ENVIRONMENTAL INDICATORS AS AN IMPORTANT PART WHEN DESCRIBING SUSTAINABLE DEVELOPMENT

Conf.univ.dr. Ildiko Tulbure
University "1 Decembrie 1918" of Alba Iulia

Abstract: In order to operationalize the concept of sustainable development a general and flexible methodology by a systematic approach is necessary to be developed. This makes possible the application of sustainable development to each concrete case with the specific conditions of the observed system. An important role play sustainable development indicators and their components. Such indicators are needed in order to establish aims, to quantify them, to verify the possible effects of measures before introducing them and to help the decision making process. In the development of SDIs three directions are to be observed. Fuzzy logic offers the chance to integrate complexe qualitative entities in mathematical models and represents a transparent methodology. The possibility to define a modular sustainable development indicator will be discussed, wherein environmental indicators are very important. Environmental indicators are characterizing the air, water and soil pollution. An indicator for air pollution API is proposed and applied on regional level for two countries. The results will be discus-sed and conclusions concerning the usage potential of the presented methodology will be drawn.

1. The Concept of Sustainable Development

Starting with the ‘70 years the world began to realize the dangers and undesired effects of human activities, especially industrial ones. After the Conference for Environment in Stockholm in 1972 and the first report of the Club of Rome „The Limits of the Growth“ [8] was understood that besides wanted effects of technological progress, undesired and negative effects can appear. After this time the environmental awareness in the western world began changing [4]. Nowadays we confront us with a series of global problems known as the „trilemma“ of our society: world population growth, growth of the energy and natural resources consumption and environmental pollution [4].

Worldwide began discussions on political, scientifical and social levels in order to find solutions for the problems shown above. The Brundtland Report of the World Council on Environment and Development represented a result of these worldwide political discussions. The concept of sustainable development was for the first time defined in the Brundtland Report [10] and accepted as a possible solution for the global complex ecological, economical and social problems. The concept of sustainable development was very large discussed on the Conference for Environment and Development in Rio de Janeiro 1992 as in the closing document „Agenda 21“. Many actions after this time emphasize that the evolution of technical, social and ecological systems has to be analysed in synergetic relation [14].

In order to make this concept more understandable rules, strategies and principles of sustainable development were defined (see [14]). The tranformation of the concept of sustainable development in political measures and controlling instruments needs his operationalization.

2. The Methodology to Operationalize Sustainable Development

There are especially two strategic possibilities: establishing goals on global level, the measures to achieve these goals being prepared on global and national level and applied on regional level and the second one establishing goals on regional level, the measures being prepared on regional level and immediately applied; the effects of the measures being evaluated on national and global level too.

As an application example of the first strategy studies in form of scenarios could be mentioned, for instance with the goal of finding future sustainable energy supply systems with minimal effects on the environment. Such a project has been realized at the IIASA (International Institute for Applied Systems Analysis) in Laxenburg/Vienna „Globale Energieperspektiven bis 2050 und darüber hinaus" (Global Energetic Perspectives till 2050 and more) [14]. The IKARUS project (Instruments for Reducing Emissions of Gases relevant to Climatic Changes) developed by several institutes in Germany [15] represents another example. All these studies base on mathematical models to describe industrial and economic processes; with the help of a database, which describes economic, social and political frame, simulations have been realized and different development scenarios are gained. The goal is to help with concrete measures the decision making process on political level.

The second strategy is illustrated by many actions in form of Local Agendas 21 leaded especially in Western European countries after the Rio-Conference in 1992. On this point national scenario studies could be mentioned, which try to find sustainable ways for the future national development in global context, for instance the actionplan „Sustainable Netherlands" by Friends of Earth Netherlands in 1992 or the study „Zukunftsfähiges Deutschland" (Sustainable Germany) initiated from Bund (Friends of Earth - Association for Environment and Nature Protection) and Misereor and leaded by the Wuppertal Institute for Climate, Environment and Energy [2].

A general methodology in order to operationalize sustainable development is materialized in several steps, starting with defining the sustainability problem, establishing the space and time scales, then the systemic approach of the region by modelling the interactions, establishing concrete aims for the studied case , developing concepts and measures by establishing priorities, developing evaluation and control instruments, verifying possible results which could be obtained after introducing the proposed measures and ending with applying in the practice the developed concept.

The operationalization is only possible, when for an individual problem-case concrete aims are established and from these aims concepts to achieve them are developed. Sustainability is to be for each different case newly defined. The space and time scales are to be established for each case. The concept of sustainable development could be efficiently applied on regional level [14]. Specific sustainable development priorities could be different from a region to another, or from a country to another. Controlling instruments are indicators, so-called sustainable development indicators.

3. Environmental indicators

Sustainable Development Indicators permit to formulate quantitatively the proposed objectives and goals in order to obtain sustainable development. After introducing the proposed measures, the realization degree can be controlled by calculating these indicators. A lot of attempts to define indicators for sustainable development (SDI) are known in the whole world like defining one single aggregated indicator, defining a set of indicators for measuring sustainable development or defining partial aggregated indicators. In the last case for each component of sustainable development for the ecological, economical and social one a partial aggregated indicator has to be defined. As aggregated indicators can be named the Index of Sustainable Economic Welfare (ISEW), the Human Development Index (HDI) and the Ecological National Product (ENP) [3]. A system of indicators to measure sustainable development has been developed for the town Jacksonville [3] and another set of indicators in the German region Baden-Württemberg by the Academy for Technology Assessment in Stuttgart [12]. The definition of partial aggregated indicators is given by the modular design of the SDI (figure 1). Each of the three significant components of the concept of sustainable development is described by an indicator (figure 1). In order to gain one single SDI the aggregation problem of the three components has to be solved. On the other hand such indicators serve as an instrument to better understand the possible effects by introducing certain measures.

As I have mentioned, to build a sustainable development indicator means first of all to define its components. One of the components is represented by indicators for environmental aspects, as for instance indicators for air, water or soil quality.

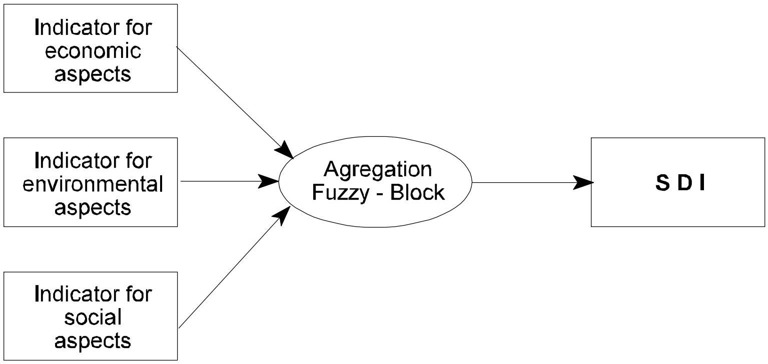

Figure 1: Aggregation levels for the proposed sustainable development indicator

Environmental indicators are used in order to characterize environmental systems. By environmental systems two aspects are from interest. One aspect concerns the description of the state of a system at a certain time. The other aspect is refering to the dynamic behaviour of the system (figure 2). Depending on the proposed limits the analyse of environmental systems can be approached on different levels, for instance on local, regional, national or global level.

Worldwide there are many preoccupations to define environmental indicators. Well known is the OECD-model, so *called pressure-state-response* model [2]. Mitchell in [9] gives a structural classification of environmental indicators in *specific, composite* and *key* indicators. Going into details a lot of indicators for air, water or soil pollution were defined and are used nowadays in many countries (see for details [11], [14]). For instance in Germany the Umweltindex for air quality is used and published every week by the VDI-Journal (Journal of the German Engineers Association). When studying all these used indicators one can observe that many of them integrate coefficients, which are

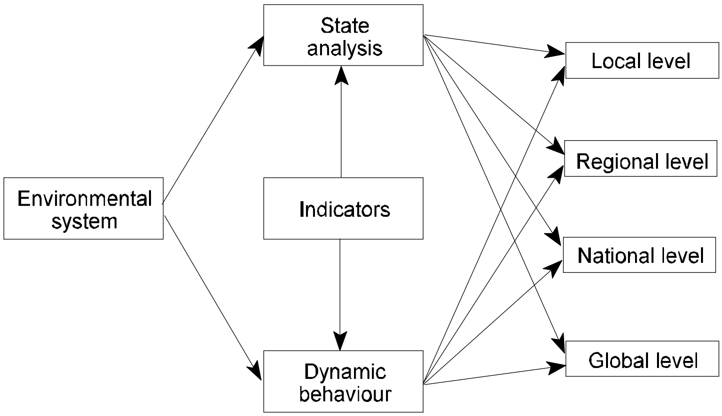

Figure 2: The role of indicators by describing environmental systems

not transparently defined or assume that impacts of different pollutants are equivalent to each other.

In order to minimize these deficiencies methods of soft-computing have to be used. Beside neuronal networks and genetic algorithms especially fuzzy logic offers possibilities to use new methods for defining indicators by its potential to integrate complexity in the systematic and exact mathematical approach.

4. Short presentation of Fuzzy Logic

Regarding this subject a great diversity of books are available at present, which treat fuzzy logic more or less detailed ([6] and other). In the following I will make after [7] only a succint presentation of the important notions related to fuzzy logic.

Fuzzy logic is based on the knowledge that reality is rather unexact than precise, because all afirmations have a certain free interpretation domain. Traditional binary logic is part of fuzzy logic as a special case operating only with two values of interpretation. A set is fuzzy limited if the assignment of one is not given to all the members of the set, that is total membership. A fuzzy set is defined by the generalized characteristic function, called the *membership function* μ. This real function can take on any values, but usually it is normalized into the interval [0, 1].

The key notion when modelling with Fuzzy Logic is the *linguistic variable*. The mathematical description of processes requires a precise quantitative presentation of the influences considered. The usual strategy is to disaggregate complex quantities into many variables connected by complex functional description. In opposition to this, verbal rules of behaviour contain fuzzy formulated knowledge, which is generally more intelligible. Beyond that, linguistically formulated variables have a higher aggregated information content, and therefore it is more difficult to quantify them.

The concept of linguistic variables connects the description of verbal and therefore fuzzy information with mathematical precision. The values of a linguistic variable are verbal expressions, called *linguistic terms*, for instance *small*. The content of each linguistic term is identified with one fuzzy set and assig-ned to the related numerical scale of the basic variable by a particular membership function (see figure 5). Thus, the fuzzy sets build the connection between linguistic expression and numerical information.

To process fuzzy formulated knowledge several linguistic variables must be linked by linguistic operators. The connecting rules represent the knowledge, that is stored in a rulebase or knowledge base, similar to expert systems.

The procedure consists of the following steps: fuzzification, inference and defuzzification (figure 3).

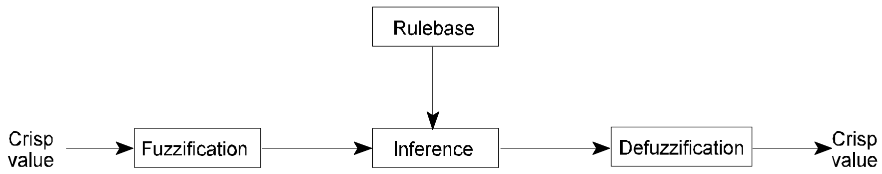

Figure 3: General operational diagram by fuzzy logic applications (after [7]).

The fuzzification step is the linguistic interpretation of any crisp input value of a basic variable. This means, the determination of the membership values of each crisp input to all linguistic terms. For this purpose, the basic numerical interval, the number of the linguistic terms and the according verbal expressions of the linguistic variable have to be previously fixed. The quantitative transformation of the verbal expressions is sensitive, especially to the shape of the membership function. Due to computing efficiency often triangular and trapeziform membership functions are used, but any other distribution function is also possible. Thus, fuzzification means finding out to which degree any linguistic term participates. In figure 5 the fuzzification step is shown for instance for the basic criteria defining the weighting coefficients for the air pollution index.

After fuzzification, the inference has to draw conclusions from the propositions with regard to the knowledge base. The knowledge formulated as IF-THEN-rules has to be applied to the new fuzzy statements. Inference consisting of aggregation of the IF-parts of each rule, implication and accumulation of the results of the rules THEN-parts, causes a weighting of each single rule on the total result. The aggregation of the left side is only necessary when more than one proposition impacts an implication. The result of the implication itself is the assignment of a proposition of a rule to a linguistic term of the output variable. Running all rules generates several different images of the output variable because of the different parts of the output linguistic terms. This result consists of different participating linguistic terms of the linguistic output variable.

On the other hand, a crisp output value could be drawn from the resulting membership distribution by several procedures. The most familiar one is to determine the center of gravity of the area representing the resulting membership distribution of the participating linguistic terms. The abscissa value represents then the crisp output value.

Such a knowledge based approach means the methodical attempt to substitute missing or inefficient algorithmic procedures by using human knowledge. Thus, even partially fulfilled conditions result in partially fulfilled conclusions, so these conditions are considered also in the result. Therefore, the possibility to consider uncertain information in systems modelling is given which encourages application in the field of environmental systems.

5. Air Pollution Index

The air pollution index (API) is to be calculated with the following relation [13]:

$$(x,y,z,t) = \frac{1}{\sum_{i=1}^{n} W_i} \cdot \sum_{i=1}^{n} \frac{C_{rel,\,i}\ (x,y,z,t)}{C_{ref,\,i}}$$

where: $C_{real,i}$ - values of pollutants concentrations at a certain place and time [ppm or mg/m^3];
$C_{ref,i}$ - reference values: admissible values of pollutants concentrations [ppm or mg/m^3] (along with German standards of TA Luft, 1986);
w_i - weighting coefficients.

Thus, API = 1 means that in the approached system all pollutants concentrations have reached their limits, API>1 means that all concentrations are above the limits and API<1 means that all of them are below the limits.

The establishment of the weighting coefficients is a complex problem because a big amount of implicit knowledge from different features has to be integrated in this process. Anyway, the usage of weighting coefficients is the expression of the conviction that the importance of the different pollutants emissions is not equal.

At present time some approaches in selecting values of weighting factors are used widely: the panel method, the monetization method and the distance-to-target method [5]. Another possibility is given by using a fuzzy logic based method [7, 15].

A transparent way to establish weighting coefficients for singular pollutants is the proposed method based on fuzzy logic. The basic criteria, which determine the weight coefficients, have been established by a number of three, presented in figure 4. These are: *impact on health, impact on ecosphere and emitted quantity*. The way, in which these influences determine the weight of a pollutant, will be described with the help of a fuzzy logic based system.

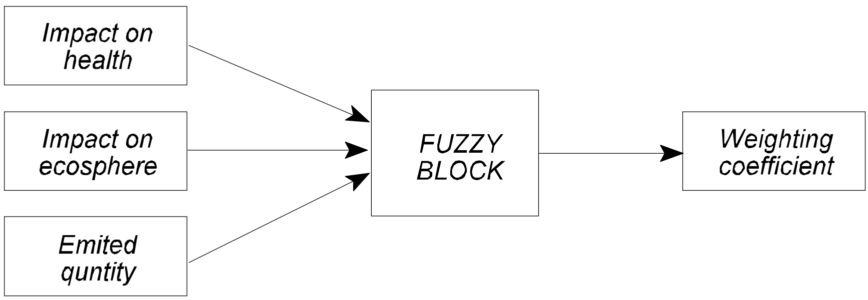

Figure 4: Aggregation level for the weighting coefficient

Linguistic variables

The chosen input criteria defined on the interval [0, 1] are formulated as linguistic variables each with the three linguistic terms *small, medium* and *high* (figure 5). The weighting coefficient as output variable has seven linguistic terms, the three mentioned above and in addition *very very small, very small, very high* and *very very high* [14]. The connection between the linguistic terms is given by the rulebase, which has 27 rules in this case. Table 1 shows the principial rulebase, wherefrom one can obtain the whole rulebase.

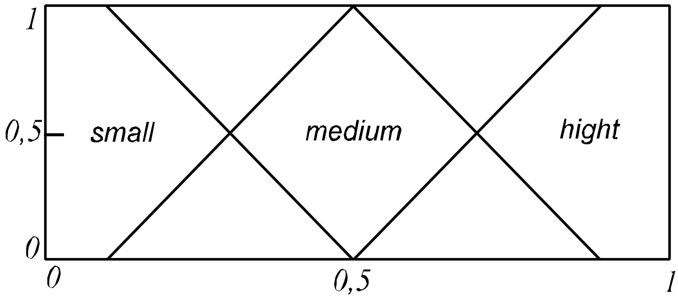

Figure 5: Linguistic terms and membership function for the linguistic variables impact on health, impact on ecosphere and emitted quantity

The weighting coefficients for API calculated with the following input values for the basic criteria are given in table 2. To establish the input values knowledge regarding the *impact on health* and *on ecosphere* of the considered pollutants was taken into account [1]. The input values corresponding to the basic criterion *quantity* are related to the reference values and given as relative values in the interval [0, 1].

The reference values are represented by emissions of CO_2 for each country. The approached pollutants emissions for the two countries correspond to the year 1991 [15, 16].

Table 1: Rulebase structure for the API weighting coefficients.

Inputs			Output
Health	Ecosphere	Quantity	Weight coef.
small	small	small	v very small
small	small	medium	very small
small	medium	medium	small
medium	medium	medium	medium
high	medium	medium	high
high	high	medium	very high
high	high	high	v very high

Table 2: Inputs of the basic criteria for the weighting coefficients for API.

	Impact on health	Impact on ecosphere	Emitted quantity		Weighting Coefficients
			D	RO	
CO_2	0.05	0.95	1.0	1.0	0.67
NO_x	0.7	0.6	0.0032	0.0036	0.46
SO_2	0.7	0.5	0.0046	0.0073	0.42
CO	0.9	0.05	0.01	0.082	0.33

In order to emphasize the working way of fuzzy logic the proposed method has been applied to one region of Romania (Jiu-Valley) and one region of Germany (Ruhr region). In table 3 are given the average pollutants concentration in the approached regions (RO: own measurements, D: VDI-Journal) as well as the admissible values of these pollutants after German standards (TA Luft) and the resulting API calculated with relation (1) for n=4.

Table 3: Pollutants concentrations [mg/m^3] and resulting API.

	CO_2 [ppm]	NO_X	SO_2	CO	**API**
Jiu-Valley	350	0.43	1.090	2.75	**3.48**
Ruhr-region	350	0.07	0.057	0.50	**0.69**
Admissible	330*	0.08	0.140	10.00	**1.00***

*not as admissible value in standards, but chosen as example by author.

Concerning the air pollution one can conclude that the Romanian region is about five times as polluted as the German region.

5. Conclusions

In the process of operationalization of sustainable development an important step is represented by developing sustainable development indicators. Worldwide there are three directions to define sustainable development indicators. A modular design of SDIs has been proposed, each module corresponding to one of the three aspects of sustainable development: economical, social and environmental aspects.

Environmental aspects are described by environmental indicators, which play an important role when defining SDIs.

In this paper an environmental pollution index was presented concerning air pollution. The air pollution index is defined as the sum of the weightened, relative pollutants concentrations, whereat the weighting coefficients were established using a fuzzy logic based method.

The fuzzy logic application presented in this paper shows its manifold possibilities to solve environmental problems. It can be used especially for transparent assessment, when the available knowledge is diffuse, unstructured and disorderly.

References

[1] M. Bank: Basiswissen Umwelttechnik; 2. Auflage, Vogel Buchverlag, Würzburg (1994).
[2] BUND / MISEREOR (Ed.): *Zukunftsfähiges Deutschland;* Birkhäuser, Basel 1996.
[3] W. van Dieren (Ed.), *Taking Nature into Account;* Springer, New York 1995.
[4] M. F. Jischa: *Herausforderung Zukunft*; Spektrum Akademischer Verlag, Heidelberg 1993.
[5] K. M. Lee: *A Weighting Method for the Korean Eco-Indicator*; in: The International Journal of LCA, ecomed publishers, Landsberg, Vol. 4, No. 3, 1999, pp. 161-165.
[6] B. Ludwig: *Methoden zur Modellbildung in der Technikbewertung*, doctorate thesis, TU Clausthal, 1995, see also CUTEC-Schriftenreihe Nr. 18, Papierflieger, Clausthal-Zellerfeld.
[7] B. Ludwig and I. Tulbure: *Ein fuzzy-unterstützter Ansatz zur Erfassung und Bewertung von Umweltinformationen am Beispiel der Luftverunreinigung (A fuzzy based method to evaluate environmental information regarding air pollution).* In: C. Ranze u.a. (Ed.): Intelligente Methoden zur Verarbeitung von Umweltinformationen. Metropolis Verlag. Marburg (1996), S. 181-192.
[8] D. and D. Meadows: *The Limits to Growth;* Universe Book, New York (1972).
[9] G. Mitchell: *Problems and Fundamentals of Sustainable Development Indicators*; in:

Sustainable Development, Vol. 4, Number 1, March 1996, pp. 1-11.
[10] *Our Common Future*, The Brundtland Report to the World Commission on Environment and Development; Oxford Univ. Press, Oxford (1987).
[11] W. R. Ott: *Environmental Indices – Theory and Practice*; Ann Arbor Science, Michigan (1978).
[12] G. Pfister and O. Renn: *Ein Indikatorensystem zur Messung der nachhaltigen Entwicklung in Baden-Württemberg;* Arbeitsbericht Nr. 64 der Akademie für Technikfolgenabschätzung in Baden-Württemberg, Stuttgart (1996).
[13] I. Tulbure and B. Ludwig: *Umweltindikatoren – Schlüssel zu Sustainable Development.* Umwelt, Springer VDI, Nr. 4-5, pp.45-49 (2000).
[14] I. Tulbure: *Zustandsbeschreibung und Dynamik umweltrelevanter Systeme (State and Dynamic Analysis of Environmental Systems);* Doctorate thesis, TU Clausthal 1997, see also CUTEC-Schriftenreihe Nr. 25.
[15] VDI-Berichte 1043: *Instrumente zur Minderung energiebedingter Klimagasemissionen IKARUS*; VDI-Verlag, Düsseldorf (1993).