World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:6, No:7, 2012

Fuzzy Based Environmental System Approach for Impact Assessment - Case Studies

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Open Science Index, Environmental and Ecological Engineering Vol:6, No:7, 2012 publications.waset.org/12330.pdf

***Abstract*—**Environmental studies have expanded dramatically all over the world in the past few years. Nowadays businesses interact with society and the environment in ways that put their mark on both sides. Efforts improving human standard living, through the control of nature and the development of new products, have also resulted in contamination of the environment. Consequently companies play an important role in environmental sustainability of a region or country. Therefore we can say that a company's sustainable development is strictly dependent on the environment. This article presents a fuzzy model to evaluate a company's environmental impact. Article illustrates an example of the automotive industry in order to prove the usefulness of using such a model.

***Keywords*—**fuzzy approach, environmental impact assessment, sustainability

I. Introduction

Human development through industrialization, especially in the twentieth century, represents an intrusion into the overall balance that maintains the earth as a habitable place. Interaction between industry and the environment tends to become increasingly complex. Usually companies are facing directions of actions such as the use of environmentally friendly technologies or some that would bring higher profits in the short term, it may be subject to strict laws regarding the environment or may choose to relocate to another country where these laws are more lax. It is obvious that companies put their imprint on the environment and also the environment affect their existence, consequently the company welfare is tied to welfare of the society the firm exist in. Factories ordinarily need a number of external inputs to function, such as energy, matter, and labor, for example, and they transform matter into finished products while at the same time they generate pollution which is released into the environment. Sustainability of organizations is associated with their activities, emissions, impact of products, installations, policies, etc. It is desirable to improve all activities, that is, reduce emissions, improve products, build environmentally friendly installations, contribute to the economic welfare of the society, and so on [1].

Environmental impact assessment related to firm is becoming a major issue worldwide and particularly in Europe. To assess the performance of an environmental system of a company is necessary to make an integrated analysis of a variety of factors and the existing relationships between these factors often form a complicated problem.

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The boundaries of an organization are defined by its physical ones but they are not necessarily limited by them. Space and time are two fundamental parameters in evaluating environmental impact and both depend on the particular company being evaluated. For instance, an automotive company has local environmental impact but since vehicles are exported to the whole word and materials are often imported from remote countries, this impact is extended to the whole supply and consumption chain. Speaking of time, greenhouse gas emissions should be assessed knowing that their environmental impact will stay for tens of years or longer. Carbon monoxide emissions on the other hand will have only a short term effect. Each organization has its own space and time demands when environmental impact is assessed.

The values of indicators used in the model are provided by the company or are estimated using a number of techniques such as average emission factor models, etc. This technique does not represent the scope of this paper, but they can be found easily in specialty literature.

In this paper, fuzzy model was developed, which uses data sampled from different environmental parameters in order to assess the company impact on environment. Based on this approach it has been developed a fuzzy model which uses environmental indicators, as inputs and employs fuzzy reasoning to provide an output. The model can be used to evaluate the environmental sustainability of the company and also can identify areas of particular interest to managers. The method could become a useful tool to decision makers as they strive towards environmental assessment.

II. Fuzzy System Approach

There are many approaches and tools available for undertaking analysis of environmental impacts. Selecting the appropriate method depends upon the purpose and aim of the analysis.

Fuzzy logic is often referred to as a way of “reasoning with uncertainty.” It provides a well-defined mechanism to deal with uncertain and incompletely defined data, so that one can make precise deductions from imprecise data. The fuzzy theory provides a mechanism for representing linguistic constructs such as “many,” “low,” “medium,” “often,” “few.” In general, the fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities [2]. In practice, fuzzy logic means computation of words. Since computation with words is possible, computerized systems can be built by embedding human expertise articulated in daily language. Also called a fuzzy inference engine or fuzzy rule-base, such a system can perform approximate reasoning somewhat similar to but much more primitive than that of the human brain.

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The utility of fuzzy sets lies in their ability to model uncertain or ambiguous data so often encountered in real life [3].

Fuzzy modeling techniques, namely, the construction of fuzzy rule-based inference systems, can be viewed as grey-box modeling because they allow the modeler to extract and interpret the knowledge contained in the model, as well as to imbue it with a-prior knowledge. However, the construction of fuzzy models of large and complex systems—with a large number of intricately related input and output variables—is a hard task demanding the identification of many parameters Fuzzy logic is capable of representing uncertain data, emulating skilled humans, and handling vague situations where traditional mathematics is ineffective. Based on this approach our aim is to attempt to devise a model for environmental assessment, such that it will both reduce to a minimum the risks arising from performance of tasks by unsuitable decision-making [4].

This system will allow incorporation of all information which may be to hand, however ambiguous or subjective it may be, and cope with the lack of precision that is a concomitant of this sort of decision making process. Environmental assessment for the varying activities performed by organizations requires a coherent approach, which cannot be simplistic, to the information held. The use of fuzzy membership functions is convenient because it allows the problem to be recognized as it is in real life. All this makes the environmental assessment challenging, yet a crucial task to perform. A lot of organizations have experts who are responsible for this task. Currently, the environmental assessment is performed manually and we think that every technique meant to automate this process can prove invaluable for everybody involved.

III. The Model Overview

Assessing the environmental impact related to a industrial company is becoming a major issue worldwide. To evaluate the impact on environment requires an integrated analysis of a variety of factors and the existing relationships between these factors which often form a complicated problem. Indicators are often used with other types of information. In order to cope with environmental impact assessment specific tools are needed and creative approaches. The model which deals with these parameters is presented in Fig.1.

Environmental impact assessment model (ENVIRONMENTAL IMPACT) is composed of four primary components, air (AIR), water (WATER) soil (SOIL), and biodiversity (BIOD). Each of primary components has three inputs, status, pressure and response represented by TYPE1, TYPE2 and respectively TYPE3 indicator, which comprise the secondary inputs or components. The secondary inputs depend on any number of basic indicators.

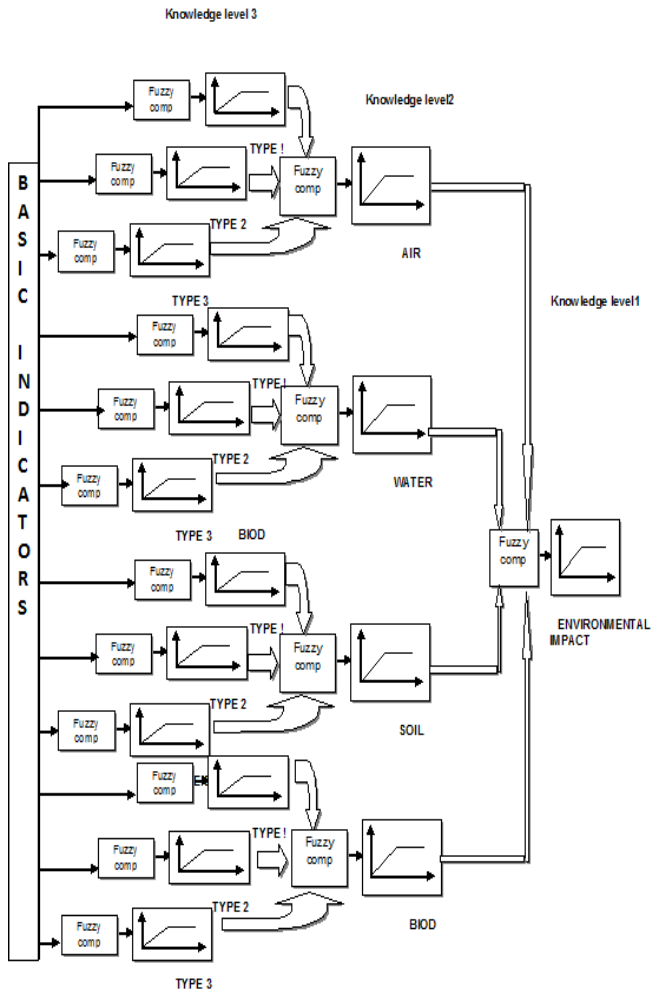

Fig. 1 Configuration of environmental impact assessment model

The model consists in four different sets of knowledge levels. The inputs of each knowledge level represent the parameters which can be provided by the user or composite indicators collected from other knowledge levels. By using fuzzy logic and IF-THEN rules, these inputs are combined to yield a composite indicator as output which represents an input for the subsequent knowledge level. For instance, the third order knowledge level that computes indicator AIR combines indicators TYPE 1, TYPE 2, and TYPE 3 indicators of air quality, which are outputs of fourth order knowledge level. Then, AIR is used in combination with SOIL and WATER as input for the first order knowledge level and so assesses ENVIRONMENT IMPACT. The indicators from the third knowledge level were divided into three types of parameters because this way the analyze we believe would be is more accurate [5].

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.

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IV. Case Studies

In order to test the model publicly available data have been collected from our national auto producer which is member of a multinational automotive manufacturer. It was not possible to collect data about BIOD. Consequently, for our case the model is presented in Fig. 2.

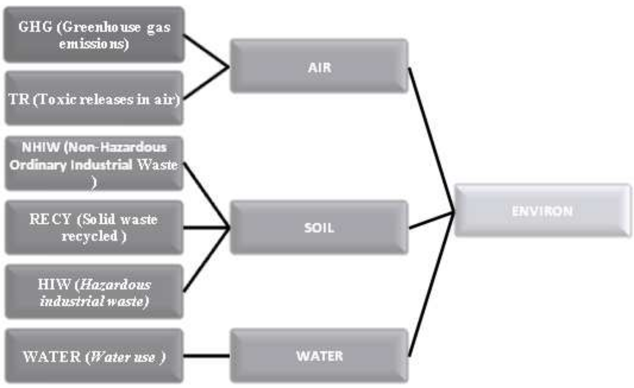

Fig. 2 Company hierarchical impact assessment model

A. Basic Indicators

The choice of basic indicators depends on the type of organization under consideration. Norm and targets for these indicators are dictated by legal requirements and expert knowledge. Below are given definitions of the basic indictors taken under consideration for our case and their most desirable and least desirable values related to the specific industry.

For AIR indicator:

- GHG*: Greenhouse gas (GHG) emissions* (teq CO2 - equivalent emitted per million euro 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 gases (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'environement*.[6],[7].
- 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 consists of atmospheric emissions of SO_2 and NO_x. The atmospheric emissions of SO_2 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 over all data points and it is TTR =0,3 kg per unit of production.

The maximum value is UTR = 0,5 kg/unit.[6],[7].

For *SOIL* indicator:

- 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.). Less waste is also an economic benefit, since companies that produce less waste will spend less money on raw materials, run a lower risk of environmental fines and penalties and have less land and waste removal costs.

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 TSW = 1 t/unit is considered to be the threshold for sustainability and the maximum USW = 1,5 t/unit produced as the smallest undesirable value[6],[7].

- 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 τ_{RECY} = 95%, where it is assumed that sustainability is one [6]-[7].
- 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 UHW = 20 kg/unit [6],[7].

For *WATER* indicator:

- WATER: *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 m^3 of water per unit product and the lower unsustainable value to the maximum over all companies, U_{water} = 10 . The quantity of toxic metals is the total average daily flow of toxic metals discharged, weighted by a coefficient of toxicity.

This quantity, expressed in kg per day, is calculated as follows:

Toxic metals = 5 flows (Ni+Cu) + 10 flows (Pb+As) + 1 flow (Cr+Zn) + 50 flows (Hg+Cd) [6]-[7].

B. Normalization

Firstly, all basic indicators are passed through a filter that normalizes their values in [0,1]. If the value of a basic indicator is x, its target an interval [a_i, A_i], its minimum value b_i and its maximum value B_i, then its normalized value y is as in (1):

$$y = \begin{cases} \dfrac{x - b_i}{a_i - b_i}, b_i \le x \le a_i \\ 1, \qquad a_i \le x \le A_i \\ \dfrac{B_i - x}{B_i - A_i}, A_i \le x \le B_i \end{cases} \tag{1}$$

Normalized values, given in parentheses, are computed by linear interpolation between most desirable (target) and least desirable indicator values. In order to use exponential smoothing for the normalized values is performed by using weighted sum of present and past indicator data as input to the model.

TABLE I
BASIC INDICATORS AND CORRESPONDING NORMALIZED VALUES FOR SELECTED COMPANY

Ind	Annual indicator value - normalized value						
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
GHG	91309. 5 159,91 (0)	91882,8 76,22 (0,4756)	75437,7 47,86 (1)	76611,5 36,86 (1)	70285,3 33,87 (1)	135531 63,67 (0,726)	183248 67,65 (0,647)
TR	92.44 0,967 (0)	149.9 1,034 (0)	128.2 0,518 (0)	82 0,356 (0.024)	61.5 0,238 (0,448)	58.6 0,188 (0,648)	75.6 0,217 (0,532)
NHIW	166666 1,743 (0)	199090. 8 1,373 (0)	342963. 4 1,386 (0)	271404. 8 1,178 (0)	215403. 2 0,834 (0,332)	181122. 8 0,582 (0,836)	191964 0,55 (0,9)
RECY	N A	NA	NA	0,8 (0,843)	0,8 (0,843)	0,85 (0,895)	0,85 (0,895)
HIW	2844.5 29,745 (0)	2567.9 17,713 (0,228)	3388.8 13,692 (0,638)	4008.6 17,38 (0,262)	5924.5 22,92 (0)	5326.2 17,11 (0,289)	5741 16,386 (0,3614)
WATER	2650.6 27.718 (0)	2550.1 17.59 (0)	1740.7 7,032 (0,4064)	1310.4/ 5,684 (0,8632)	948.4/ 3.669 (1)	1109.4/ 3.56 (1)	1191.4/ 3.416 (1)

"NA" indicates that no data were available for the corresponding year

For example, the greenhouse gas emissions were 183.248 metric tons CO2 equivalent per million Euros of annual net sales for company in 2010. The corresponding normalized value is (100-67,65)/(100-50)=32,35/50=0,647

The normalized time series for each indicator are aggregated into a single normalized value using the method of weighted sum. The results are shown in Table 2.

TABLE II
NORMALIZED VALUE USING WEIGHTED SUM

Indicator	Normalized value
GHG	0.6926
TR	0.236
NHIW	0.2954
RECY	0.4965
HIW	0.2541
WATER	0.6099

C. Fuzzification

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. 3.[8]

For example, the crisp value $y_{CHG} = 0.647$ for year 2010 of Table 2 belongs to the fuzzy set M of Fig. 3 with grade (1 − 0.647) / (1 − 0.6) ≈ 0.8825 and to the fuzzy set S with grade (0.647 − 0.6) / (1 − 0.6) ≈ 0.1175. Also, from Fig. 4 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) ≈ 0.7264 and VG with grad (1 − 0.8632)/(1 – 0.5) ≈ 0.2736.

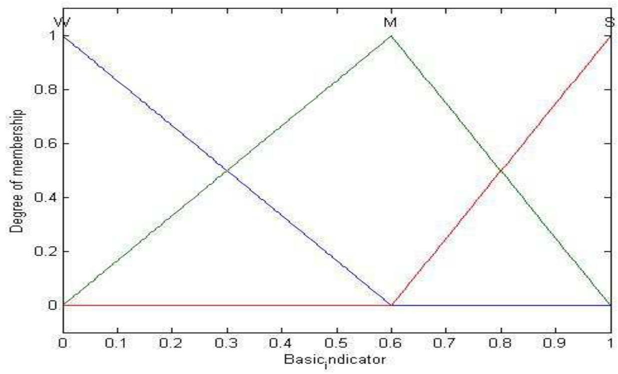

Fig. 3 Membership functions for basic indicators

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 composite indicators are used five fuzzy sets with linguistic values "very bad" (VB), "bad" (B), "average" (A), "good" (G), and "very good" (VG), as depicted on Fig.4

To represent the ENVIRONMENTAL IMPACT (ENVIRON) a larger number of fuzzy sets must be used, but for simplicity it has been considered five membership functions will do as in Fig.4.

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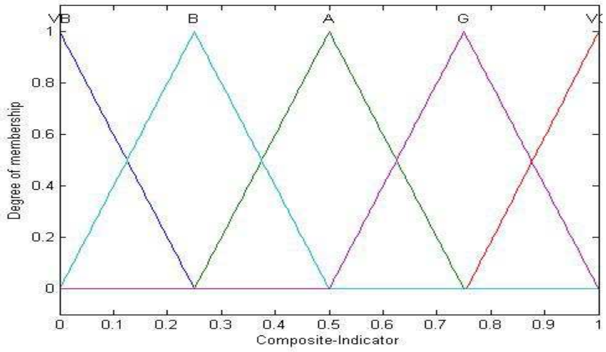

Fig. 4 Membership functions for composite indicators

In order to compute the number of linguistic values for ENVIRON 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 [9].

ENVIRON has 3 inputs, namely, SOIL, AIR, and WATER. Its fuzzy set is determined with the following equation (2):

$$\text{SUM} = \text{SOIL} + \text{AIR} + \text{WATER} \quad (2)$$

So the ENVIRON is as in (3):

$$\text{ENVIRON} = \begin{cases} \text{VB}, & 0 \le \text{SUM} \le 1 \\ \text{B}, & 2 \le \text{SUM} \le 4 \\ \text{A}, & 5 \le \text{SUM} \le 7 \\ \text{G}, & 8 \le \text{SUM} \le 10 \\ \text{VG}, & 11 \le \text{SUM} \le 12 \end{cases} \quad (3)$$

Te secondary indicator AIR for instance has two inputs computed as in (4).

$$\text{SUM} = \text{GHG} + \text{TR} \quad (4)$$

The rule base is shown below:

Rule 1: If *GHG* is *W* and *TR* is *W* then *AIR* is *VB* (0)
Rule 2: If *GHG* is *W* and *TR* is *M* then *AIR* is *B* (1)
Rule 3: If *GHG* is *W* and *TR* is *S* then *AIR* is *B* (1)
Rule 4: If *GHG* is *M* and *TR* is *W* then *AIR* is *B* (1)
Rule 5: If *GHG* is *M* and *TR* is *M* then *AIR* is *A* (2)
Rule 6: If *GHG* is *M* and *TR* is *S* then *AIR* is *G* (3)
Rule 7: If *GHG* is *S* and *TR* is *W* then *AIR* is *A* (2)
Rule 8: If *GHG* is *S* and *TR* is *M* then *AIR* is *G* (3)
Rule 9: If *GHG* is *S* and *TR* is *S* then *AIR* is *VG*(4)

Consequently AIR is as in (5)

$$\text{AIR} = \begin{cases} \text{VB}, & \text{SUM} = 0 \\ \text{B}, & 1 \le \text{SUM} \le 2 \\ \text{A}, & 2 \le \text{SUM} \le 3 \\ \text{G}, & 3 \le \text{SUM} \le 4 \\ \text{VG}, & \text{SUM} = 4 \end{cases} \quad (5)$$

SOIL parameter has three inputs and its fuzzy rules are determined from (6):

$$\text{SUM} = \text{NHIW} + \text{RECY} + \text{HIW} \quad (6)$$

Applying the same "modus operandi" the SOIL parameter is as in (7):

$$\text{SOIL} = \begin{cases} \text{VB}, & 0 \le \text{SUM} \le 1 \\ \text{B}, & \text{SUM} = 2 \\ \text{A}, & \text{SUM} = 3 \\ \text{G}, & 4 \le \text{SUM} \le 5 \\ \text{VG}, & \text{SUM} = 6 \end{cases} \quad (7)$$

V. Results

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

TABLE III
NORMALIZED VALUES AND MEMBERSHIP GRADES

Indicator	Value	VB(0)	B(1)	A(2)	G(3)	VG(4)
AIR		0	0.12	0.72	0.16	0
SOIL		0	0.14	0.68	0.18	0
WATER		0	0.1	0.85	0.05	0
		VB	B	A	G	VG
ENVIRON	0.541	0	0.035	0.92	0.045	0

Once the membership grades of the primary indicators have been computed, the membership grades o ENVIRON are determined by the following rules (as example)[9]:

(B)AIR+(B)SOIL+(B)WATER=1+1+1=3=> ENVIRON is B with grade 0.12X0.14X0.1=0.00168

(A)AIR+(A)SOIL+(G)WATER=2+2+3=7 => ENVIRON is A with grade 0.72X0.68X0.05=0.02448

The final crisp value for the ENVIRON parameter is computed using height defuzzification:

$$\text{ENVIRON} = \frac{0.25 \times 0.035 + 0.5 \times 0.92 + 0.097 \times 0.75}{0.035 + 0.92 + 0.045} = \frac{0.541}{1}$$

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 [10].

VI. Conclusion

The developed model, represent an attempt to provide an explicit and comprehensive description of the concept of environmental assessment via computing techniques in order to reduce adverse effects on environmental and implicit the population. Using linguistic variables and linguistic rules, the model gives quantitative measures of environmental assessment. Then, the problem of environmental impact assessment becomes one of specifying priorities among basic indicators and designing appropriate policies that will guarantee sustainable progress.

The model proposed provides new insights of environmental assessment, and it may serve as a practical tool for decision –making and policy design for the enterprise or company. In the future we will try to extend this system by incorporating more representative environmental parameters after discussions with specialists. Thus the system will be able to provide a more concrete analysis of a studied environmental system.

ACKNOWLEDGMENT

This work was supported by CNCSIS-UEFISCSU, project number PN II-RU 627/2010, PN II-RU 342/2010 and by the project PERFORM-ERA "Postdoctoral Performance for Integration in the European Research Area" (ID-57649), financed by the European Social Fund and the Romanian Government and Sectorial Operational Programme for Human Resources Development through the project "4D-POSTDOC" POSDRU/89/1.5/S/52603.

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