Proceedings of ICTAMI
International Conference on Theory and Applications in Mathematics and Informatics
17th–20th of September, 2015, Alba-Iulia, Romania
Computer Science Section

pp. 195-208

FUZZY LOGIC BASED APPROACH FOR ENVIRONMENTAL IMPACT ASSESSMENT

I. Tulbure, M.F. Jischa

Abstract. In order to carry out a comprehensive environmental impact assessment a general and flexible methodology by a systematic approach is necessary to be developed, that has to take into account concrete specific conditions of each observed system. In this context, an important role do play environmental 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 environmental indicators several directions can be observed. In this context an aggregation method based on fuzzy logic will be analysed. Fuzzy logic offers the chance to integrate complexe qualitative entities in mathematical models and represents a transparent methodology. The possibility to define in a modular way environmental indicators will be emphasised. Environmental indicators are characterizing the air, water and soil pollution. An indicator for air pollution, API, is presented and applied for several regions. The obtained results will be discussed and conclusions concerning the utilisation potential of the presented methodology will be drawn.

2010 *Mathematics Subject Classification*: 30C45.

Keywords: Environmental Knowledge Engineering, Fuzzy Logic, Environmental Impact Assessment, Environmental Indicators

1. Introduction

Already 50 years before the humanity started to recognise the possible impacts on the environment and society of the technological applications. After the World Conference for Environment that took place 1972 in Stockholm and after the publication of the first report to the Club of Rome The Limits of the Growth [6] was finally understood the complexity of the emerging situation. Scientists started to think about the fact that besides wanted effects of technological progress, undesired and negative effects could appear. As a result, after this time the environmental awareness in the

Western world began changing [4]. It became clear that the created regional and global environmental problems are very serious and need to be solved. Nowadays we confront us with a series of global problems, as for instance world population growth, growth of the energy and natural resources consumption, as well as environmental pollution [3, 4].

The Brundtland Report of the World Council on Environment and Development [9] represented a result of the worldwide political discussions to find solutions. The concept of *sustainable development* was for the first time defined in the Brundtland Report and accepted as a possible solution for the global complex ecological, economical and social problems [9]. This concept 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 [11].

In order to find appropriate solutions and strategies for environmental protection with the further goal of applying the concept of sustainable development on regional level more understandable rules, strategies and principles of sustainable development have been defined (see [4], [12]). The general Brundtland definition was worldwide accepted, but together with the rules, strategies and principles, it does not give a concept, which is to be applied to the real concrete situations in order to reduce the environmental pollution and to get a regional sustainable development [4, 13].

2. ENVIRONMENTAL IMPACT ASSESSMENT BY SUSTAINABLE DEVELOPMENT OPERATIONALISATION

Reducing the environmental impacts of human activities is a goal in order to get the sustainable development on regional level. In this context two strategic possibilities are relevant [4, 13]:

- establishing goals on global level, the measures to achieve these goals being prepared on global and national level and applied on regional level;
- establishing goals on regional level, the measures being prepared on regional level and immediately applied, the effects of the measures being evaluated on global level.

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 darber hinaus (Global Energetic Perspectives till 2050 and more) or the EU-research project "TERRA2000" [4, 10] for the Sustainable Knowledge Society in Europe. Such studies are basing on mathematical models to describe industrial and economic processes and their possible impacts. With the help of a database simulations can be run and different scenarios gained. The goal is to find the right ways for the proposed aims and to help with concrete measures the decision making process on political level [13].

The second strategy is illustrated by many actions in form of Local Agendas 21 led especially in European countries after the Rio-Conference in 1992. On this point national also scenario studies could be mentioned, which try to find sustainable ways for the future national development in the global context, for instance the actionplan Sustainable Netherlands by Friends of Earth Netherlands in 1992, the study Zukunftsfhiges Deutschland (Sustainable Germany) initiated from Bund (Friends of Earth - Association for Environment and Nature Protection) and Misereor and led by the Wuppertal Institute for Climate, Environment and Energy or the study National Sustainable Development Strategy 2013-2020-2030 (NSDS) regarding the sustainability of Romania [8], developed by the National Centre for Sustainable Development (NCSD).

A general methodology for carrying out an environmental impact assessment with the goal of applying sustainable development on regional level is materialized in the following steps [13]:

- defining the environmental pollution problem as well as the sustainability problem;
- establishing the space and time scales for environmental impact assessment;
- systemic approach of the region by modelling the interactions;
- establishing concrete aims for the studied case;
- developing evaluation and control instruments for environmental impact assessment;
- developing concepts and measures by establishing priorities;
- verifying the possible results, which could be obtained after introducing the proposed measures by running simulations and developing scenarios;
- applying into the practice these concepts and measures for environmental protection.

The environmental impact assessment with the goal of applying sustainable development on regional level is only possible when for the respective situation the assessment by using environmental indicators is led and concepts to achieve an improvement of the existing situation are developed. The space and time scales are to be established for each case. In order to make the concept of sustainable development applicable into the practice on national or regional levels, after finishing the environmental impact assessment, operational criteria are needed. Such criteria may request specific priorities, which are different from a region to another. Controlling instruments are environmental indicators as an important part of sustainable development indicators [2, 4, 11].

3. ENVIRONMENTAL INDICATORS

Environmental indicators permit to formulate quantitatively the proposed objectives and goals for environmental protection, that is why their development is very important for engineers [1, 5, 11]. After introducing the proposed measures the development direction of the system can be controlled by calculating these indicators and by comparing to the reference values. The possibility to make corrections is assured in this way [3].

Environmental indicators, as for instance indicators for air, water or soil quality, are playing an important role and are used in order to characterize environmental systems. With regard to environmental systems two aspects are from interest. One aspect concerns the description of the state of the analysed system at a certain time. The other aspect is referring to the dynamic behaviour of the analysed system (figure 1). Depending on the proposed limits of the respective analyse, environmental systems can be approached on different levels, for instance on local, regional, national or global level.

When defining new environmental indicators some requirements have to be met [1]:

- to offer informations about the process, which is described by them;
- to have a function of prevention and control;
- to use a transparent method;
- to use an intelligible aggregation method;
- to be easy to apply;
- to offer the possibility to compare different alternatives.

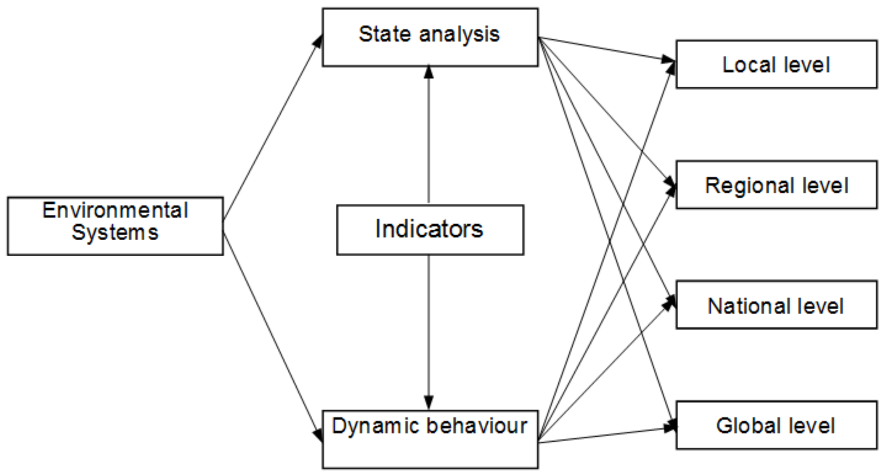

Figure 1: The role of indicators when describing environmental systems.

Worldwide there are many preoccupations to define environmental indicators. Well known is the OECD-model, the so called pressure-state-response model [3,11]. Mitchell in [7] 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 have been defined and are used nowadays in many countries (see for details [11,14]). For instance in Germany the LBI index 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 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 for defining new environmental indicators by its potential to integrate complexity in the systematic and exact mathematical approach [5,12,15].

4. FUZZY LOGIC BASED MATHEMATICAL APPROACH

Regarding this subject a great diversity of materials and books are available at present, which are approaching fuzzy logic more or less detailed [4, 11, 15].

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. In contrast to the well-defined sets of the set theory, real existing sets are rather fuzzy limited, essentially due to the uncertainties in used language. 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 . This real function can take on any values [15], 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. So, a mathematical description of such variables usually leads to an information loss [11, 15].

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, medium, high (Figure 2). The content of each linguistic term is identified with one fuzzy set and assigned to the related numerical scale of the basic variable by a particular membership function (see Figure 6). 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 [15]. The procedure consists of the following steps: fuzzification, inference and defuzzification (Figure 2).

The fuzzification step is the linguistic interpretation of any crisp input value of a basic variable, what 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. Due to computing efficiency often triangular and trapeziform membership functions are used, but any other distribution function is also possible [15]. Thus, fuzzification means finding out to which degree any linguistic term participates. In Figure 2 the fuzzification step is shown for a linguistic variable with three terms.

After fuzzification, the inference has to draw conclusions from the propositions

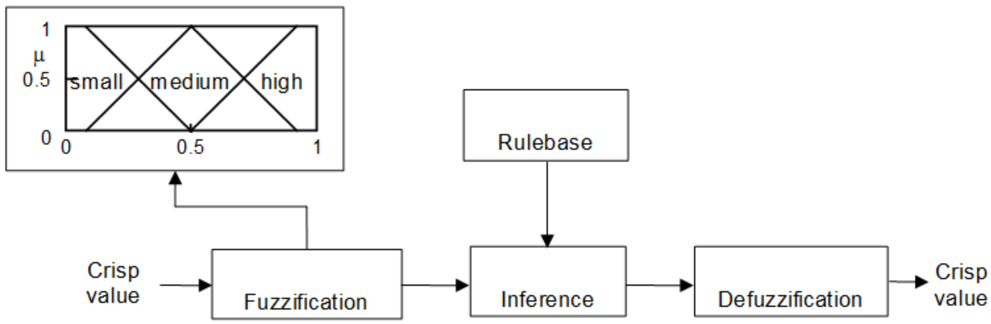

Figure 2: General operational diagram by fuzzy logic applications (after [11]).

with regard to the knowledge base. The knowledge formulated as IF-THEN-rules has to be applied to the fuzzy statements. The inference causes a weighting of each single rule on the total result. The result of the inference 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. These have to be accumulated to a single conclusion by a union operator because of the alternative character of the rules. This result consists of different participating linguistic terms of the linguistic output variable. It could be approximated verbally by the most suitable linguistic terms of the 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, fact that encourages applications in the field of environmental systems.

5. AIR POLLUTION INDEX

The air pollution index (API) is a specific environmental indicator, used for characterizing the air quality, and is calculated with the following relation [11]:

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

where

- $C_{real,i}$ - values of pollutants concentrations at a certain place and time [ppm or mg/m3];
- $C_{ref,i}$ - reference values: admissible values of pollutants concentrations [ppm or mg/m3], along with respective standards in each country;
- 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 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. Another possibility is given by using a fuzzy logic based method, that will be presented after [11] in the following.

A transparent way to establish weighting coefficients for singular pollutants is the proposed method based on fuzzy logic. The basic criteria, which are determining the weighting coefficients, have been established by a number of three, presented in Figure 3. 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.

<u>Linguistic variables</u>

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 (see Figure 4). 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. The connection between the linguistic terms is given by the rulebase, which has 27 rules in this case.

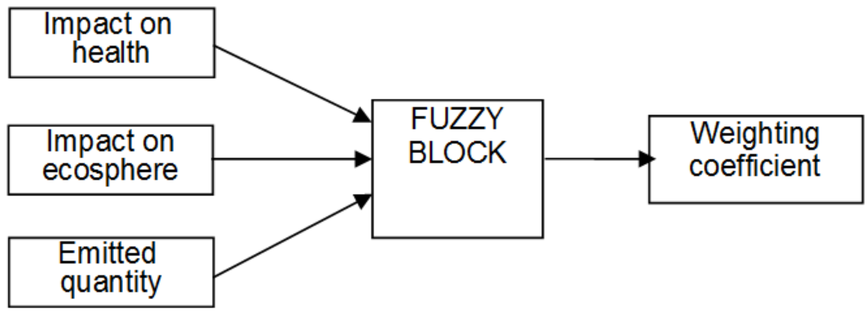

Figure 3: Aggregation level for the weighting coefficient.

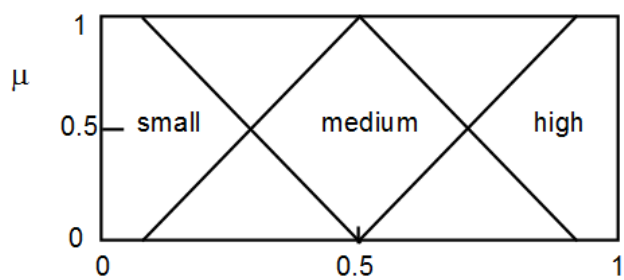

Figure 4: Linguistic terms and membership function for the linguistic variables *impact on health, impact on ecosphere and emitted quantity.*

In Table 1 the rulebase structure for determining the weighting coefficients is presented, wherefrom the complete rulebase can be obtained.

Table 1: Rulebase structure for calculating the weighting coefficients for API.

Inputs			Output
Health	Ecosphere	Quantity	Weighted 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

Weighting coefficients

The weighting coefficients (WeCo) for API calculated with the following input values for the basic criteria are given in Table 1. To establish the input values knowledge regarding the impact on health (He) and on ecosphere (E) 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]. In this example the situation of four countries regarding pollutants emissions has been taken into account. The reference values are represented by emissions of CO2 for each country. The approached pollutants emissions for the four countries correspond to the year 1997 [13].

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

	Impact on		Emitted quantity				**Weighting coefficients**
	health	ecosphere	B	D	H	P1	
CO_2	0.05	0.95	1	1	1	1	**0.67**
NO_x	0.7	0.6	0.0026	0.0025	0.011	0.0078	**0.46**
SO_2	0.7	0.5	0.0030	0.0034	0.0027	0.0032	**0.42**
CO	0.9	0.05	0.079	0.0074	0.018	0.0064	**0.33**

Results

In order to emphasize the working way of fuzzy logic the proposed method has been applied to several European regions. In Figure 5 the annual average pollutants concentrations in the approached regions for 2005 (URL: http://www.eea.eu.int) are given. The admissible values of these pollutants have been taken after German standards (TA Luft). The resulting API has been calculated with the given relation (1) for n=4 and the calculated values are shown in Figure 6. From Figure 6 one can observe that the values for API in the analysed regions are below the limit which is API = 1. The made progress concerning the air quality in some regions as for instance Budapest or Katowice from 1990 to 2005 is emphasized by API. It would be interesting to apply API to very polluted regions too, but unfortunately for such regions it is very difficult to get the necessary environmental data.

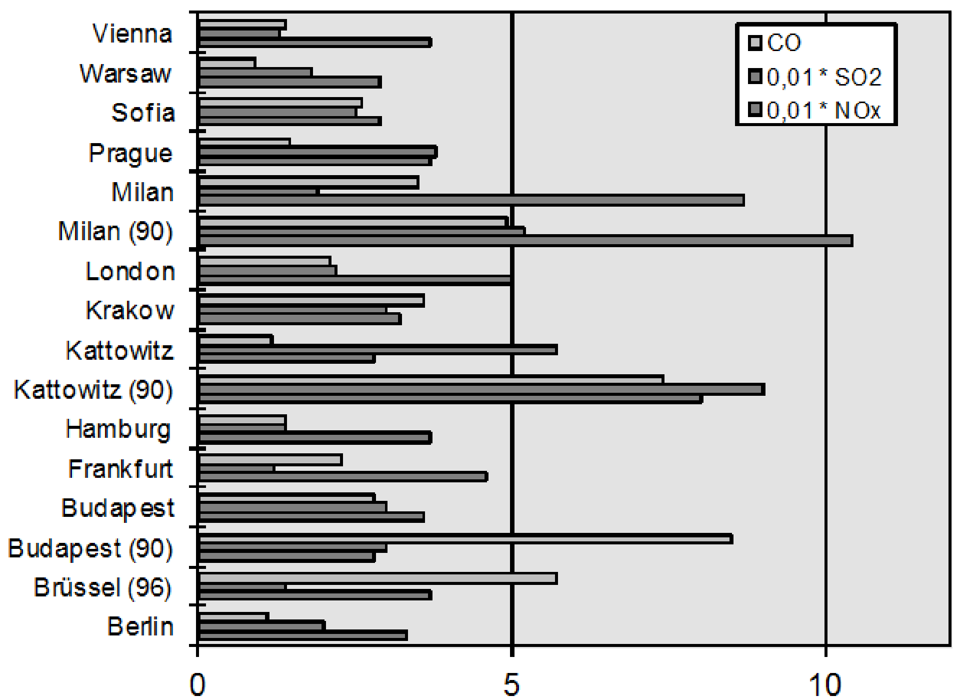

Figure 5: Average pollutants concentrations [mg/m 3] for some European regions in 2005.

6. Conclusions

In the process of operationalization of sustainable development an important step is represented by analysing environmental aspects. Environmental aspects are described by environmental indicators, which play an important role when defining SDIs.

In this paper an environmental indicator concerning the air pollution was presented. The air pollution index, API, was defined as the sum of the weightened, relative pollutants concentrations, where the weighting coefficients were established

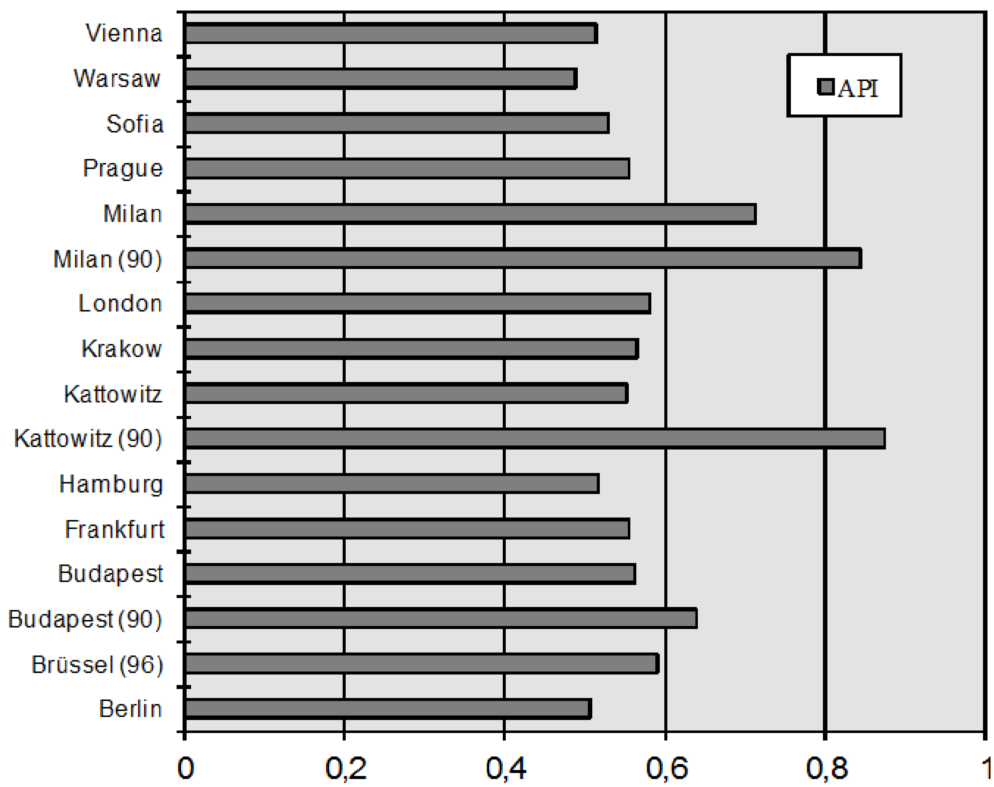

Figure 6: Resulting Air Pollution Index for some European regions in 2005.

by using a fuzzy logic based method. The presented environmental indicator can be extended from one to two or three components including also water and soil characterisation. In this way an entire environmental pollution index can be obtained. Following the same algorithm economic, environmental and social indicators can be aggregated to a sustainable development indicator.

The fuzzy logic based method offers new possibilities by its potential to integrate complexity in the systematic and exact mathematical approach and assures a transparent assessment. The fuzzy logic application presented in this paper shows the manifold and important possibilities of fuzzy logic based methods to solve environmental problems. It can be used especially for transparent assessment, when the available knowledge is rather diffuse, unstructured and disorderly, as also by approaching subjects regarding defining environmental indicators and sustainable development indicators.

References

[1] R. H. Armon, O, Hnninen (Eds.): *Environmental Indicators*, Springer, Berlin (2015)
[2] H. Bossel: *Indicators for Sustainable Development.Theory, Method, Applications. A report to the Balaton Group.* International Institute for Sustainable Development. Manitoba, Canada (1999)
[3] W. van Dieren (Ed.), *Taking Nature into Account*; Springer, New York (1995)
[4] M. F. Jischa: *Herausforderung Zukunft; New Edition.* SpringerSpektrum, Berlin Heidelberg (2014)
[5] M. F. Jischa: *About climate change and future energy systems. Swiss Bulletin fr angewandte Geologie*, Nr. 18/2, p.83-93 (2013)
[6] D. and D. Meadows: *The Limits to Growth*; Universe Book, New York (1972).
[7] G. Mitchell: *Problems and Fundamentals of Sustainable Development Indicators*; in: Sustainable Development, Vol. 4, Number 1, March 1996, pp. 1-11 (1996)
[8] *The National Centre for Sustainable Development (NCSD): National Sustainable Development Strategy 2013-2020-2030 (NSDS)* (2008)
[9] *Our Common Future, The Brundtland Report to the World Commission on Environment and Development*; Oxford Univ. Press, Oxford (1987).
[10] *TERRA2000: Information Society and Sustainable Development.* http://www.terra-2000.org
[11] I. Tulbure: *Zustandsbeschreibung und Dynamik umweltrelevanter Systeme (State and Dynamic Analysis of Environmental Systems)*; Doctorate thesis, TU Clausthal, Germany, CUTEC-Schriftenreihe Nr. 25 (1997)
[12] I. Tulbure: *Technikbewertung. Vorlesungsskript.* TU Clausthal. Clausthal-Zellefeld, Germany (2013)
[13] I. Tulbure: *Integrative Modellierung zur Beschreibung von Transformationsprozessen (Integrative Modelling for Describing Transformation Processes).* Habilitation Thesis, TU Clausthal, VDI-Fortschrittsberichte,Reihe 16, Nr. 154, VDI-Verlag, Dsseldorf (2003)
[14] Umweltbundesamt (Federal Environmental Agency): *Daten zur Umwelt 2011*, Umweltbundesamt, Berlin (2011)
[15] H.-J. Zimmermann: *Neuro + Fuzzy: Technologien - Anwendungen*; VDI-Verlag, Dsseldorf (2013).

Ildiko Tulbure
University “1 Decembrie 1918”
N. Iorga- Str. Nr. 11 - 13, RO-510009 Alba Iulia, Romania
AND
Clausthal University of Technology,

Adolph-Roemer-Str. 2A, D-38678 Clausthal-Zellerfeld, Germany
email: *ildiko.tulbure@tu-clausthal.de*

Michael F. Jischa
Clausthal University of Technology,
Adolph-Roemer-Str. 2A, D-38678 Clausthal-Zellerfeld, Germany
email: *michael.jischa@tu-clausthal.de*