Using soft-computing methods for environmental quality assessment

Ildiko Tulbure

University „1 December 1918" Alba Iulia, Romania;Clausthal University of Technology, Clausthal-Zellerfeld, Germany. Corresponding author: I. Tulbure, ildiko.tulbure@tu-clausthal.de

Abstract. In order to quantify environmental impacts of economic activities environmental indicators are relevant to be used. Discussions on a global level regarding the environmental quality are nowadays connected to the concept of sustainable development. For the operationalisation of sustainable development indicators for economic, environmental and social aspects have to be developed and used. Worldwide several environmental indicators are used, especially for air and water pollution. In the present paper a possibility to define in a modular way an environmental indicator will be presented by taking into consideration the impact on health, impact on ecosphere as well as the emitted quantity of different air pollutants. An aggregation method based on fuzzy logic will be presented. The obtained results will be discussed and conclusions concerning the usage potential of the presented methodology will be drawn.

Key Words: environmental assessment, environmental indicators, fuzzy logic, air pollution index.

Introduction. Starting with the '70 years the world began to realize also the dangers and undesired effects of human activities, especially industrial ones. After the Conference for Environment in Stockholm, 1972 and the first report to the Club of Rome „The Limits to Growth" (Meadows et al 1972) 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. At that time it became very clear that the occurred regional and global environmental problems are very serious and urgently need to be solved. Nowadays we confront us with several global problems, which can be mostly grouped in three categories: world population growth, growth of energy and natural resources consumption and environmental pollution (Jischa 2005) (Figure 1).

Worldwide began discussions on scientific, political and social levels in order to find solutions for the problems shown above, which could be applicable with respect to regional differences to the developed as well as to the developing countries. 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 defined in the Brundtland Report 1987 (Hauff 1987) and accepted as a possible solution for the global complex ecological, economical and social problems. The concept of sustainable development was very much discussed during the Conference for Environment and Development in Rio de Janeiro 1992, the most important result of the debates in 1992 being represented by the conference closing act, the „Agenda 21" (Agenda 21 1992).

Many actions after this time have emphasized that the evolution of technical, social and ecological systems has to be analysed in synergetic relation. At this point several events can be mentioned like, for instance, the Western Cape Sustainable Development Conference 2005 in Cape Town, South Africa (SD Conference) as well as the World Summit on the Information Society (WSIS), held in two phases, 2003 in Geneva, Switzerland, and 2005 in Tunis, Tunisia (WSIS 2005).

Sustainable development has become a widely used term today. However, looking at texts dealing with the topic, the impression arises that there are as many definitions of sustainable development as there are users of the term. In order to make this concept more understandable rules, strategies and principles of sustainable development have been defined (NRC 2000). The general Brundtland definition was worldwide accepted, but together with the definitions, rules, strategies and principles, it does not give a concrete methodology, how to apply it to the real concrete situations on the regional level (Jischa 2005).

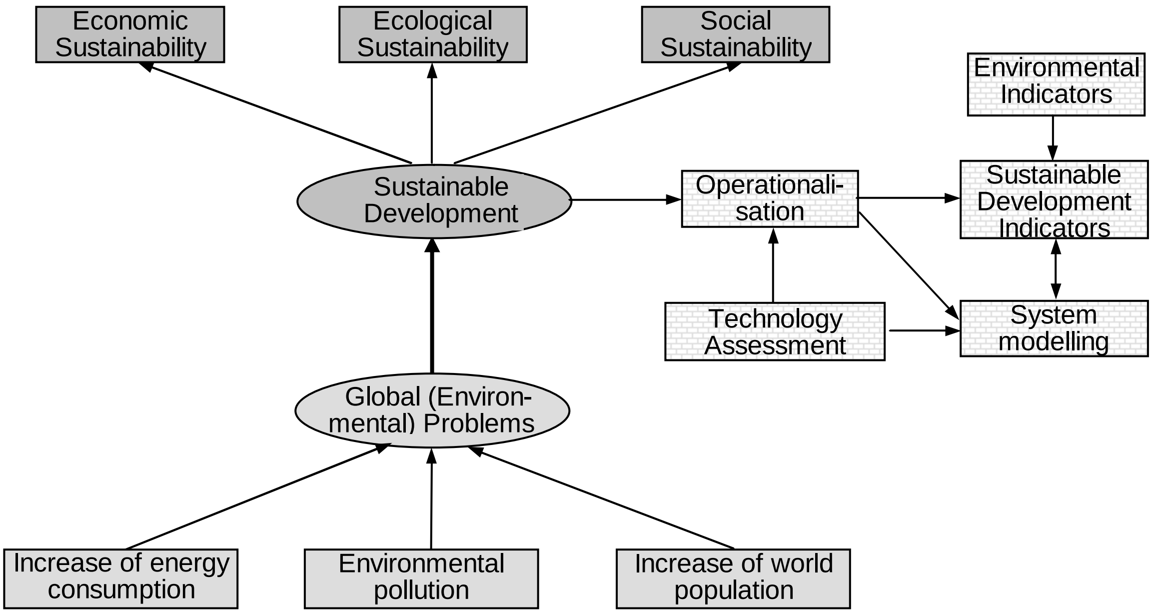

Figure 1. Global (environmental) problems and the concept of sustainable development.

Operationalisation of sustainable development. The operationalisation of the concept of sustainable development means the transformation or translation of its goals into political measures and controlling instruments. When studying all the literature, worldwide published, about how to apply sustainable development on different levels, one can distinguish two strategic possibilities (Tulbure 2003):

- establishing goals on global or national level, the measures to achieve these goals being prepared on global and national level and applied on national or regional level;
- establishing goals on regional level, the measures being prepared on regional or local level; the effects of these measures are 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 to find future sustainable energy supply systems with minimal effects on the environment. Such a project has been realized at IIASA (International Institute for Applied Systems Analysis) in Laxenburg/Vienna having the title "Global Energy Perspectives" (Nakicenovic et al 1998). Another study was carried out in Germany, IKARUS, with the goal to deliver a concrete instrument to reduce the pollutants emissions in the air (VDI 1993). At this point international and national scenario studies could be mentioned, which try to find sustainable ways for the future national development in a global context, for instance the actionplan „Sustainable Netherlands" by Friends of Earth Netherlands in 1992, 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 (BUND/MISEREOR 1996) or the study „Towards a Sustainable Europe" carried out in Germany 1995 by the Wuppertal Institute. The mentioned studies are basing on mathematical models, in order to describe industrial and economic processes and their impacts. With the help of databases, which describe economic, social and political frames, simulations have been carried out and different development scenarios have been 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.

The second strategy is illustrated by many actions in form of Local Agendas 21 led especially in Western European countries after the Rio-Conference in 1992. Also studies concerning regional future energy supply systems in the context of economic, environmental and social impacts can be mentioned here (Jischa 2005).

When discussing about the operationalisation of sustainable development on a regional level, very important is to take into consideration also technical and technological aspects, which can be very relevant in this context (Tulbure 2012). This is possible to be made by using technology assessment (Figure 1), that actually means to analyse the stability of complex dynamic environmental, economic and social systems in order to try to discover possible developments which lead to instabilities (Tulbure 2003). In this context there are many fields where research is needed; after Jischa (1999) these fields are:

- state description using sustainable development indicators;
- dealing with uncertain, unclear knowledge or non-existent knowledge;
- improvement of methods and instruments;
- orientation with values and dealing with value conflicts;
- developing criteria for evaluation and making judgement;
- modelling and simulation of dynamic systems.

By taking into account all these considerations, it is possible to develop a general methodology for operationalising sustainable development, which can be materialized in the following steps (Tulbure 2003):

- defining the sustainability problem;
- establishing the space and time scales;
- 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, indicators;
- verifying the possible results, which could be obtained after introducing the proposed measures, comparing different scenarios;
- applying into the practice the developed concept.

The operationalisation 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 newly defined for each different case. The space and time scales are to be established for each case (Jischa 2005).

Evaluation and control instruments are sustainable development indicators. These indicators permit to formulate quantitatively the proposed objectives and goals of sustainable development. After applying the proposed measures, the realization degree can be controlled and verified by calculating these indicators and by comparing to the reference values. The possibility to make corrections is assured in this way. On the other hand indicators serve as an instrument which helps to better understand the possible effects of measures and to inform the general public.

In the last time there is consent among political economists and engineers that the gross national product (GNP) alone does not represent a measure for the quality of life of the population in a country. It gives information about national economies, but it does not consider many aspects which influence the quality of life, as for instance: environmental pollution, irreversible use of fossil fuels, social aspects etc.

By defining new indicators some requirements have to be met:

- 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 be applicable;
- to offer the possibility to compare different alternatives.

A lot of attempts to define indicators for sustainable development are known in the whole world. In the development of sustainable development indicators three directions are to be observed (Jischa 2005):

- defining one single aggregated indicator;
- defining a set of indicators for measuring sustainable development;
- defining partial aggregated indicators for each component of sustainable development, for the ecological, economical and social one.

To illustrate the first direction I want to name as aggregated indicators the Human Development Index HDI (HDR 2003), the Index of Sustainable Economic Welfare (ISEW) (FOE 2005), and the Ecological National Product (ENP) (Dieren 1995).

The second direction is represented by a system of indicators to measure sustainable development. In order to exemplify studies in this direction I want to mention the indicators system used in the German region Baden-Württemberg and developed by the Academy for Technology Assessment in Stuttgart (Renn et al 2000) or the indicators system for the town Jacksonville (Dieren 1995).

The third possibility is given by the modular design of sustainable development indicators. Each of the three significant components of the concept of sustainable development is described by an indicator (Figure 2). When we want to get one single indicator, then we have to solve the aggregation problem of the three components.

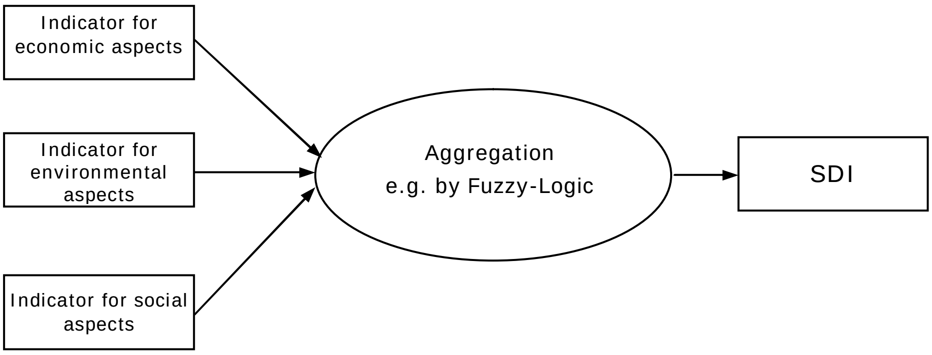

Figure 2. Aggregation levels for a possible sustainable development indicator.

There are many aggregation methods, for instance by calculating mean values. As simple as the method is, it bases on the restriction, that all components have the same weight by the aggregation. Other method is basing on weighting coefficients, whereat the establishing way of such coefficients has to be clarified. In our department in Germany at the Clausthal University of Technology we developed an aggregation method based on fuzzy logic, which assures a transparent aggregation and eliminates the negative aspects of other methods (Ludwig 1995; Tulbure 1997). This method will be shortly described in this paper and exemplarily used for developing an environmental indicator.

Environmental indicators. Worldwide there are many preoccupations to define environmental indicators. Well known is the mentioned *pressure-state-response model* (BUND/MISEREOR 1996). Eurostat published in (Eurostat 1999) a list with 60 indicators for the pressure, state and response part. On the other side there is 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 (Tulbure 1997). For instance in Germany the "Umweltindex" as an index for air quality is used and published every week by the VDI-Journal (Journal of the German Engineers Association).

When studying especially indicators which describe the quality of air or water, 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 can 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 (Ludwig 1995; Tulbure 1997). We have to go into details and first of all to look at the working way of Fuzzy Logic, then how to apply it for developing environmental indicators (Tulbure 2003).

Short presentation of fuzzy logic. Regarding this subject a great diversity of materials and books are available at present, which treat fuzzy logic more or less detailed (Zimmermann 1993; Ludwig 1995). In the following I will make after (Tulbure & Ludwig 2000) 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. 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, μ. This real function can take on any values, but usually it is normalized into the interval [0, 1] (Zimmermann 1993).

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.

The concept of linguistic variables connects the description of verbal and therefore fuzzy information with mathematical precision (Zimmermann 1993). The values of a linguistic variable are verbal expressions, called linguistic terms, for instance small, medium or high. 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. Thus, the fuzzy sets are building 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).

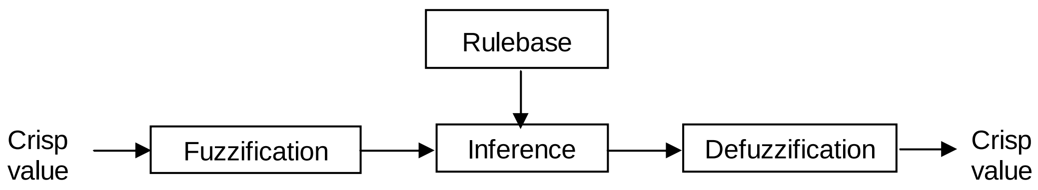

Figure 3. General operational diagram by fuzzy logic applications (after (Ludwig 1995).

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 (Zimmermann 1993).

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. This could be obtained by appropriate intersection operators (t-norms). The result of the implication itself is the assignment of a proposition of a rule to a linguistic term of the output variable (Zimmermann 1993). 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 (t-conorm) 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 (Zimmermann 1993). Therefore, the possibility to consider uncertain information in systems modelling is given which encourages applications in the field of environmental systems (Ludwig 1995; Tulbure 1997).

Air pollution index. From the given considerations it is more than clear that Fuzzy Logic has a great potential in order to be used when assessing the environmental quality, especially by its possibility to integrate verbal descriptions with exact mathematical data.

An application example on how highly aggregated entities can be integrated into mathematical models by using fuzzy logic is represented by the Air Pollution Index (API), which can be calculated with the following relation (Tulbure & Ludwig 2000):

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

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];

w_i - weighting coefficients.

Thus, API = 1 means that all pollutants concentrations in the approached system 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 relevance of the different pollutants emissions is not equal. A fuzzy logic based application for determing weighting coefficients has been developed for this goal and will be presented shortly in the following (for more details see (Tulbure 1997).

The weighting coefficients are determined by three basic criteria, presented in figure 4. These are: impact on health, impact on ecosphere and emitted quantity. The way, in which these basic criteria are determining the weighting coefficient of a pollutant, will be described with the help of a fuzzy logic based system.

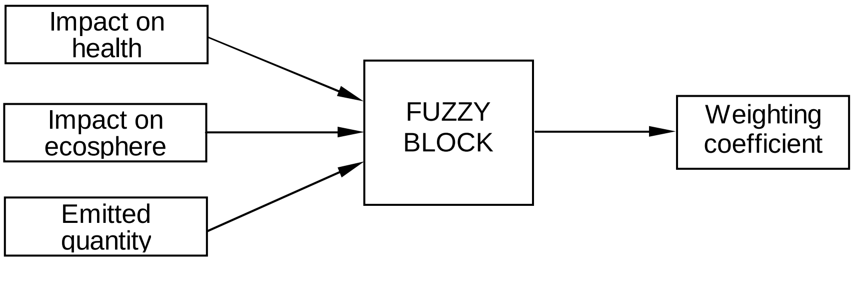

Figure 4. Aggregation level for the weighting coefficient.

Linguistic variables. The chosen input criteria are defined on the interval [0, 1] and are formulated as linguistic variables, each with the three linguistic terms small, medium and high. 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 a rulebase, which has 27 rules in this case (Zimmermann 1993).

The weighting coefficients 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 and the impact on ecosphere of the considered pollutants was taken into account (Bank 1994). The input values corresponding to the basic criterion quantity are related to the reference values and given as relative values on the interval [0, 1]. The reference values are represented by emissions of CO_2 for each country. The approached pollutants emissions correspond to the year 2009 (Umweltbundesamt 2011).

Table 1

Inputs of the basic criteria for the weighting coefficients for API

	Impact on health	*Impact on ecosphere*	*Emitted quantity*				*Weighting coefficients*
			B	*D*	*H*	*PL*	
CO_2	0.1	0.95	1.0	1.0	1.0	1.0	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

In order to emphasize the working way of fuzzy logic the proposed method has been applied to some European regions. Table 2 shows the annual average pollutants concentrations in the approached regions for 2009 (http://www.eea.eu.int) as well as the admissible values of these pollutants after German standards (TA Luft) and the resulting API for n=4.

Table 2

Pollutants concentrations as annual average values [mg/m^3] for some European regions in 2009 and resulting API

European regions	*CO_2 [ppm]*	*NO_X*	*SO_2*	*CO*	*API*
Berlin	350	0.033	0.019	1.08	0.507
Brussels (1998)	350	0.039	0.012	5,68	0.589
Budapest (1995)	350	0.026	0.026	8.48	0.638
Budapest	350	0.035	0.027	2.82	0.562
Frankfurt	350	0.044	0.011	2.27	0.554
Hamburg	350	0.035	0.012	1.38	0.515
Katowice (1995)	350	0.082	0.088	7.36	0.872
Katowice	350	0.029	0.056	1.18	0.551
Krakow	350	0.028	0.027	3.57	0.562
Warsaw	350	0.033	0.017	0.95	0.487
Admissible (after TA Luft)	350*	0.08	0.140	10.00	1.00

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

As we can remark from Table 2 the values of API in the analysed regions are below the limit, which is API = 1, as it was explained before. The made progress concerning air quality in some towns as for instance Budapest or Katowice from 1995 to 2009 is emphasized by API. It would be interesting to apply in the future API to other regions too, in order to estimate the air quality.

Conclusions. In the process of operationalisation of sustainable development an important step is represented by evaluating environmental impacts, in order to carry out the environmental impact assessment. For assessing the environmental impacts often environmental indicators have to be used. When looking at the detailed components of these indicators, it is to be remarked that sometimes there is a need to work with a great number of variables. This is in the most of the cases a difficult and untransparent process, that is why aggregation methods have to be used.

A fuzzy logic based method has been discussed by defining new indicators. It offers new possibilities by its potential to integrate complexity in the systematic and exact mathematical approach and assures a transparent assessment. An application example regarding characterization of air quality has been presented. The air pollution index API was defined as the sum of the weightened, relative pollutants concentrations, where the weighting coefficients were established by using fuzzy logic.

Following the same algorithm other environmental as well as social indicators can be defined and aggregated to a sustainable development indicator. Fuzzy logic can be used especially for transparent assessment, when the available knowledge is diffuse, unstructured and disorderly. Fuzzy logic offers the possibility to integrate complexe qualitative entities in mathematical models and represents a transparent methodology.

Aggregated environmental indicators can characterize not only air, water or soil pollution, but can combine different media. Such aggregated environmental indicators are needed in order to establish objectives, to quantify them, to verify the possible effects of environmental measures before applying them, and to support the decision making process. The problem of aggregation or disaggregation of different relevant system parameters has to be carefully discussed for each concrete situation.

References

Bank M., 1994 Basiswissen Umwelttechnik (Basics of environmental engineering). Second Edition, Vogel Buchverlag, Würzburg.

BUND/MISEREOR (ed), 1996 Zukunftsfähiges Deutschland (Sustainable Germany), Birkhäuser, Basel.

Eurostat, 1999 Towards environmental pressure indicators for the EU; European Commission.

Hauff V. (ed), 1987 Our common future. The Brundtland Report of the World Commission on Environment and Development. Oxford Univ. Press, Oxford.

Jischa M. F., 1999 Technikfolgenabschätzung in Lehre und Forschung (Technology Assessment in Teaching and Research). In: T. Petermann und R. Coenen (eds.): Technikfolgen-Abschätzung in Deutschland (Technology Assessment in Germany); Campus, Frankfurt, pp. 165-195.

Jischa M. F., 2005 Herausforderung Zukunft (Challenging the Future). Second edition, Elsevier, Spektrum Akademischer Verlag, Heidelberg.

Ludwig B., 1995 Methoden zur Modellbildung in der Technikbewertung (Modelling Methods in Technology Assessment) , doctorate thesis, TU Clausthal, see also CUTEC-Schriftenreihe Nr. 18, Papierflieger, Clausthal-Zellerfeld, Germany.

Meadows D., Meadows D., Randers J., Behrens III W. W., 1972 The limits to growth. A report for the Club of Rome's Project on the Predicament of Mankind, 208 pp.

Nakicenovic N., Grübler A., Mc Donald A. (eds), 1998 Global energy perspectives. Cambridge Univ. Press.

National Research Council, NRC, 2000 Our common journey – a transition toward sustainability. National Academy Press, Washington, D.C.

Renn O., Leon Ch., Clar G., 2000 Nachhaltige Entwicklung in Baden-Württemberg (Sustainable Development in Baden-Württemberg); Status Report; Academy for Technology Assessment in Baden-Württemberg, Stuttgart.

Tulbure I., 1997 Zustandsbeschreibung und Dynamik umweltrelevanter Systeme (State and Dynamic Analysis of Environmental Systems). Doctorate thesis, Clausthal University of Technology, Germany, 1997, see also CUTEC-Schriftenreihe Nr. 25, Papierflieger, Clausthal-Zellerfeld, Germany.

Tulbure I., 2003 Integrative Modellierung zur Beschreibung von Transformationsprozessen (Integrative Modelling to Describe Transformation Processes). Habilitationsschrift, TU Clausthal. VDI-Fortschrittsberichte, Reihe 16, Nr. 154, VDI Publishing House, Düsseldorf.

Tulbure I., 2012 Technikbewertung – Vorlesungsskript (Technology Assessment - Lecture Notes). Institute for Applied Mechanics, Clausthal University of Technology, Germany.

Tulbure I., Ludwig B., 2000 Umweltindikatoren – Schlüssel zu Sustainable Development (Environmental Indicators - A Key for Sustainable Development). Umwelt, Springer VDI Publishing House, Nr. 4-5/2000, pp. 45-49.
Umweltbundesamt (Federal Environmental Agency in Germany), 2011 Daten zur Umwelt 2011 (Environmental Data 2011), Umweltbundesamt, Dessau-Roßlau.
van Dieren W. (ed), 1995 Taking Nature into Account; Springer, New York.
VDI, 1993 Instrumente zur Minderung energiebedingter Klimagasemissionen (Instruments for Decreasing the Climate-Damaging Pollutants Emissions because of the Energy Production) IKARUS; VDI-Report 1043, VDI Publishing House, Düsseldorf.
Zimmermann H. J., 1993 Fuzzy Technologien; VDI-Verlag, Düsseldorf.
*** Agenda 21, 1992 http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21toc.htm
*** SD Conference, 2005, http://www.capegateway.gov.za/eng/your_gov/406/events/101218
*** WSIS, 2005, http://www.itu.int/wsis
*** http://www.ta-akademie.de.
*** HDR, 2003, http://hdr.undp.org/statistics/indices/about_hdi.cfm.
*** FOE, 2005, http://www.foe.co.uk/campaigns/climate_change.
*** http://www.eea.eu.int.

Received: 11 July 2014. Accepted: 02 September 2014. Published online: 30 September 2014.
Author:
Ildiko Tulbure, University „1 December 1918“, N. Iorga Str. 11-13, RO-510009 Alba Iulia, Romania; Clausthal University of Technology, Graupenstr. 3A, D-38678 Clausthal-Zellerfeld, Germany, e-mail: ildiko.tulbure@tu-clausthal.de

How to cite this article:
Tulbure I., 2014 Using soft-computing methods for environmental quality assessment. Ecoterra 11(3):58-66.