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Assessment of Company Environmental Impact using Fuzzy Logic

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Abstract. Nowadays businesses interact with society and the environment in ways that put their mark on both sides. 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 model of fuzzy reasoning to evaluate a company's environmental impact The model takes into account four components that characterize ecological component of the ecological environment (air, water, soil and biodiversity) which in turn are characterized by a number of specific parameters to assess the sustainability of a certain company. The model can be used to evaluate the environmental sustainability of the company and also can identify areas of particular interest to managers. Article illustrates an example in the automotive industry in order to prove the usefulness of using such a model.

Keywords: environmental impact assessment, fuzzy logic, company evaluation

1. Introduction

Interaction between an enterprise and the surrounding 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.

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. 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

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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.

2. Model presentation

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.

Environmental impact assessment (ENVIRON) has 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.

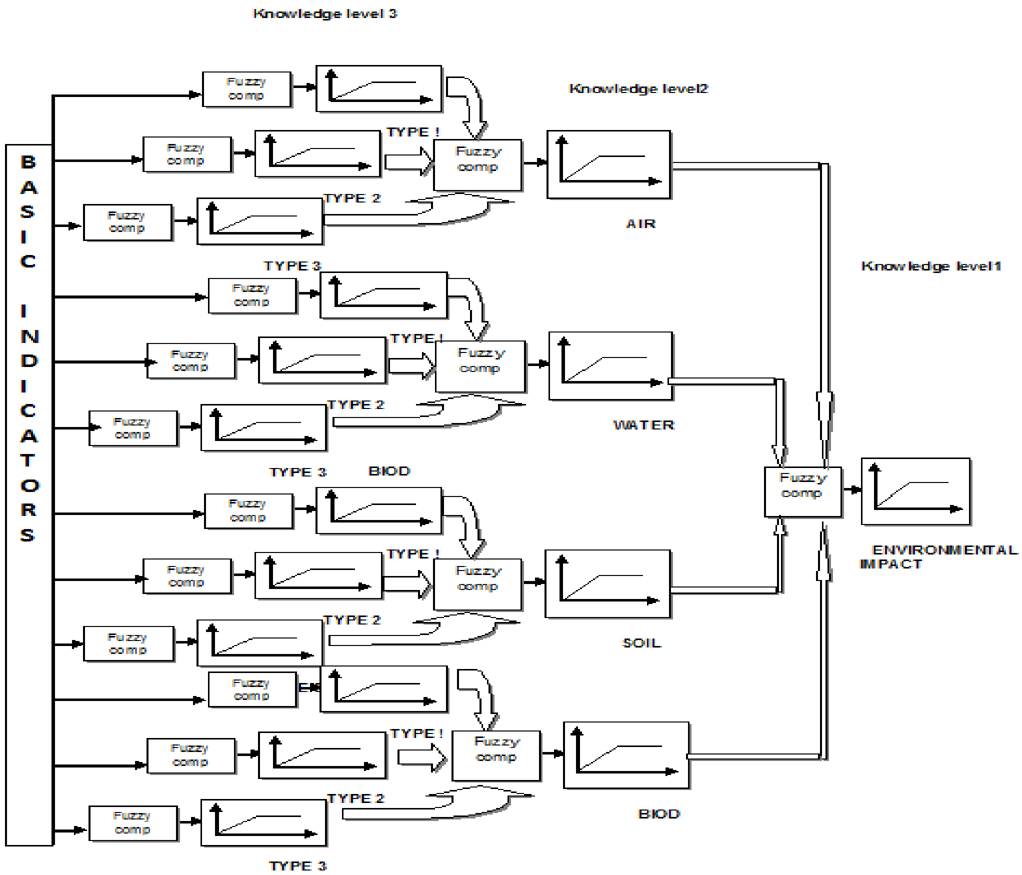


Fig. 1: Configuration of environmental sustainability model

The configuration of the model is shown in Fig.1. The model is composed from 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 ASSESSMENT. 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 [2].

3. 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 figure 2.

3.1. 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.

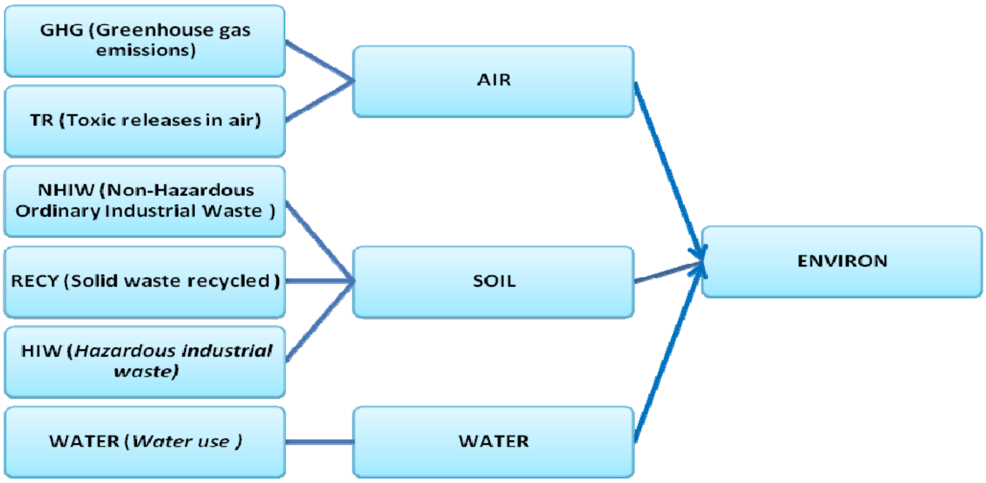


Fig. 2: Company environmental impact assessment

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.
- *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 T_{TR} =0,3 kg per unit of production. The maximum value is U_{TR} = 0,5 kg/unit.

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.). 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.
- *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.

- *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 T_{HW} = 10 kg/unit (industry average) is sustainable with value one, with sustainability decreasing linearly to the maximum value U_{HW} = 20 kg/unit.

For **WATER** indicator:

- *WATER: Water use* (m^3 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). 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).

3.2. Normalization

Normalized values, given in parentheses, are computed by linear interpolation between most desirable (target) and least desirable indicator values.

Table 1. Basic indicators and corresponding normalized values for selected company

Indicator	**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

Table2. 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

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.[3]

3.3. Fuzzification

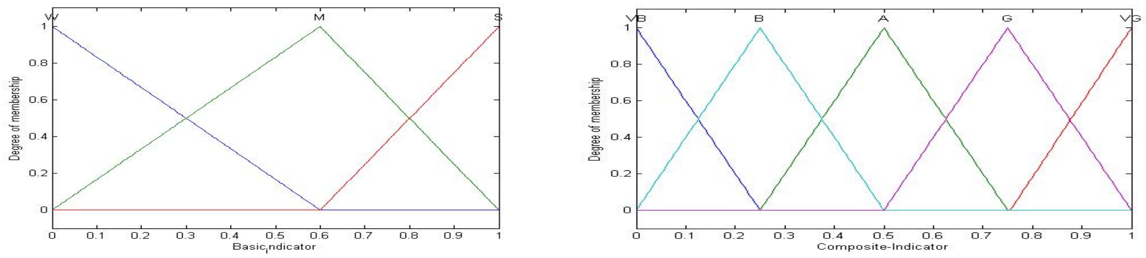
We use the membership functions below to fuzzify the values of indicators. A fuzzy assessment of sustainability involves fuzzy inputs and fuzzy outputs. All sustainability indicators, basic and composite, are normalized. Therefore we must define appropriate fuzzy partitions in [0, 1]. There are many ways to define fuzzy partitions. One such possibility is described below.[4]

Normalized basic indicators are fuzzified using three fuzzy sets with linguistic values “weak” (W), “medium” (M), and “strong” (S), whose membership functions are shown in Fig. 3.a. For secondary 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 figure 3.b.We assign the linguistic value W to low or average values of normalized indicators. Hence, the fuzzification is somewhat pessimistic which agrees with widely accepted assessment practices. For those five linguistic values are assigned integer values, such that 0 correspond to VB, 1corespond to B, and so on [3].

ENVIRON has 3 inputs, namely, SOIL, AIR, and WATER. Its fuzzy set is determined with the following equation: SUM= SOIL+AIR+WATER .

The values for parameter ENVIRON can be seen in equation below:

$$\mathrm{ENVIRON}=\begin{cases} \mathrm{VB}, & 0\leq \mathrm{SUM}\leq 1 \\ \mathrm{B}, & 2\leq \mathrm{SUM}\leq 4 \\ \mathrm{A}, & 5\leq \mathrm{SUM}\leq 7 \\ \mathrm{G}, & 8\leq \mathrm{SUM}\leq 10 \\ \mathrm{VG}, & 11\leq \mathrm{SUM}\leq 12 \end{cases}$$



a) b)

Fig. 3 Membership functions

4. Conclusions and results

Table3. 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

Table 3 shows the environmental impact assessment for the selected company using the model. The result of computation is presented below.

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

(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.

5. Acknowledgements

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