\breve{9}$	$\breve{7}$	$\breve{9}$	$\breve{9}$	$\breve{9}$	$\breve{7}$
E4	D8	$\breve{9}$	$\breve{7}$	$\breve{7}$	$\breve{7}$	$\breve{9}$	$\breve{7}$	$\breve{9}$	$\breve{9}$	$\breve{9}$	$\breve{5}$
	D9	$\breve{7}$	$\breve{9}$	$\breve{7}$	$\breve{9}$	$\breve{9}$	$\breve{7}$	$\breve{9}$	$\breve{9}$	$\breve{9}$	$\breve{7}$
	D10	$\breve{7}$	$\breve{7}$	$\breve{9}$	$\breve{9}$	$\breve{9}$	$\breve{7}$	$\breve{7}$	$\breve{9}$	$\breve{9}$	$\breve{9}$
E5	D11	$\breve{7}$	$\breve{5}$	$\breve{5}$	$\breve{9}$	$\breve{9}$	$\breve{5}$	$\breve{7}$	$\breve{9}$	$\breve{5}$	$\breve{5}$
	D12	$\breve{7}$	$\breve{9}$	$\breve{7}$	$\breve{9}$	$\breve{9}$	$\breve{7}$	$\breve{7}$	$\breve{9}$	$\breve{9}$	$\breve{7}$
E6	D13	$\breve{7}$	$\breve{7}$	$\breve{7}$	$\breve{5}$	$\breve{7}$	$\breve{7}$	$\breve{7}$	$\breve{9}$	$\breve{5}$	$\breve{3}$
	D14	$\breve{7}$	$\breve{9}$	$\breve{5}$	$\breve{3}$	$\breve{5}$	$\breve{9}$	$\breve{7}$	$\breve{7}$	$\breve{7}$	$\breve{3}$
	D15	$\breve{7}$	$\breve{7}$	$\breve{7}$	$\breve{3}$	$\breve{5}$	$\breve{7}$	$\breve{5}$	$\breve{7}$	$\breve{5}$	$\breve{3}$

TABLE IIV
Pair-wise comparison matrix of criteria for the "Entreprise" category of stakeholders

Enterprise	U.	T. E.	U.W.	V.	A.	A. E.	S. W.	P. H.	S.	E.
U.	$\breve{1}$	$\breve{1}$	$\breve{1/3}$	$\breve{1/3}$	$\breve{1/3}$	$\breve{3}$	$\breve{1}$	$\breve{1}$	$\breve{1/3}$	$\breve{1/3}$
T. E.		$\breve{1}$	$\breve{1/3}$	$\breve{1/3}$	$\breve{1/3}$	$\breve{3}$	$\breve{1}$	$\breve{1}$	$\breve{1/3}$	$\breve{1/3}$
U. W.			$\breve{1}$	$\breve{1}$	$\breve{1}$	$\breve{5}$	$\breve{3}$	$\breve{3}$	$\breve{1}$	$\breve{1}$
V.				$\breve{1}$	$\breve{1}$	$\breve{5}$	$\breve{3}$	$\breve{3}$	$\breve{1}$	$\breve{1}$
A.					$\breve{1}$	$\breve{5}$	$\breve{3}$	$\breve{3}$	$\breve{1}$	$\breve{1}$
A. E.						$\breve{1}$	$\breve{1/3}$	$\breve{1/3}$	$\breve{1/5}$	$\breve{1/5}$
S. W.							$\breve{1}$	$\breve{1}$	$\breve{1/3}$	$\breve{1/3}$
P. H.								$\breve{1}$	$\breve{1/3}$	$\breve{1/3}$
S.									$\breve{1}$	$\breve{1}$
E.										$\breve{1}$
Fuzzy AHP Weights	0	0	0,2	0,2	0,2	0	0	0	0,2	0,2

The pair-wise comparison matrix fills like shown in Table 4. Since this matrix is symmetrical, we only need to represent the upper triangle). In total, we fill 6 pair-wise comparison matrices, each one representing a group of stakeholders.

TABLE V
Weights of criteria as calculated by Fuzzy AHP, the last row is an average per column

	U.	T. E.	U.W.	V.	A.	A. E.	S. W.	P. H.	S.	E.
E1	0	0	0	0	0,33	0	0	0,33	0,33	0
E2	0	0	0,2	0,2	0,2	0	0	0	0,2	0,2
E3	0,25	0	0,25	0	0,25	0	0,25	0	0	0
E4	0,11	0,11	0,11	0,11	0,11	0	0,11	0,11	0,11	0,11
E5	0,2	0	0	0	0,2	0	0,2	0,2	0,2	0
E6	0	0	0	0	0	0	0,5	0,5	0	0
Average Weights	0,093	0,018	0,093	0,052	0,182	0	0,177	0,191	0,141	0,052

The FAHP is known for eliminating weak criteria, this explains the abundance of zeros, if a criterion obtains a null weight for a stakeholder, it does not justify eliminating it, only the case of the aquatic ecology (a.k.a "aquatic") deserved a null weight because it is insignificant for all stakeholders. The row of average weights is an arithmetic mean of all stakeholders weights for one criterion, each cell represents a weight for a criterion per a stakeholder, comparing the average weight of a criterion with its weight per stakeholders can reveal how the stakeholders tend to favor or disregard a criterion compared to the remaining stakeholders. Hence, the evaluations are points in the 3D space defined by the axes {weight, stakeholder, criteria}.

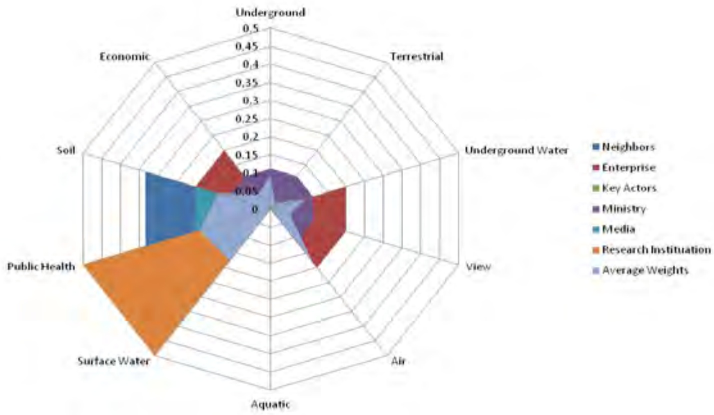

Fig 5. Radar plot comparing weights for criteria as per stakeholders

The average weights- which are the weights that will be used to continue the study- viewed the public health to be the most impacted and important factor/criterion (19%); the pollution of surface water (18%) and soil (14%) is the vector of the endangerment of public health, consequently, air can be linked to the contamination of soil and water which release biogases, knowing the presence of strong winds in the city of Tangier and the proximity of the landfill to the urban settlements, the weight of this criterion can be justified (18%).

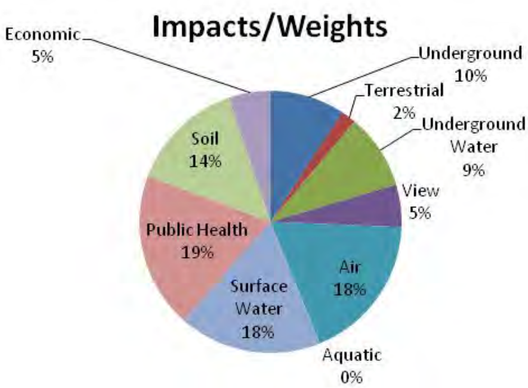

Fig 6. Average weights of criteria and their contributation to the environmental impact of the landfill in the city of Tangier

Each alternative is judged for its effectiveness in reducing the EI of the landfill. Table 6 displays the judgment values attributed by the stakeholders to the alternatives. In this table, the judgments are in there verbal form, they are converted into fuzzy triangular number then deffuzied in table 7 where they are inserted in the performance table of Fuzzy ELECTRE III method.

TABLE VI
Table of verbal performance ratings of alternatives

		Alternatives					
		A1	**A2**	**A3**	**A4**	**A5**	**A6**
U.	Cr1	VE	ME	ME	VE	VUE	E
T. E.	Cr2	VE	ME	UE	VE	VUE	E
U. W.	Cr3	VE	UE	VE	VE	VUE	UE
V.	Cr4	VE	UE	E	E	UE	UE
A.	Cr5	VE	ME	E	ME	E	VUE
A. E.	Cr6	VE	UE	VE	VE	ME	ME
S. W.	Cr7	VE	UE	E	E	ME	ME
P. H.	Cr8	VE	ME	E	VE	VE	VUE
S.	Cr9	VE	E	VUE	VUE	VUE	VUE
E.	Cr10	E	UE	VE	UE	UE	UE

TABLE VII
Performance rating matrix for Fuzzy ELECTRE III outranking process

		Wj (in %)	qj	pj	vj	Alternatives					
						A1	**A2**	**A3**	**A4**	**A5**	**A6**
U.	Cr1	9,35	1,82	3,77	7,75	9,04	5,07	5,07	9,04	1,29	7,05
T. E.	Cr2	1,85	1,82	3,77	7,75	9,04	5,07	3,11	9,04	1,29	7,05
U. W.	Cr3	9,35	1,82	3,77	7,75	9,04	3,11	9,04	9,04	1,29	3,11
V.	Cr4	5,18	1,82	3,77	7,75	9,04	3,11	7,05	7,05	3,11	3,11
A.	Cr5	18,23	1,89	3,77	7,75	9,04	5,07	7,05	5,07	7,05	1,29
A. E.	Cr6	0	1,82	3,77	7,75	9,04	3,11	9,04	9,04	5,07	5,07
S. W.	Cr7	17,68	1,82	3,77	7,75	9,04	3,11	7,05	7,05	5,07	5,07
P. H.	Cr8	19,07	1,82	3,77	7,75	9,07	5,07	7,05	9,04	9,04	1,29
S.	Cr9	14,07	1,82	3,77	7,75	9,04	7,05	1,29	1,29	1,29	1,29
E.	Cr10	5,18	1,82	3,77	7,75	7,05	3,11	9,04	3,11	3,11	3,11

TABLE VIII
Concordance matrix

	A1	**A2**	**A3**	**A4**	**A5**	**A6**
A1	1	0,71	0,15	0.6	0.1	0.38
A2	0.98	1	0,59	0,91	0,4	0,69
A3	0,98	0,86	1	0,84	0,48	0,77
A4	1	0,89	0,39	1	0,46	0,75
A5	1	0,99	0,98	1	1	0,91
A6	0,98	0,98	0,76	0,97	0,61	1

TABLE IX
Discordance matrix

	A1	A2	A3	A4	A5	A6
A1	0	0,14	0,20	0,15	0,60	0,37
A2	0,01	0	0,09	0,04	0,27	0,12
A3	0	0,07	0	0,07	0	0,07
A4	0	0	0,07	0	0,24	0,19
A5	0	0	0	0	0	0,05
A6	0,02	0	0,01	0,02	0,29	0

TABLE X
Credibility matrix

Alternatives	A1	A2	A3	A4	A5	A6
A1	1	0	0,01	0	0	0
A2	0,98	1	0,59	0,91	0,16	0
A3	0,98	0,86	1	0,84	0,47	0,77
A4	1	0,89	0,22	1	0	0
A5	1	0,99	0,98	1	1	0,91
A6	0	0,98	0,76	0	0	1

The graph of alternative's ranking shows the distillated ranking (fig. 7.) and none-distillated rankings (fig. 8.). In the none-distillated ranking, the outranking relations are displayed by an arrow directed from the outranked to the outranking alternative.

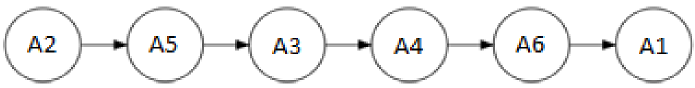

Fig 7. Distillated ranking of the six alternatives by ELECTRE III

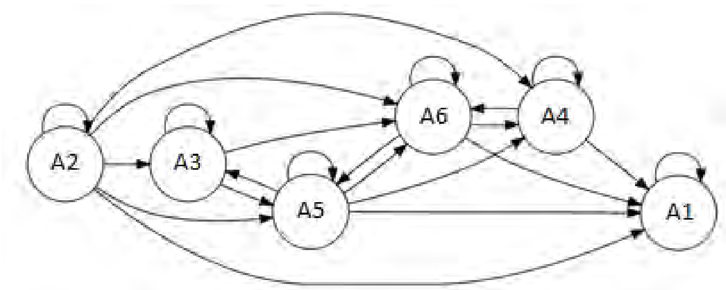

Fig 8. Non-distillated ranking of the six alternatives by ELECTRE III

TABLE XI
Definitive ranking of alternatives

Ranking	Label	Alternative
1	A1	Planification and Construction of new landfill site
2	A6	Stabilization of the landfill site's soil
3	A4	Unit of Lixiviat Treatment
4	A3	Recycling Unit
5	A5	BioGaz Unit
6	A2	Construction of new Ringroad

VI. SENSITIVITY ANALYSIS

A sensitivity analysis monitors the robustness of the preference ranking among alternatives [25], it proceeds by creating several weight combinations and executing the ELECTRE method for each one of them. The changes in rankings indicate to which extent the principal ranking -the one obtained by usage of Fuzzy AHP calculated weights- is stable.

TABLE XII
Weight combinations of criteria

	Cr1	Cr2	Cr3	Cr4	Cr5	Cr6	Cr7	Cr8	Cr9	Cr10
Current weights	0,093	0,018	0,093	0,052	0,182	0	0,177	0,191	0,141	0,052
Case 1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
Case 2	0,9	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011
Case 3	0,011	0,9	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011
Case 4	0,011	0,011	0,9	0,011	0,011	0,011	0,011	0,011	0,011	0,011
Case 5	0,011	0,011	0,011	0,9	0,011	0,011	0,011	0,011	0,011	0,011
Case 6	0,011	0,011	0,011	0,011	0,9	0,011	0,011	0,011	0,011	0,011
Case 7	0,011	0,011	0,011	0,011	0,011	0,9	0,011	0,011	0,011	0,011
Case 8	0,011	0,011	0,011	0,011	0,011	0,011	0,9	0,011	0,011	0,011
Case 9	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,9	0,011	0,011
Case 10	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,9	0,011
Case 11	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,9

Table 12 gives the weight combinations, the first row is the current weight combination, the second row (case 1) relates a case where all criteria have equal weights, the rest of the cases favor one criterion over all other. For each of the remaining cases -from two to eleven-, each time a criterion holds, in turn, 90% of the importance while the nine other criteria share the left 10%.

TABLE XIII
Ranking of alternatives for each weight combination

	Ranked 1	Ranked 2	Ranked 3	Ranked 4	Ranked 5	Ranked 6
Current weights	A1	A6	A4	A3	A5	A2
Case 1	A1	A6	A4	A3	A5	A2
Case 2	A1	A4	A6, A5	A3, A2	-	-
Case 3	A6	A3	A5	A1	A4	A2
Case 4	A1	A6	A4	A3	A5	A2
Case 5	A1	A6	A4	A3	A5	A2
Case 6	A1	A6	A5, A4, A3	A2	-	-
Case 7	A1	A6	A4	A3	A5	A2
Case 8	A1	A6	A4	A3	A5, A2	-
Case 9	A1	A6	A4	A3	A5	A2
Case 10	A5	A1	A6	A4	A3	A2
Case 11	A1	A6	A3	A4	A5	A2

In table 13, the resulting rankings show that the alternative A1 is ranked first ten times out of twelve, A6 is ranked second nine times out of twelve, A4, A3, A5 and A2 are ranked consecutively third, fourth, fifth and sixth seven times out of twelve. These results point out the overall stability of the ranking obtained by Fuzzy AHP calculated weights.

In the second case, A6 and A5 are both ranked third while A3and A2 rank fourth, in the sixth case A5, A4 and A3 rank all third and in the eighth case A5 and A2 rank both fifth; such observations suggest that the A4, A3, A5 and A2 can exchange rankings with regard to one criterion, meaning that these alternatives are relatively instable criterion-wise although being stable criteria-wise.

VII. CONCLUSIONS

Environmental Impact Assessment faces the difficulty of complexity due to the divergent fields implicated in it; this complexity causes the model to reduce the reality, thus inducing a loss in its predictive power, it is then necessary to lower any other source of prediction-loss, especially crispness in human judgments.

The work developed a combined AHP-ELECTRE-Stakeholders methodology to apply for the purposes of assessing the environmental impact. As for AHP and ELECTRE III, fuzzy sets allowed to capture the indecisiveness the stakeholders encounter in judging the importance of the impact of an environmental factor/criterion and rating the alternative solutions to mitigate this negative impacts. Such an approach is comprehensive in practicing Environmental impact assessment (EIA) in the perspective of decision makers (DM) and is designed to rationalize and confirm their intuitive conclusions.

Tangier is one of the largest cities of Morocco with consequent touristic and economic activities, the stakeholders, by virtue of the judgments of impact they gave, are overwhelmingly in accord about a negative judgment of the impact of the current landfill site on public health, surface water and air. This lead the DMs to favor the action of creating a new site for waste disposal, meanwhile the stabilization of current landfill’s soil and the installation of a lixiviat treatment unit were judged to consequently decrease the environmental impact.

In the future, this method should incorporate a more comprehensive robustness analysis, this will allow exploring result-variations, which is an even further step in capturing the indecisiveness of stakeholders.

REFERENCES

[1] El-Fadel, M.; Findikakis, A. N.; Leckie, J. O., "Environmental impact of solid waste landfilling", J. of Environmental Management vol. 50, pp. 1-25, 1997.

[2] Voinov, A., Bousquet, F., "Modeling with stakeholders", Environmental Modeling & Software, vol. 25, pp. 1268-1281, 2010.

[3] Rosso, M., Bottero, M., Pomarico, S., La Ferlita, S., Comino, E., "Integrating multicriteria evaluation and stakeholders analysis for assessing hydropower projects", Energy Policy, vol. 67, pp. 870-881, 2014.

[4] Freeman, R. E., Strategic Management: A stakeholder approach, Publisher: Pitman, Boston, 1984.

[5] Ramirez, R.., Stakeholder analysis and conflict management. In Cultivating Peace: Conflict and Collaboration in Natural Resource Management; Buckles D., Publisher: International Development Research Centre, The World Bank, Ottawa/Washington, 1999.

[6] Nash, R. ,Hudson, A., Luttrell, A., Mapping political context, a toolkit for civil society organization, Publisher: Overseas Development Institute, London, 2006.

[7] Kontogianni, A. D., Papageorgiou, E. I., Tourkolias, C., "How do you perceive environmental change? Fuzzy cognitive mapping informing stakeholder analysis for environmental policy making and non-market valuation", Appl. Soft Comput., vol. 12,pp. 3725–3735

[8] Starkl, M., Brunner, N. Flogl, W., Wimmer, J., "Design of an institutional decision-making process: the case of urban water management", J. Environ. Manag., vol. 90, pp. 1030–1042, 2009.

[9] Olanda, S., Landin, A., "Evaluation of stakeholder influence in the implementation of construction projects", International Journal of project Management, vol. 23, pp. 321-328, 2005.

[10] Abbassi, M., Mshrafi, M., Tashnizi, E., 2014, "Selecting balanced protfolios of R&D projects with interdependencies: a cross-entropy based methodology", Technovation, vol. 31(1), pp. 54-63, 2005.

[11] Hwang, C. I., Yoon, K., Multiple Attribute Decision Making Methods and Applications. Springer-Verlag, New York, 1981.

[12] Hatimi-Marbini, A., Tavana, M., Moradi, M., Kangi, F., "A fuzzy group ELECTRE method for safety and health assessment in hazardous waste recycling facilities", Safety Science, vol. 51, pp. 414-426, 2013.

[13] Saaty, T. L., The Analytic Hierarchy Process, McGraw-Hill, New York, 1977.

[14] Calabrese, A., Costa, R., Menichini, T., "Using Fuzzy AHP to manage intellectual capital assets: an application to the ICT service industry", Expert Systems with Application, vol. 40, pp. 3747-3755, 2010.

[15] Chang, D., "Applications of the extent analysis method on fuzzy AHP", European journal of operational research, vol. 95 (3), pp. 645-655, 1996.

[16] Kabak, M., Burmaoğlu, S., Kazançoğlu, Y., "A fuzzy hybrid MCDM approach for professional selection", Expert Systems with Applications, vol. 39 (3), pp. 3516–3525, 2012.

[17] Figueira, J., Mousseau, V., Roy, B., "Electre Methods", International Series in Operations Research & Management Science , vol. 78, pp. 133-153, 2005.

[18] Certa, A., Enea, M., Lupo, T., "ELECTRE III to dynamically support the decision maker about the periodic replacements configurations for a multi-component system", Decision Support Systems, vol. 55, pp. 126-134, 2013.

[19] Montazer, G. A., Saremi H. Q., Ramezani, M., "Design a new mixed expert decision aiding system using fuzzy ELECTRE III method for vendor selection", Expert Systems with Applications , vol. 36 (8), pp. 10837–10847, 2009.

[20] Leyva-Lopez, J. C., Fernadez-Conzalez, E., "A new method for group decision support based on ELECTRE III methodology", European journal of operational research, vol. 148, pp. 14-27, 2003.

[21] Marzouk, M. M.,"ELECTRE III model for value engineering applications", Automation in construction, vol. 20, pp. 596-600, 2011.

[22] Abedi, M., Ali Torabi, S., Norouzi, G., Hamzeh, M., "ELECTRE III: A knowledge-driven method for integration of geophysical data with geological and geochemical data in mineral prospectivity mapping", Journal of applied geophysics, vol. 87, pp. 9-18, 2012.

[23] Karagiannidis, A., Moussiopoulos, N., "Application of ELECTRE III for integrated management of municipal solid wastes in the greater Athens Area", Lecture Notes in Economics and Mathematical Systems , vol. 448, pp. 568-578, 1997.

[24] Hokkanen, J., Salminen, P., "Choosing a solid waste management system using multicriteria decision analysis", European Journal of Operational Research , vol. 98 (1), pp. 19–36, 1997.

[25] Kaya, T., Kahraman, C., "An integrated fuzzy AHP-ELECTRE methodology for environmental impact assessment", Expert Systems with Applications , 38 (7), 8553–8562, 2011.

[26] Ekmekcioglu, M., Kaya, T., Kahraman, C., "Fuzzy multicriteria disposal method and site selection for municipal solid waste", Waste Management, vol. 30, pp. 1729-1736, 2010.

[27] Kulak, O., Kahraman, C., "Fuzzy Multi-Criterion Selection Among Transportation Companies Using Axiomatic Design and Analytic Hierarchy Process", Information Sciences, vol. 170, pp. 191-210, 2005.

[28] Leung, L. C., Chao, D., "On Consistency and Ranking of Alternatives in Fuzzy AHP", European Journal of Operational Research, vol. 124, pp. 102-113, 2000.

[29] Kahraman, C., Cebeci, U., Ulukan, Z., "Multi-Criteria Supplier Selection Using Fuzzy AHP", Logistics Information Management, vol. 16 (6), 2003.

[30] Figueira, J., Greco, S., Ehrgott, M., Multiple Criteria Decision Analysis: State of the Art Surveys, Publisher: Springer, New York, 2005.

[31] Tsaur, S. H., Chang, T. Y., Yen, C. H., "The evaluation of airline service quality by fuzzy MCDM", Tourism Management, vol. 23, pp. 107–115, 2002.

[32] Yager, R. R., "Multiple objective decision-making using fuzzy sets", International Journal of Man–Machine Studies, vol. 9, pp. 375–382, 1997.

[33] Zimmermann, H. J., Fuzzy Set Theory and Its Applications, Publisher: Kluwer Academic Publishers, Boston, 1996.

[34] Sena, B., Süzen, M. L., Doyuran, V., "Landfill site selection by using geographic information systems", Environmental Geology, vol. 69 (3), pp. 376-388, 2006.

[35] Wang, G., Qin, L., Li, G., Chen, L., "Landfill site selection using spatial information technologies and AHP: a case study in Beijing, China", Journal of environmental management, vol. 90 (8), pp. 2414-2421, 2009.

[36] Wang, F., Smith, D. W., El-Din, M. G., "Application of advanced oxidation methods for landfill leachate treatment – A review", Revue du génie et de la science de l'environnement, vol. 2 (6), pp. 413-427, 2003.

[37] Keenan, J. D., Steiner, R. L., Fungaroli, A. A., " Landfill leachate treatment", Journal of Water pollution control federation, vol. 56 (1), 1984.

[38] Desideri, U., Di Maria, F., Leonardi, D., Proietti, S., "Sanitary landfill energetic potential analysis: a real study", Energy conversion and management, vol. 44 (12), pp. 1969-1981, 2003.

[39] Mouine, M., Combinaison de deux methods d'analyse de sensibilité, Université Laval, 2011.

[40] Pires, A., Chang, N., Martinho, G., "An AHP-based fuzzy interval TOPSIS assessment for sustainable expansion of the solid waste management system in Setubal Peninsula, Portugal", Resources, Conservation and Recycling, vol. 56, pp. 7-21, 2011.

[41] Perkoulidis, G., Papageorgiou, A., Karagiannidis, A., Kalogirou, S., "Integrated assessment of a new Waste-to-Energy facility in Central Greece in the context of regional perspectives". Waste Management, vol. 30 (7), pp. 1395–1406, 2010.

[42] Bojkovic, N., Anic, I., Pejcic-Tarle, S., "One solution for cross-country transportsustainability evaluation using a modified ELECTRE method". Ecological Economics vol. 69 (5), pp. 1176–1186, 2010.

[43] Banias, G., Achillas, C., Vlachokostas, C., Moussiopoulos, N., Tarsenis, S., "Assessing multiple criteria for the optimal location of a construction and demolition waste management facility". Building and Environment vol. 45 (10), pp. 2317–2326, 2010.

[44] Achillas, C., Vlachokostas, C., Moussiopoulos, N., Banias, G., "Decision support system for the optimal location of electrical and electronic waste treatment plants: a case study in Greece". Waste Management vol. 30, pp. 870–879, 2010.