

ENVIRONMENTAL MANAGEMENT OF A COMPANY BASED ON FUZZY MODEL

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Abstract—Environmental concerns worldwide has grown dramatically over the past 20 years. Raising awareness of environmental issues generated by economic activity has led to social and political pressure on firms to reduce their impact on natural environment. The capacity of organizations to manage their environmental performance has become a strategic issue for companies. This is not just a matter of embracing environmental values, but can have a direct impact on successful sustainable economic development. In this context, the aim of this study is to assess the environmental performance using fuzzy logic theory for a car company. A fuzzy rule-based system is presented in order to provide an explicit and comprehensive description of the concept of environmental performance evaluation via computing techniques.

Keywords— environmental assessment, proactive strategy, fuzzy model.

I. INTRODUCTION

OVER recent years companies have begun to consider environmental factors in their corporate decisions and strategic marketing. The environmental factor has been taken into consideration by organizations' management, mainly as a result of the considerable relevance attached to social pressure, to comply with the existing legislation on environmental issues and to obtain a competitive advantage generated by such incorporation. In the same time the firms feel obliged to satisfy the new demands from consumers who require more serious concern for sustainable development. These conditions are changing the competitive scene, posing new challenges and opportunities, and promoting the adoption of new environmentally friendly technologies. Besides, they are the main consumers and transformers of environmental resources, as well as a major source of pollution and waste. It has been demonstrating that high levels of firm performance coincide with high levels of environmental performance only if the firm's environmental management technology has a pollution proactive orientation [1].

A very important factor that is most likely to directly influence environmental practices at the facility level, besides, regulatory, and social factors is represented by

the market. Market pressures that encourage facilities to adopt a proactive orientation have increased as facilities and customers have become increasingly aware of the natural environment. Greater awareness mainly has been due to improved availability of environmental information about industrial environmental practices. This information affects an organization's reputation and its ability to market its products. By yielding to market pressures such as these, and adopting Environmental Management Systems, facilities may be able to confer greater moral legitimacy for their environmental practices. Environmental management encompasses the technical and organizational activities undertaken by the firm for the purpose of reducing environmental impacts and minimizing their effects on the natural environment. The environmental management literature point the fact that the adoption of environmental practices by firms leads to good environmental performance [2]. The discussion can continue on and on but the main issue is regarding our objectivity in evaluating environmental performance. In order to make this assessment a integrated analysis of a these factors and the existing relationships between them is required, fact which often proves to be a very complicated problem.

Literature highlights several methods for analyzing of environmental impacts of firms and consequently to assess the environmental performance. Selecting the appropriate method depends on upon the purpose and aim of the analysis.

Fuzzy logic due to the capability of representing uncertain data, emulating human thinking and handling vague situations qualifies as a performing tool in order to assess environmental impact. Fuzzy models have an interesting ability to represent the process with different types of data.

Environmental indicators and their values are made available to the public through websites or are estimated using a number of techniques such as average emission factor models, which can be found easily in specialty literature. Environmental performance can be assessed against domestic objectives (e.g. receiving water standards, effluent limits, pollution load reduction targets) and specific commitments. In this paper, the

fuzzy model was developed, which uses data sampled from different environmental parameters in order to assess the environmental performance.

II. FUZZY ASSESSMENT OF ENVIRONMENTAL PERFORMANCE

To assess the environmental performance of an organization is necessary to make an integrated analysis of a variety of factors and the existing relationships between these factors

There has never been a more pressing need for effective environmental policies or strategies as there is today. Due to the growing body of environmental data, policymakers face complex challenges such as incomplete and conflicting data, causal complexity varying values and preferences, and uncertainty. The ecosystem in which the company operates is composed of four modules: water quality (WATER) soil integrity (SOIL) air quality (AIR) and biodiversity & habitat (BIOD) as in Fig. 1.

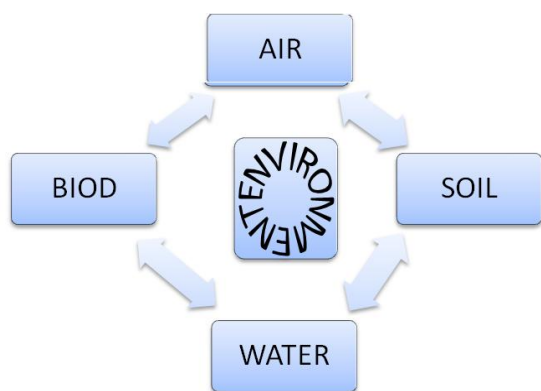


Fig. 1. Dependence of sustainability components.

In order to cope with environmental performance assessment specific tools are needed and creative approaches. The fuzzy inference system is a popular computing framework based on the concepts of fuzzy set theory, fuzzy if-then rules and fuzzy reasoning.

A fuzzy system is a rule – based system that maps an input vector of numerical or linguistic variables into a numerical output. Fuzzy or linguistic variables do not describe numerical data, but are scaled between zero and one by the membership functions. Operations performed with fuzzy variables and associated fuzzy rules are based not on precise models of the process, but on a qualitative understanding of physical phenomena, such as: IF (temperature is high) THEN (decrease order). The purpose of a fuzzy inference system is to reach a conclusion based on uncertain information [3]. In general, the linguistic and numerical requirements entail the fuzzy modeling process to make an important compromise between accuracy and interpretability of the model. In other words, the goal is to provide high numerical precision while incurring as little loss of

linguistic descriptive power as possible. Depending on the particular application, the output of a fuzzy system may be a control action, diagnosis, decisions or assessment.

A fuzzy model is constructed using knowledge from a human expert who identifies the parameters of a fuzzy inference system to predict the behavior of the real system. The task grows in difficulty when the available data is incomplete, so the use of automatic approaches to fuzzy modeling is required. The dimension of the problem is a major issue because the computation requirements grow exponentially with the number of variables [4]. Environmental performance assessment for the varying activities performed by organizations requires a pertinent approach, which cannot be simplistic, to the information held.

A. The model overview

As shown in Fig. 2, the environmental performance assessment (EPA) encompasses four broad components named soil integrity (SOIL), water quality (WATER), air quality (AIR) and biodiversity & habitat (BIOD). These components are called primary indicators and are depending on basic indicators as can be seen in the Fig. 2.

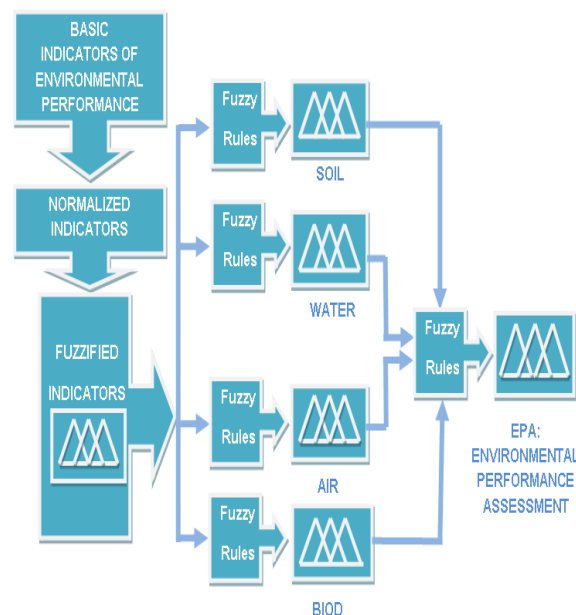


Fig.2. Fuzzy environmental performance measurement process

Fuzzy logic is suited to handle uncertainty inherent in vague and fastidious situations. The concept of environmental performance assessment supposes indeed a quite pretentious concept in absence of a mathematical definition. This is a situation where “if-then” fuzzy rules are best suitable. EPA (environmental performance assessment) is computed using a hierarchical network of fuzzy inference engines as shown in Fig.2. Each inference engine computes a component of EPA. The

multistage inference is a process of sequential reasoning whereby the consequence of inference stage is passed as input to other stages. The hierarchical inference is a multistage inference without feedback [5]. Compared to single stage inference system, hierarchical fuzzy systems can cope better with the curse of rule explosion in problems involving many variables and changing environments [6]. Each inference engine computes a component of EPA. It is equipped with a rule base, that is, a collection of “if-then” linguistic rules which aggregate more primary indicators of EPA into a composite one. The rules represent the interrelations and principles governing the various indicators and components of EPA and their contribution to the composite indicator. The output of an inference stage is passed to other engines, and so forth, while the last inference engine combines the major components AIR, SOIL, WATER and BIOD to compute the overall environmental performance EPA. The rules and inputs/output of each rule base are expressed symbolically in the form of words or phrases of a natural language and mathematically as linguistic values and fuzzy sets. An example of “if-then” rules used in the model is:

IF AIR IS bad AND WATER IS good AND SOIL IS good AND BIOD is good THEN EPA IS AVERAGE;

When the environmental impact of a given company is assessed, the model to be used should be tuned to the particular realities of the corporation.

III. ENVIRONMENTAL PERFORMANCE MEASUREMENT

A measure of environmental performance for a specific company has to be the resultant of several components such as the degree of recycling, environmental impact, available technologies, etc.

Organization limits are defined by the physical ones, but are not necessarily limited to them. Space and time are two fundamental parameters for the environmental assessment and both depend on the company which is evaluated. If we refer to a car company the impact is upon local environment, but since the vehicles are exported worldwide and materials are often imported from distant countries, this impact is extended to supply and consumption chain. Speaking of time, emissions of greenhouse gasses should be evaluated knowing that their environmental impact will remain for decades or more. Emissions of carbon monoxide on the other hand, will have only a short-term effect. The main idea is that each and every organization has its own space and time requirements when environmental performance is evaluated.

I want to emphasize that there are certain features of the evaluation process which are subject to a more complex analysis such as quality of the recycled product, what extent the habitat (involving biodiversity) is affected. Besides for the analyzed case was not possible

to collect data about parameter biodiversity&habitat (BIOD). Consequently, the model is depicted in Fig. 3.

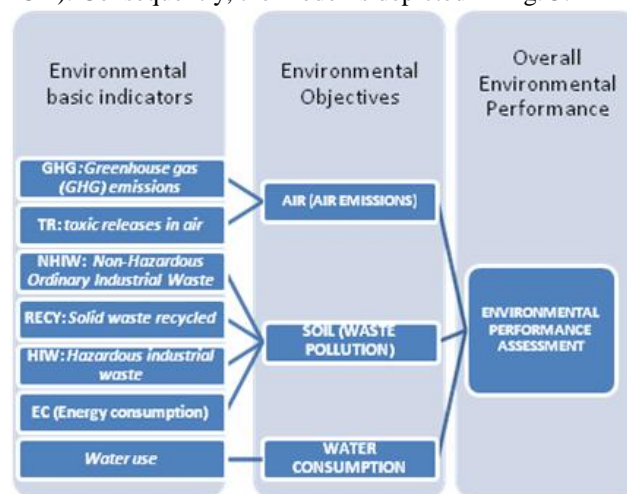


Fig.3 Car company environmental performance assessment

To test the model publicly available data have been collected from the biggest Romanian automotive manufacturer which is member of a multinational automotive alliance. Also to be noted that for the present model has been taken into consideration only the most representative environmental parameters. Some of them represent a group of several indicators with similar characteristics. For example, TR (toxic releases in air tons/year) includes both atmospheric emissions of SO₂ and NO_x. The model is designed to ensure that, whenever an indicator of environmental performance is improved the overall EPA increases. A preliminary version of this work appears in [7].

A. Indicators of Environmental Performance Assessment

The choice of basic indicators depends on the type of organization under consideration. A short definition and information of the basic indicators used are provided below. For everyone it is specified the most desirable and least desirable values related to the specific industry. Norm and targets for these indicators are dictated by legal requirements and expert knowledge. But for some of these basic indicators minimum and maximum values couldn't be established in which case some calculus were computed based on average values of the industry.

For AIR indicator:

1) GHG: *Greenhouse gas (GHG) emissions* (teq CO₂ - equivalent emitted per million euros of annual net sales) measure a company's impact on climate change. It is assumed that lower is better and that any value below a certain threshold is sustainable, i.e., its normalized value is one. The threshold is set at $T_{GHG} = 50$ tons CO₂ equivalent per million euro annual net sales. The upper bound at which sustainability is zero is the maximum value over all years for all companies. This value is $U_{GHG} = 100$. The auto constructor made its first inventory of

greenhouse gasses (GHG) sources in 2004. Following this inventory, the manufacturer modified its reporting protocol to better reflect the total emissions of the group and to comply with the recommendations of the GHG Protocol and the French protocol developed by Entreprises pour l'environnement [8],[9].

2) TR: *toxic releases in air* (tons/year) lead to lower sustainability since more emissions to the air harm humans and the ecosystem. In our case toxic releases consist of atmospheric emissions of SO₂ and NO_x. The atmospheric emissions of SO₂ and NO_x included in the data correspond to emissions produced by the burning of fossil fuels in fixed combustion facilities at all site, excluding transport to the site. Only sites with fuels whose characteristics differ significantly from standard factors have used data approved by their energy supplier. For toxic releases, similarly to GHG emissions, we assume that lower is better. The upper target value is chosen as the average of all data points and it is T_{TR} = 0,3 kg per unit of production. The maximum value is U_{TR} = 0,5 kg/unit.[8],[9].

For SOIL indicator:

3) NHIW: *Non-Hazardous Ordinary Industrial Waste* (tons per unit produced) is the mass of solid waste that is dumped by the company into a landfill, rather than reused or recycled in some manner. A lower amount of waste dumped is better for the environment due to less pollution of the land and greater amount of land available to the ecosystem for other purposes (farming, animal habitat, etc.).

The waste included in data is waste that leaves the geographical confines of the site. Non-hazardous waste includes ordinary waste and inert waste, the latter being presented separately for greater clarity.

Construction waste from manufacturer sites is not reported (in the Inert waste category) unless a contractual clause explicitly states that the construction company is not responsible for such waste. As previously, the average value T_{SW} = 1 t/unit is considered to be the threshold for sustainability and the maximum U_{SW} = 1,5 t/unit produced as the smallest undesirable value[8],[9].

4) RECY: *Solid waste recycled* (percent of total) is a measure of how efficient the company is at limiting its ecological footprint. The more waste is reused or recycled, the lower the company's impact on the ecosystem. A higher rate of recycling is more sustainable. A lower threshold of U_{RECY} = 50% waste recycling is subjectively chosen as unsustainable. A higher rate of recycling increases sustainability linearly to T_{RECY} = 90%, where it is assumed that sustainability is one [8]-[9].

5) HIW: *Hazardous industrial waste* (tons per unit produced) generated by the company harms the ecosystem because that waste must be treated or dumped. The less hazardous waste the company produces, the more sustainable it is. Suppose that any level of waste

production below THW = 10 kg/unit (industry average) is sustainable with value one, with sustainability decreasing linearly to the maximum value U_{HW} = 20 kg/unit [8],[9].

6) EC: Energy consumption (MWh/vehicle) energy use per unit of production it harms the ecosystem because the waste production. Lower energy use is better, so we set the upper target level to the industry average T_{water} = 2 MWh/vehicle of water per unit product and the lower unsustainable value to the maximum over all companies, U_{water} = 4 MWh/vehicle .

For WATER CONSUMPTION indicator:

7) WAT: *Water use* (m3 thousands) is a measure of the company's impact on water resources. Measured volumes include water obtained by pumping (underground and surface water) and/or external networks (drinking water, industrial water). If less water is used to make a given amount of product, more water is available for humans and other species to use. Fresh water is an increasingly valuable and scarce resource; since production requires water as an input, a good measure of water efficiency is the ratio of water used to product generated. Lower water use is better, so we set the upper target level to the industry average T_{water} = 5 m3 of water per unit product and the lower unsustainable value to the maximum over all companies, U_{water} = 10 . Table I shows the values of basic indicators mentioned before. The basic indicators exhibit a variability of quality and scale that calls for normalization. Normalized values on [0, 1] are obtained by linear interpolation between the target (most desirable) and the least desirable values shown in Table II, which are determined by experts.

B. Preliminary Data Analysis and Normalization

TABLE I
 BASIC INDICATORS VALUES FOR SELECTED COMPANY

Indicat or	2007	2008	2009	2010	2011	2012
GHG	9188 2,8	75437, 7	7661 1,5	7028 5,3	135531	183248
TR	150	128.2	82	61.5	58.6	75.6
NHIW	1990 90.8	34296 3.4	2714 04.8	2154 03.2	181122	191964
RECY	NA	NA	0,8	0,8	0,85	0,85
HIW	2568	3388.8	4008	5924	5326.2	5741
WAT	2550	1740.7	1310	948.4	1109.4	1191.4
EC	NA	2.39	2.13	1.83	1.52	1.65

“NA” indicates that no data were available for the corresponding year.

Let X be the value of a basic indicator of environmental performance. The corresponding normalized value X_n is calculated as follows:

$$X_n = \frac{X - (\text{least desirable value})}{(\text{target value} - \text{least desirable value})} \quad (1)$$

For example, the greenhouse gas emissions were 183.248 metric tons CO₂ equivalent per million Euros of annual net sales for the company in 2010. The corresponding normalized value is $(67,65-100)/(50-100)=0,647$.

TABLE II
 NORMALIZED VALUES FOR BASIC INDICATORS

Indicator	2007	2008	2009	2010	2011	2012
GHG	76,22 0,475	47,86 1	36,86 1	33,87 1	63,67 0,726	67,65 0,647
TR	1,034 0	0,518 0	0,356 0,024	0,238 0,448	0,188 0,648	0,217 0,532
NHIW	1,373 0	1,386 0	1,178 0	0,834 0,332	0,582 0,836	0,55 0,9
RECY	NA	NA	0,8 0,843	0,8 0,843	0,85 0,895	0,85 0,895
HIW	17,71 0,228	13,69 0,638	17,38 0,262	22,92 0	17,11 0,289	16,38 0,361
WAT	17,59 0	7,032 0,4064	5,684 0,8632	3,669 1	3,56 1	3,416 1
EC		0,805	0,935	1	1	1

Basic indicators describe certain aspects of the sustainability of a company in a specific year. The values for the basic indicators in a given year occasionally are missing or fraught with uncertainty due to measurement errors. Therefore, a systematic method is needed to improve the quality of information. To deal with such problems and for simplicity we use weighted sums [5]. The normalized time series for each indicator are aggregated into a single normalized value using the method of the weighted sum. The results are shown in Table III.

TABLE III
 NORMALIZED VALUES USING WEIGHTED SUM

Indicator	Normalized value
GHG	0.6926
TR	0.236
NHIW	0.2954
RECY	0.4965
HIW	0.2541
WAT	0.6099
EC	0.942

C. Fuzzification and Rule Base

When two or more indicators are combined into a single composite indicator, information loss is unavoidable. This loss can be mitigated by using more linguistic values for the composite indicators. If consider n inputs of an inference engine, each one with m linguistic values, then would be necessary m^n fuzzy rules to construct a complete rule base in which case number of fuzzy sets quickly explodes and this approach becomes inefficient. Therefore, some compromise between information loss and rule explosion is necessary. In order to fuzzify the values of basic indicators must use the membership functions whereby a crisp value is transformed into a linguistic variable. Each and every one linguistic variable has a number of fuzzy sets. In our

case the linguistic variables of basic indicators have three fuzzy sets with linguistic values “weak” (W), “medium” (M), and “strong” (S), whose membership functions are shown in Fig. 4 [10].

For example, the crisp value $Y_{CHG} = 0.647$ for year 2010 of Table II belongs to the fuzzy set M of Fig. 4 with grade $(1 - 0.647) / (1 - 0.6) \approx 0.8825$ and to the fuzzy set S with grade $(0.647 - 0.6) / (1 - 0.6) \approx 0.1175$. Also, from Fig. 5 we see that the crisp value $X_{WATER} = 0,8632$ for year 2007 is G with membership grade $(0.8632 - 0.5)/(1 - 0.5) \approx 0.7264$ and VG with grad $(1 - 0.8632)/(1 - 0.5) \approx 0.2736$.

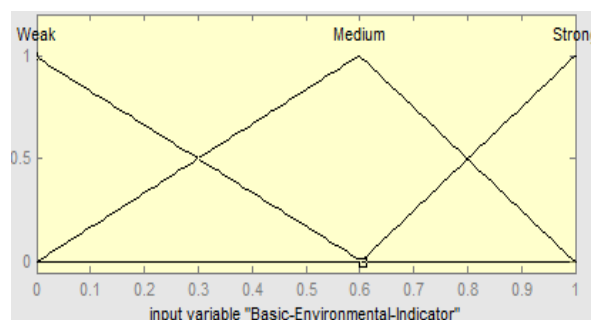


Fig. 4. Membership functions for basic environmental indicators

In order to combine two or more fuzzy inputs into a composite indicator it must use more fuzzy sets to represent the composite fuzzy variable. For simplicity in this case we are using still three fuzzy sets or composite variables (AIR, SOIL, and WATER) and five fuzzy sets with linguistic values “very bad” (VB), “bad” (B), “average” (A), “good” (G), and “very good” (VG), as depicted on Fig.5. for overall performance assessment EPA.



Fig. 5. Membership functions for environmental performance assessment indicators

In order to compute the number of linguistic values for EPA should be assigned the integer values 0,...,4 to the five linguistic values, such 0 corresponds to VB, 1 corresponds to B, and so on [11].

EPA is composed of three parameters, namely, SOIL, AIR, and WATER. The EPA fuzzy set is determined by aggregation of those three as in (2):

$$Ag = SOIL + AIR + WATER \quad (2)$$

IV. RESULT

Table IV shows the environmental impact assessment for the selected company using the model. The result of computation is presented below.

TABLE IV
 NORMALIZED VALUES AND MEMBERSHIP GRADES

Indicator	Value	VB (0)	B (1)	A (2)	G (3)	V G (4)
AIR		0	0.10	0.74	0.16	0
SOIL		0	0.12	0.72	0.16	0
WATER		0	0.10	0.80	0.10	0
		VB	B	A	G	V G
ENVIRON	0.541	0	0.033	0.916	0.051	0

Once the membership grades of the AIR, SOIL and WATER parameters have been computed, the membership grades of EPA are determined by the following rules [5], [11]. Two examples are provided as below:

$$B(AIR) + B(SOIL) + B(WATER) = 1 + 1 + 1 = 3 \Rightarrow$$

$$EPA \text{ is } B \text{ with grade } 0.10 \times 0.12 \times 0.1 = 0.0012 \quad (3)$$

$$A(AIR) + A(SOIL) + G(WATER) = 2 + 2 + 3 = 7 \Rightarrow$$

$$EPA \text{ is } A \text{ with grade } 0.74 \times 0.72 \times 0.10 = 0.05328 \quad (4)$$

The final crisp value for the EPA parameter is computed using height defuzzification as in (5):

$$EPA = \frac{0.25 \times 0.033 + 0.5 \times 0.916 + 0.75 \times 0.051}{0.033 + 0.916 + 0.051}$$

$$= \frac{0.5045}{1} \quad (5)$$

The value obtained reflects the impact it has on the environment chosen company. As these values are close to 1 means that the company impact on the environment is less harmful [12].

V. CONCLUSION

The fuzzy rule-based system presented in this paper provides new point a view regarding environmental performance assessment. It also may serve as a practical tool for decision-making and policy design for the corporate concerning environmental issues.

Using linguistic variables and linguistic rules, the model gives quantitative measures of environmental assessment. The starting point for the environmental performance measurement process consists of creating a framework that addresses the company's most significant environmental concerns. The company must identify major performance aspects, establish objectives, select specific indicators and metrics, and commit to achieving specific targets. Then, the problem of environmental performance assessment becomes one of the specifying priorities among basic indicators and designing appropriate policies that will guarantee environmental sustainability.

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REFERENCES

- [1] M., Wagner, "How to reconcile environmental and economic performance to improve corporate sustainability: corporate environmental strategies in the European paper industry". *Journal of Environmental Management* 76, 2005, pp.105–118.
- [2] S., Melnyk, R., Sroufe, R., Calantone, "Assessing the impact of environmental management systems on corporate and environmental performance" *Journal of Operations Management* 21, 2003, pp.329–351.
- [3] R.R. Yager, D.P. Filev, *Essentials of Fuzzy Modeling and Control* John Wiley & Sons., New York, 1994.
- [4] C.A. Pena Reyes, *Coevolutionary Fuzzy Modeling*, Springer-Verlag, Berlin, 2004.
- [5] Y.A. Phillis, V.S. Kouikoglou, *Fuzzy Measurement of Sustainability*, Nova Science Publishers, New York, 2009.
- [6] V. Torra "A review of the construction of hierarchical fuzzy systems," *International Journal of Intelligent Systems*, Vol. 17, 2002, pp. 531–543.
- [7] M.Pislaru, A. Trandabat "Fuzzy-Based Environmental System Approach for Impact Assessment - Case Studies" *International Conference on Environmental and Ecological Impacts (ICEEI 2012)*, World Academy of Science Engineering and Technology, issue 67, 2012, pp.474-479.
- [8] <http://www.renault.com/en/groupe/developpement-durable/fiches-sites/Pages/pitesti-dacia.aspx>
- [9] Annual Report- Registration Document, Renault, 2006-2012.
- [10] JS.N.Sivanandam, S. Sumathi and S. N Deepa, *Introduction to Fuzzy Logic using MATLAB* Springer-Verlag ,Berlin Heidelberg 2007.
- [11] Y.A. Phillis, Benjamin J.Davis "Assessment of Corporate Sustainability via Fuzzy Logic" *J Intell Robot Syst*, vol.55, 2008, pp. 3-20.
- [12] M. Pislaru, A. Trandabat and S. Avasilcai, "Neuro-fuzzy model for environmental impact assessment" *Environmental Engineering and Management Journal*, vol.10, 2010, pp.381-386,