AN EVALUATION MODEL FOR COMPANY ENVIRONMENTAL PRACTICES BASED ON INTERACTING CRITERIA

Rocío de Andrés Calle[1], **Teresa González-Arteaga**[2], **Luis Martínez**[3]

[1] *University of Salamanca*, rocioac@usal.es
[2] *University of Valladolid*, teresag@eio.uva.es
[3] *University of Jaén*, martin@ujaen.es

Abstract

Evaluation of the environmental performance is becoming more and more important for companies. In this work we present a multi-criteria decision model for evaluating company's environmental practices. This proposal involves a number of collectives of reviewers related to the company's activity directly or indirectly. In addition, it is considered quantitative and qualitative information with different scales according to the appraisers' knowledge. Due to the relationships among criteria we propose using the Choquet integral as an aggregation operator. The ultimate aim is to compute partial and global indicators that can be used to make decisions regarding the environmental issues.

Keywords: Multi-criteria decision making, Environmental performance, Non-homogeneous information, Choquet integral.

1 INTRODUCTION

Environmental issues are rapidly emerging as an important factor for business and management to consider. The ability of organizations to manage their environmental performance is emerging as a strategic issue for firms. Many studies have been reported about the relation between environmental performance and environmental management systems (see [14]) or the relation with business performance (see [3]) with a variety of results depending on diverse factors.

Environmentally conscious practices refer to programs to improve processes and products environmental performance in diverse forms like design for environment, recycling, waste management, life cycle analysis, green supply chain management, environmental certification (ISO 14000), environmental management systems (EMS), etc. They have evolved with influences from reactive and proactive policies taken by organizations (see [11] and [3]).

Even though evaluation of *environmental performance* (EP) is becoming more and more important recently, there is not a total agreement on what environmental performance is or how to measure it. As a consequence, every organization proposes a different way to define it and to do it (see [14],[3]).

It is recognized the importance to include multiple viewpoints of the concerned parties (see [3]) to increase internal efficiency and external legitimacy. However, many companies use formal methods based just on the opinion of one or various reviewers, in some cases from top environmental managers (see [11] and [3]). Then, the results of the evaluation process could not represent correctly the company environmental situation and they can be biased because the evaluation relies on reviewers that are not the only relevant people to evaluate company's environmental practices.

Several multi-criteria decision making approaches have been used as a basis to deal with environmental issues in various studies in the literature. Some examples of such approaches are Analytical Hierarchy Process (AHP) [10], Analytical Network Process (ANP) [15], grey relational analysis [13], Fuzzy TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) [1], and others specifically developed models.

Moreover, despite there are different types of criteria, quantitative and qualitative, most of the current methods provide only a quantitative precise modelling for their assessments. This fact can produce a lack of precision in the assessments provided by the reviewers for qualitative criteria due to the difficulty of expressing uncertain knowledge in a precise way.

In order to overcome the drawbacks associated with the previous established models to evaluate environmental practices, in this paper we propose a method where different sets of reviewers (internal and external, experts and non-experts) have to evaluate company's environmental practices attending to different criteria (quantitative and qualitative). Taking into account that the different groups of reviewers may have a different degree of knowledge about the company's environmental practices and the different criteria nature, we then propose a flexible heterogeneous framework in which appraisers may express their assessments by means of numerical or linguistic information according to the criteria nature. In addition, we propose the use of the Fuzzy Linguistic Approach to model qualitative information by means of linguistic variables (see [8]). This approach has been successfully used for this purpose in other evaluation fields and others topics (see [12]).

This paper is organized as follows. Section 2 is devoted to introduce the proposed MCDM model. Section 3 details the rating process that includes the aggregation phase. The paper ends pointing out some concluding remarks.

2 AN ENVIRONMENTAL EVALUATION MODEL

In this section, we present our proposal for evaluating company environmental practices based on a classic decision analysis scheme whose accommodation to our problem is showed in Figure 1.

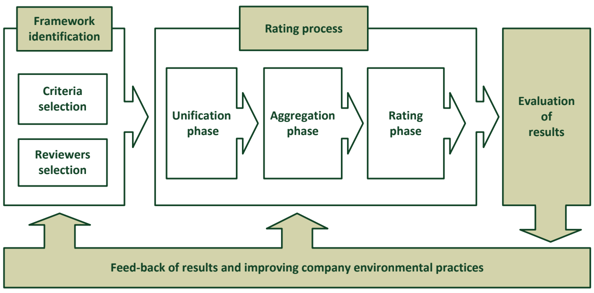

Figure 1: Decision scheme for evaluating company environmental practices

a) Framework identification. In this step of the evaluation process, the criteria and the reviewers of the company's environmental practices are identified.

• *Selection of criteria*. Environmental performance indicators (EPIs) are used to depict the vast quantity of environmental information of a firm in a comprehensive and concise manner. Following the standard ISO 14031, in this paper we consider two general categories of EPIs: *management performance indicators* (MPI) and *operational performance indicators* (OPI). The former provide information about management efforts in relation with the policy, people, practices, procedures, decisions and actions at all levels of the organization. The latter provide information about environmental performance relative to organization's physical facilities and equipment (material and energy flows). Following these categories of indicators we can distinguish two types of criteria associated to them: management criteria and operational criteria.

• *Selection of reviewers*. According to the standard itself [9], in this paper we propose an evaluation method where the assessments are carried out from diverse collectives related to the activity and not only from top environmental managers. Moreover, the proposal method distinguishes between experts and non-experts reviewers.

b) Rating process. To obtain a global environmental performance indicator of each facility site, all information provided by the appraisers must be aggregated. Due to the fact that the framework deals with heterogeneous information, this process is carried out in three phases:

(1) *Normalization and unification information phase*. As the different collectives provide information in different domains we cannot operate directly with it in order to accomplish computations required for the evaluation model. We conduct the original information into a common domain in the way we detail below.

(2) *Aggregation phase*. In this phase the information is aggregated considering different groups of reviewers and different criteria. We use a multi-step aggregation methodology (see Figure 2).

(3) *Rating phase*. The aim of this phase is ranking evaluated facility sites following the goals established by the Department of Environment.

c) Evaluation of the results. One of the most important aspect of an environmental practices evaluation process is to provide feedback about the environmental performance to facility sites. Based on the outcomes, the company can identify and prioritize opportunities for improving the environmental practices.

2.1 EVALUATION FRAMEWORK

In order to show how a company could carry out an environmental practices evaluation process, let us suppose a company which wants to evaluate the environmental practices of its facility sites. It is supposed the company has a set of facility sites $X = \{x_1, ..., x_n\}$ to be evaluated by the following collectives:

• **Internal reviewers**. This reviewers' collective, A, is composed by:

- A set of company's internal experts: $A^E = \{a_1^E, ..., a_m^E\}$.

- A set of company's internal non-experts such as managers, staff, employees, etc.: $A^{NE} = \{a_1^{NE}, ..., a_r^{NE}\}$.

• **External reviewers**. This reviewers' collective, B, consists of:

- A set of company's external experts such as auditors: $B^E = \{b_1^E, ..., b_s^E\}$.

- A set of company's external non-experts evaluators which is made up of two different reviewers' collectives:

1. A set of other "stakeholders" (shareholders, suppliers, government regulators, local communities, intermediate customers, large retailers, final consumers): $B^{NE-G} = \{b_1^{NE-G}, ..., b_t^{NE-G}\}$.
2. A set of social constituents (community groups, trade associations, labor unions, environmental groups): $B^{NE-S} = \{b_1^{NE-S}, ..., b_u^{NE-S}\}$.

Moreover, reviewers evaluate company environmental practices attending to two different types of criteria. Both of them may contain criteria of qualitative or quantitative nature. Due to this fact, we consider a general set of criteria C which includes two subsets of criteria, the quantitative C_1 and the qualitative C_2. The criteria structure is then the following:

- Management performance criteria $C^M = C_1^M + C_2^M$

$$C^M = \{c_k^M \mid c_k^M \in C_1^M \text{ or } c_k^M \in C_2^M,\ k = 1, \ldots, p\}$$

- Operational performance criteria $C^O = C_1^O + C_2^O$

$$C^O = \{c_k^O \mid c_k^O \in C_1^O \text{ or } c_k^O \in C_2^O,\ k = 1, \ldots, q\}.$$

Notice that the same criterion can not be evaluated using different expression domains, in consequence $C_1^M \cap C_2^M = \emptyset$ and $C_1^O \cap C_2^O = \emptyset$.

The assessments provided by the members of the different collectives of reviewers $a_{i,j}^E \in A^E$, $a_{i,j}^{NE} \in A^{NE}$, $b_{i,j}^E \in B^E$, $b_{i,j}^{NE-G} \in B^{NE-G}$ and $b_{i,j}^{NE-S} \in B^{NE-S}$ on the facility site x_j according to the criterion c_k^- are denoted by $a_{i,j,k}^E$, $a_{i,j,k}^{NE}$, $b_{i,j,k}^E$, $b_{i,j,k}^{NE-G}$ and $b_{i,j,k}^{NE-S}$, respectively. Therefore, there are at most $(m+r+s+t+u)(p+q)$ assessments for each locality site since each collective of reviewers could only assess the facility site attending to a number of them following the guidelines established by the Department of Environment.

In this paper we consider an evaluation model which mixes quantitative and qualitative criteria. As a consequence, reviewers can express their opinions for each criterion in different domains, depending on the criteria nature and attending to their knowledge about the evaluated criterion. In this way:

- $a_{i,j,k}^E \in \mathbb{R}^+ \bigvee S_{A^E}^k$ for $i \in \{1, \ldots, m\}$, $j \in \{1, \ldots, n\}$.
- $a_{i,j,k}^{NE} \in \mathbb{R}^+ \bigvee S_{A^{NE}}^k$ for $i \in \{1, \ldots, r\}$, $j \in \{1, \ldots, n\}$.
- $b_{i,j,k}^E \in \mathbb{R}^+ \bigvee S_{B^E}^k$ for $i \in \{1, \ldots, s\}$, $j \in \{1, \ldots, n\}$.
- $b_{i,j,k}^{NE-G} \in \mathbb{R}^+ \bigvee S_{B^{NE-G}}^k$ for $i \in \{1, \ldots, t\}$, $j \in \{1, \ldots, n\}$.
- $b_{i,j,k}^{NE-S} \in \mathbb{R}^+ \bigvee S_{B^{NE-S}}^k$ for $i \in \{1, \ldots, u\}$, $j \in \{1, \ldots, n\}$.

We can note that any appropriate linguistic term set S_-^k is characterized by its cardinality or *granularity*, $|S_-^k|$.

3 RATING PROCESS

Our proposal considers that reviewers can express their opinions about facility sites in different domains, numerical and linguistic according to the criterion to be evaluated and to the reviewer's knowledge and experience. Therefore and before carrying out the aggregation process, it is necessary to standardize or normalize all gathered information into a unique domain, the interval $[0, g]$, where g is the granularity of the linguistic common domain.

3.1 NORMALIZATION AND UNIFICATION PHASE

Since criteria used to evaluate environmental practices can be quantitative or qualitative, it is necessary to achieve the normalization process by means of two different ways depending on the criterion nature.

On the one side, if gathered information is about a quantitative criterion, we have to distinguish between benefit or cost criterion to accomplish accurately the normalization process. This classification of the quantitative criteria is made based on whether their value is positively or negatively related with the environmental impact incurred. Namely, the same criterion cannot be benefit and cost simultaneously

Let $y_{i,j,k}$ be the assessment of the reviewer j, referred to the facility site x_i over the quantitative criterion k. The normalized previous assessment is defined as $\widetilde{y}_{i,j,k}$ and is carried out as:

$$\widetilde{y}_{i,j,k} = \begin{cases} g\left(\frac{y_{i,j,k}}{y_{k\,max}}\right), & \text{if } k \text{ is a benefit criterion,} \\ g\left(1 - \frac{y_{i,j,k}}{y_{k\,max}}\right), & \text{if } k \text{ is a cost criterion,} \end{cases}$$

where $y_{k\,max}$ is the maximum assessment expressed for all reviewers over all facility sites attending to the k-th criterion, or

$$\widetilde{y}_{i,j,k} = H(y_{i,j,k})$$

On the another side, if the compiled information is with regards to a qualitative criterion, we assume that $S = \{s_0, \ldots, s_h\}$ is a linguistic label set and each label $s_j \in S$ and it should be transformed into a value in the interval $[0, g]$. Moreover, and due to the fact that each collective of reviewers can use different linguistic term sets to evaluate qualitative criteria for each facility sites first of all, we need to unified such sets into a unique linguistic term set commonly called *Basic Linguistic Term Set* (see [6]), denoted by $\overline{S} = \{\overline{s}_0, \ldots, \overline{s}_g\}$ and which granularity $|\overline{S}|$ is g. In order to achieve that, following [6], we use the next transformation functions

$$H_S : S \xrightarrow{T_{S\overline{S}}} \mathscr{F}(\overline{S}) \xrightarrow{\chi} \langle\overline{S}\rangle \xrightarrow{\Delta_{\overline{S}}^{-1}} [0,g]$$

where $T_{S\overline{S}}$, χ and $\Delta_{\overline{S}}^{-1}$ are defined below.
The idea is to assign a degree of membership to every linguistic label in S for each linguistic label being transformed. The degree of membership is computed by finding the interaction of two linguistic labels belonging to S and $\overline{S}$. After that, the new fuzzy set is transformed into a linguistic 2-tuple.

Definition 1 Let $S = \{s_0, s_1, \dots, s_h\}$ and $\overline{S} = \{\overline{s}_0, \overline{s}_1, \dots, \overline{s}_g\}$ be two linguistic term sets, with $h \leq g$. The *linguistic transformation function* $T_{S\overline{S}} : S \longrightarrow \mathscr{F}(\overline{S})$ is defined by:

$$T_{S\overline{S}}(s_j) = \{(\overline{s}_0, \gamma_0), (\overline{s}_1, \gamma_1), \dots, (\overline{s}_g, \gamma_g)\}$$
$$\gamma_i = \max_y \min\{\mu_{s_j}(y), \mu_{\overline{s}_i}(y)\},\ i = 0, 1, \dots, g$$

where $\mathscr{F}(\overline{S})$ is the set of fuzzy sets on $\overline{S}$, and μ_{s_j} and $\mu_{\overline{s}_i}$ are the membership functions of the linguistic labels $s_j \in S$ and $\overline{s}_i \in \overline{S}$, respectively.

Definition 2 Let $S = \{s_0, \dots, s_g\}$ be a set of linguistic terms. The *2-tuple set associated with* S is defined as $\langle S\rangle = S \times [-0.5, 0.5)$. We define the function $\Delta_S : [0,g] \longrightarrow \langle S\rangle$ given by,

$$\Delta_S(\beta) = (s_i, \alpha), \ \text{ with } \left\{ \begin{array}{l} i = \text{ round}\,(\beta), \\ \alpha = \beta - i, \end{array} \right.$$

where *round* assigns to β the integer number $i \in \{0, 1, \dots, g\}$ closest to β.

We note that Δ_S is bijective [7] and $\Delta_S^{-1} : \langle S\rangle \longrightarrow [0,g]$ is defined by $\Delta_S^{-1}(s_i, \alpha) = i + \alpha$. In this way, the 2-tuples of $\langle S\rangle$ will be identified with the numerical values in the interval $[0,g]$.

Definition 3 Given the linguistic term set $\overline{S} = \{\overline{s}_0, \overline{s}_1, \dots, \overline{s}_g\}$, the function $\chi : \mathscr{F}(\overline{S}) \longrightarrow \overline{S} \times [-0.5, 0.5)$, is defined by

$$\chi\left(\{(\overline{s}_0, \gamma_0), (\overline{s}_1, \gamma_1), \dots, (s_g, \gamma_g)\}\right) = \Delta_{\overline{S}} \left(\frac{\sum_{j=0}^{g} j\gamma_j}{\sum_{j=0}^{g} \gamma_j} \right).$$

In the end, the transformed assessments for each collective are $\widetilde{a}^E_{i,j,k}$ for internal experts reviewers, $\widetilde{a}^{NE}_{i,j,k}$ for internal non-experts reviewers, $\widetilde{b}^E_{i,j,k}$ for external experts reviewers and $\widetilde{b}^{NE-G}_{i,j,k}$ and $\widetilde{b}^{NE-S}_{i,j,k}$ for external non-experts reviewers.

We can note that all the information provided by the different collectives has already unified into the interval $[0,g]$. Therefore, we can operate to obtain aggregations of the appraisal results.

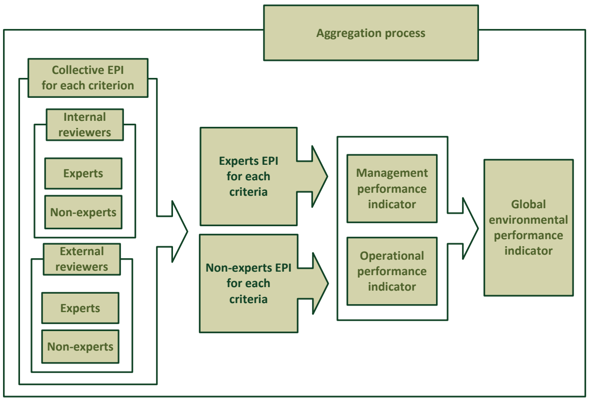

Figure 2: Steps of the aggregation phase

3.2 AGGREGATION PHASE

To obtain a global environmental performance indicator for each facility site, we carry out an aggregation method which has several steps (see Figure 2). To do so, individual assessments will be aggregated by using aggregation operators. They are chosen according to the needs of each aggregation step and considering their properties.

In the specialized environmental evaluation literature, the relationship among EPIs is brought to the attention (see for instance [15]) although it is not explicitly defined. In this paper we are going to manage such a relationship in the aggregation process by means of Choquet integral (see [4] and [5]). This aggregation operator allows us, in comparison to other multi-criteria analysis techniques, to take into account interactions among EPIs or criteria by mean of expressing the significance degree of a combination of them. Also, the global importance of each criterion is considered.

Definition 4 Let $C = \{c_1, \dots, c_n\}$ be a finite universe. A *fuzzy measure* or *capacity* is a set function $\mu : \mathscr{P}(C) \longrightarrow [0,1]$ which satisfies:

1. $\mu(\emptyset) = 0$ and $\mu(C) = 1$,
2. $A \subseteq B \Rightarrow \mu(A) \leq \mu(B)$,

where $\mathscr{P}(C)$ is the set of all subsets of C.

Definition 5 Let $f : C \longrightarrow \mathbb{R}^+$ be a function with $y_k = f(c_k)$ for $k \in \{1, \dots, n\}$ and $y_0 = 0$. The *discrete Choquet integral* of f with respect to a fuzzy measure μ is given by

$$G_\mu(y_1, \dots, y_n) = \sum_{k=1}^{n} \left(y_{(k)} - y_{(k-1)}\right)\ \mu\left(A_{(k)}\right),$$

where $\left(y_{(1)}, \dots, y_{(n)}\right)$ is a non-decreasing permutation of $(y_1, \dots, y_n)$ and $A_{(k)} = \left\{y_{(k)}, \dots, y_{(n)}\right\}$.

Remark 1 As it has been proved in several references such as [4], and [2], among others, the Choquet integral fulfills very significant mathematical properties like *idempotence*, *continuity*, *non-decreasing monotonicity*, *stability under the same positive linear transformation*, *decomposability* and *compensativeness*.

There are many different methods to determine an appropriate fuzzy measure (see [5] and [2]) for each application. It is remarkbly to point out that the fuzzy measure plays a key role in the Choquet integral comparable with the choice of weights in the weighted mean. Moreover, the weighted mean and the OWA aggregation operator are special cases of the Choquet integral for specific fuzzy measures which are connected with the weighting vector (see [2]). We propose to use the OWA operator in some of the steps in our aggregation process. In those cases the weighting vectors can be computed using the well-known non-decreasing quantifiers proposed by Yager [16].

A further detailed description of each stage of the aggregation process is presented. It is important to note that each aggregation procedure can use a different fuzzy measure that implies a different Choquet integral. The detailed choice of fuzzy measures are going to be a matter for future works.

1. *Computing environmental performance indicators for each reviewers' collective and each criterion.*

   The reviewers' assessments are aggregated for each criterion and each collective by means of a OWA operator, G_{-}^{-} (because OWA operators are anonymous). Then, for each collective and for every criterion c_k^-, the process is conducted in the following manner.

   - For **internal reviewers** (experts and non-experts, respectively):

$$\begin{aligned} I_k^{A^E}(x_j) &= G_k^{A^E}(\widetilde{a}_{1,j,k}^E, \ldots, \widetilde{a}_{m,j,k}^E), \\ I_k^{A^{NE}}(x_j) &= G_k^{A^{NE}}(\widetilde{a}_{1,j,k}^{NE}, \ldots, \widetilde{a}_{r,j,k}^{NE}). \end{aligned}$$

   - For **external reviewers** (experts and non-experts, respectively):

$$\begin{aligned} I_k^{B^E}(x_j) &= G_k^{B^E}(\widetilde{b}_{1,j,k}^E, \ldots, \widetilde{b}_{s,j,k}^E), \\ I_k^{B^{NE}}(x_j) &= G_k^{B^{NE}}\left(I_k^{B^{NE-G}}(x_j), I_k^{B^{NE-S}}(x_j)\right), \end{aligned}$$

   where $I_k^{B^{NE-G}}(x_j)$ is the environmental performance indicator for stakeholder reviewers:

$$I_k^{B^{NE-G}}(x_j) = G_k^{B^{NE-G}}(\widetilde{b}_{1,j,k}^{NE-G}, \ldots, \widetilde{b}_{t,j,k}^{NE-G}),$$

   and $I_k^{B^{NE-S}}(x_j)$ is the environmental performance indicator for social constituents reviewers:

$$I_k^{B^{NE-S}}(x_j) = G_k^{B^{NE-S}}(\widetilde{b}_{1,j,k}^{NE-S}, \ldots, \widetilde{b}_{u,j,k}^{NE-S}).$$

2. *Computing environmental performance indicators for experts/non-experts reviewers and each criterion.*

   The previous environmental performance indicators for the x_j facility site: $I_k^{A^E}(x_j)$, $I_k^{A^{NE}}(x_j)$, $I_k^{B^E}(x_j)$ and $I_k^{B^{NE}}(x_j)$ are aggregated for each criterion taking into account if the reviewers are experts or not. The previous indicators belonging to the experts reviewers are then aggregated by means of an OWA operator for each criterion c_k^-. Let $G_k^E : [0,g]^2 \longrightarrow [0,g]$

$$I_k^E(x_j) = G_k^E\left(I_k^{A^E}(x_j), I_k^{B^E}(x_j)\right).$$

   Analogously to the experts reviewers, an environmental performance indicator is computed for each criterion c_k^- by aggregating the opinions of all non-experts reviewers. Let $G_k^{NE} : [0,g]^2 \longrightarrow [0,g]$

$$I_k^{NE}(x_j) = G_k^{NE}\left(I_k^{A^{NE}}(x_j), I_k^{B^{NE}}(x_j)\right).$$

3. *Computing management and operational performance indicators.*

   They are obtained by means of aggregating the previous experts and non-experts indicators taking into account the two types of criteria: management and operational. In this step of the aggregation process, we use Choquet integral as an aggregation operator because it allows us, in comparison to other multi-criteria analysis techniques, to take into account interactions among EPIs or criteria through expressing the significance degree of a combination of EPIs or criteria.

   • *Management performance indicator.* In order to calculate this indicator we aggregate the experts and non-experts indicators for management criteria, $c^M = \{c_1^M, \ldots, c_p^M\}$ by means of a Choquet integral. Let $G^M : [0,g]^p \longrightarrow [0,g]$

$$I^M(x_j) = G^M(I_1^E(x_j), \ldots, I_p^E(x_j), I_1^{NE}(x_j) \ldots, I_p^{NE}(x_j)).$$

   • *Operational performance indicator.* Analogously to management performance indicator, an operational performance indicator is computed for operational criteria, $c^O = \{c_1^O, \ldots, c_q^O\}$ by aggregating the experts and no-experts indicators for such criteria by means of a Choquet integral. Let $G^O : [0,g]^q \longrightarrow [0,g]$

$$I^O(x_j) = G^O(I_1^E(x_j), \ldots, I_q^E(x_j), I_1^{NE}(x_j), \ldots, I_q^{NE}(x_j)).$$

4. *Computing a global environmental performance indicator.*

   It is obtained by aggregating the management and the operational performance indicators, by means of a Choquet integral. Let $G : [0,g]^2 \longrightarrow [0,g]$

$$I(x_j) = G\left(I^M(x_j), I^O(x_j)\right).$$

All the indicators obtained in each step of the aggregation process, $I_k^{A^E}(x_j)$, $I_k^{A^{NE}}(x_j)$, $I_k^{B^E}(x_j)$, $I_k^{B^{NE-G}}(x_j)$, $I_k^{B^{NE-S}}(x_j)$, $I_k^E(x_j)$, $I_k^{NE}(x_j)$, $I^M(x_j)$, $I^O(x_j)$ and I are used for evaluating company environmental practices.

3.3 RATING PHASE

In the exploitation phase, the management team shall classify and order facility sites according to the environmental performance indicators obtained in the previous phase.

Theses values in the interval [0, g] are transformed into lingistic terms in the BLTS using the function Δ_S (definition 2). The sorting and ranking of facility sites are carried out according to the ordinary lexicographic order presented in [7].

4 CONCLUDING REMARKS

In this contribution we have presented a MCDM model for evaluating the company's environmental practices. This model takes into account that appraisers express objective and subjective perceptions and might present different degrees of knowledge about evaluated facility sites. The presented model not only obtain a global environmental performance indicator for each facility site, but also it obtains intermediate environmental performance indicators according to the opinions of each set of reviewers and criterion, and a management and operational performance indicators. Besides, a deeper study about making adjustment of the Choquet integral as an aggregation operator for environmental evaluations seems to be necessary, the particular good properties of these fuzzy integrals look promising. It is worth emphasizing that the proposed model is quite flexible and it allows to the management team customizes how to aggregate the individual opinions.

Acknowledgements

This paper has been partially supported by the research projects: TIN2009-08286, Spanish Ministerio de Educación y Ciencia (Project ECO2009-07332), and ERDF.

References

[1] A. Awasthi, S.S. Chauhan, and S.K. Goyal. A fuzzy multicriteria approach for evaluatin environmental performance of suppliers. *International Journal of Production Economics*, 126:370–378, 2010.

[2] G. Beliakov, A. Pradera, and T. Calvo. *Aggregation Functions: A Guide for Practitioners*. Springer, Berlin, 2007.

[3] N. Darnall, I. Henriques, and P. Sadorsky. Do environmental management systems improve business performance in an international setting. *Journal of International Management*, 14:364–376, 2008.

[4] M. Grabisch. The application of fuzzy integrals in multicriteria decision making. *European Journal of Operational Research*, 89:445–456, 1996.

[5] M. Grabisch and C. Labreuche. A decade of application of the choquet and sugeno integrals in multicriteria decision aid. *Annals of Operations Research*, 175:247–286, 2010.

[6] F. Herrera, E. Herrera-Viedma, and L. Martínez. A fusion approach for managing multi-granularity linguistic term sets in decision making. *Fuzzy Sets and Systems*, 114:43–58, 2000.

[7] F. Herrera and L. Martínez. A 2-tuple fuzzy linguistic representation model for computing with words. *IEEE Transactions on Fuzzy Systems*, 8:746–752, 2000.

[8] F. Herrera, L. Martínez, and P. J. Sánchez. Managing non-homogeneous information in group decision making. *European Journal of Operational Research*, 166:115–132, 2005.

[9] ISO. *Environmental management systems - requirements with guidance for use (ISO 14001: 2004).* 2004.

[10] A.H.I. Lee, H. Kang, C. Hsu, and H. Hung. A green supplier selection model for high-tech industry. *Expert Systems with Applications*, 36:7917–7927, 2009.

[11] B. Lin, C.A. Jones, and C. Hsieh. Environmental practices and assessment: a process perspective. pages 71–79, 2001.

[12] L. Martínez. Sensory evaluation based on linguistic decision analysis. *International Journal of Aproximated Reasoning*, 44:148–164, 2007.

[13] M.L.Tseng and A.S.F. Chiu. Evaluating firm's green supply chain management in linguistic preferences. *Journal of Cleaner Production*, in press:1–10, 2010.

[14] D. Nawrocka and T. Parker. Finding the connection: environmental management systems and environmental performance. *Journal of Cleaner Production*, 17:601–607, 2009.

[15] J. Sarkis. A strategic decision framework for green supply chain management. *Journal of Cleaner Production*, 11:397–409, 2003.

[16] R. R. Yager. On ordered weighted averaging operators in multicriteria decision making. *IEEE Transactions on Systems, Man, and Cybernetics*, 18:183–190, 1988.