

Fuzzy Logic based method for air pollution assessment

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Abstract. In order to quantify environmental impacts of economic activities, environmental indicators are necessary to be used. Debates on a global level regarding environmental pollution are nowadays connected to the concept of sustainable development. For its operationalization indicators for economic, environmental and social aspects have to be developed and used. In the present paper a possibility to define in a modular way an air pollution indicator is presented by considering 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: air pollution assessment, environmental indicators, soft-computing methods, 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, especially related to air pollution are very serious and urgently need to be solved. Nowadays humanity is confronting itself 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).

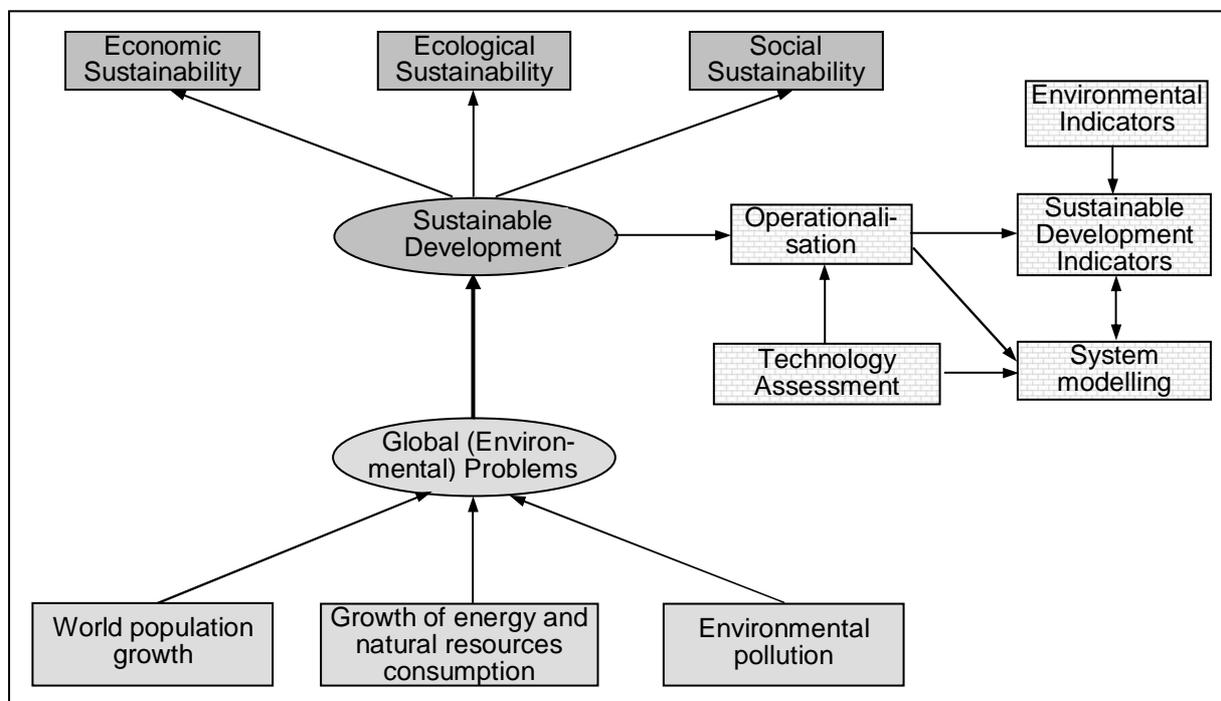


Figure 1. Global (environmental) problems and the concept of sustainable development.

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, economic 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“ (Agenda21 1992).

Many actions after this time emphasized that the evolution of technical, social and ecological systems has to be analyzed 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 2005) 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 currently become a widely used term. 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 deliver a concrete methodology on how to apply it to the real concrete situations on the regional level (Jischa 2005).

Connected to the operationalization of the concept of sustainable development assessing the regional environmental pollution is very relevant. In this context an aggregated air pollution indicator will be presented by considering the impact on health, impact on ecosphere as well as the emitted quantity of different air pollutants, where a fuzzy logic based aggregation method will be applied for different European regions.

Material and Method. Air pollution assessment is representing a much relevant part in the context of the operationalization of the concept of sustainable development on regional level. This actually means the transformation or translation of its goals first of all into political measures and controlling instruments, thereafter concrete technical actions have to be carried out. When studying the worldwide published literature about how to apply sustainable development on different levels, one can distinguish two strategic possibilities (Tulbure 2013):

- 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. Global Energy Perspectives have been debated at different levels and in different countries, such projects being carried out for instance at IIASA (International Institute for Applied Systems Analysis) in Laxenburg near Vienna Vienna or in Germany, the project IKARUS, having the goal to deliver concrete instruments to reduce the pollutants emissions in the air (Goldthau 2013). 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 carried out by the Wuppertal Institute for Climate, Environment and Energy 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 (Goldthau 2013).

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 2015). 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 (2005) 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 operationalizing 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 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 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 as aggregated indicators can be mentioned the Human Development Index HDI (HDR 2003), the Index of Sustainable Economic Welfare (ISEW) (FOE 2005), and the Ecological National Product (ENP) (Jischa 2005). The second direction is represented by a system of indicators to measure sustainable development. In order to exemplify studies in this direction can be mentioned the indicators system used in the German region Baden-Württemberg and developed by the Academy for Technology Assessment in Stuttgart or the indicators system for the town Jacksonville (Bank 2006).

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 one single indicator has to be obtained, then the aggregation problem of the three components has to be solved.

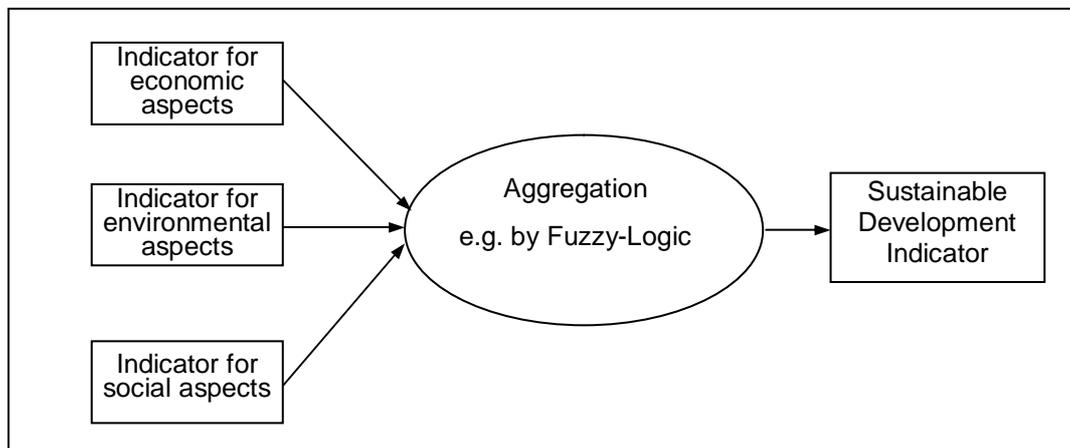


Figure 2. Aggregation levels for a possible sustainable development indicator.

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 (Jischa 2005; Tulbure 2016). This method will be shortly described in this paper and exemplarily used for developing and applying an environmental indicator in the form of an air pollution indicator, API.

Worldwide there are many preoccupations to define environmental indicators. Well known is the mentioned *pressure-state-response model*. Eurostat published first of all 1999 a list with 60 indicators for the pressure, state and response part, that has been updated since then several times (Bank 2006). On the other side environmental indicators can be classified after a structural approach 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 2016). For instance in Germany an environmental indicator is frequently used, called as "Umweltindex", which is an indicator for air quality and is published every week by the VDI-Journal (Journal of the German Engineers Association) (Bank 2006; Tulbure 2013).

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 which assume that potential 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 is offering possibilities to use new methods for defining indicators by its potential to integrate complexity in the systematic and exact mathematical approach (Jischa 2005; Zimmermann 2013; Tulbure 2015). In order to go into details regarding using possibilities of Fuzzy Logic for defining environmental indicators, first of all the working way of Fuzzy Logic has to be presented, then its applying ways for developing environmental indicators (Jischa 2005, Bank 2006).

About 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 2013). In the following only a succinct presentation of the most important notions related to fuzzy logic will be made (Tulbure 2003; Zimmermann 2013).

Fuzzy logic is based on the knowledge that reality is rather unexact than precise, because all affirmations 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 members of the set, the value of one meaning the total membership to the respective set. 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, 2013).

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 behavior contain fuzzy formulated knowledge, which is generally more intelligible. Beyond that, linguistically formulated variables have more aggregated information content, and therefore it is more difficult to quantify them. So, a mathematical description of such variables in the classic manner usually leads to an information loss (Jischa 2005).

The concept of linguistic variables connects the description of verbal and therefore fuzzy information with mathematical precision (Zimmermann 2013). 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, fuzzy sets are building the connection between linguistic expressions and numerical information.

To process fuzzy formulated knowledge several linguistic variables must be linked by linguistic operators. The connecting rules represent the knowledge, which is stored in a rule-base or knowledge base, similar to expert systems. The procedure consists of the following steps: fuzzification, inference and defuzzification (Figure 3) (Zimmermann 2013).

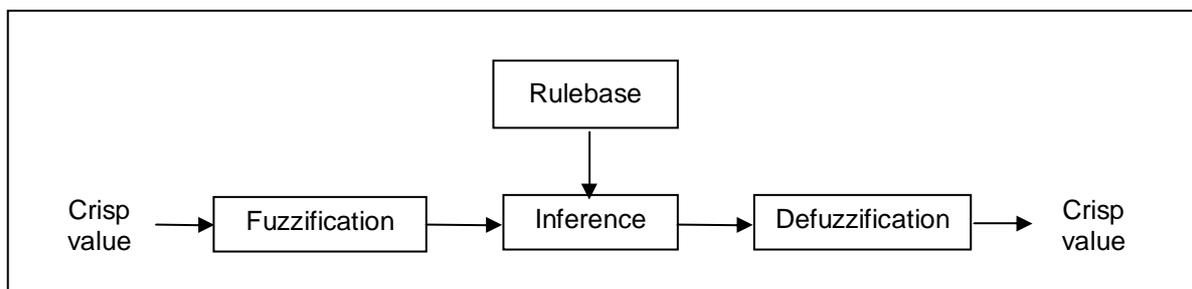


Figure 3. General operational diagram by fuzzy logic applications.

The fuzzification step means 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 trapezoid 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 the observed process (Zimmermann 2013).

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 2013). Running all the 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 in the step of defuzzification. 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 different applications in the field of environmental engineering and operationalization of sustainable development (Jischa 2005; Zimmermann 2013; Tulbure 2015).

Results and Discussion. 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 2013):

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

where:

$C_{real,i}$ - values of pollutants concentrations at a certain place and time [ppm or mg/m³];
 $C_{ref,i}$ - reference values: admissible values of pollutants concentrations [ppm or mg/m³];
 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 fields and of different features has to be integrated in this process. Anyway, the usage of weighting coefficients in the Air Pollution Index, API, is the expression of the conviction that the relevance of different pollutants emissions is not equal. A fuzzy logic based application for establishing weighting coefficients has been developed for this goal and is shortly presented in the following (for more details see (Jischa 2005; Tulbure, 2015)).

The weighting coefficients are determined by using 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.

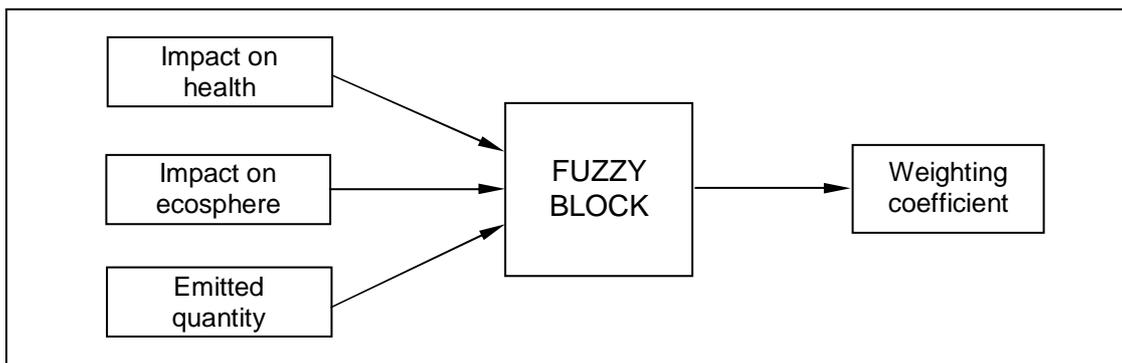


Figure 4. Relevant basic criteria aggregated by using Fuzzy Logic for establishing weighting coefficients.

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 2013).

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 2006). 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 CO₂ for several countries, as presented in Table 1, Belgium, B, Germany, D, Hungary, H as well as Poland, PL. The approached pollutants emissions correspond to the year 2013 (Goldthau 2013).

Table 1
Inputs of the basic criteria for the weighting coefficients for API

	<i>Impact on health</i>	<i>Impact on ecosphere</i>	<i>Emitted quantity</i>				<i>Weighting coefficients</i>
			<i>B</i>	<i>D</i>	<i>H</i>	<i>PL</i>	
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

Note: Emitted quantities expressed as relative quantities divided tot he emitted quantity of CO₂ for the four considered countries, Belgium, B, Germany, D, Hungary, H as well as Poland, PL

In order to emphasize the working way of fuzzy logic the proposed method has been applied to some European regions. Table 2 exemplarily shows the annual average pollutants concentrations in the approached regions for 2013 (<http://www.eea.eu.int>) as

well as the admissible values of these pollutants after German standards (TA Luft) as well as the resulting API calculated for $n=4$ and for the mentioned regions.

From Table 2 can be remarked that the values of API in the analyzed 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 2013 is emphasized by API. It would be interesting to apply in the future API to other regions too in the world, not only in Europe, in order to estimate the existing air quality in different world regions.

Table 2
Pollutants concentrations as annual average values [mg/m^3] for some European regions in 2013 and resulting API

	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.

Conclusions. In the process of operationalisation of sustainable development an important step is represented by evaluating environmental impacts on regional level, in order to carry out a regional 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 nontransparent process, following that aggregation methods have to be used. A fuzzy logic based method has been presented by defining new indicators. An application example regarding assessing air quality on regional level has been presented. The air pollution index API was defined as the sum of the weighted, 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 assessments, when the available knowledge is diffuse, unstructured and disorderly. Fuzzy logic offers the possibility to integrate complex qualitative entities in mathematical models and represents a transparent methodology. 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.

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