University Press. 1994

A FUZZY LOGIC BASED APPROACH TO ASSES SUSTAINABLE DEVELOPMENT

Livia CHISAGIU,
Drd., Institutul de Economie Naționala

Abstract. It is presented a methodology for the quantitative assessment of socio-economical development by using the Fuzzy Logic. For the aggregation of employed indicators there is described a method based on two models, which are PSR and SAFE. For the aggregation of the sustainable development indicators there are needed the Normalization for the basic indicators (a statistical method) and the Fuzzy Inference for the other indicators classes. It is illustrated the normalization method of an indicator by using the Mathcad programming environment for mathematical computation.
Keywords: sustainable development, fuzzy logic, Mathcad
JEL Classification: Q01, C00

1. Introduction

The Sustainable Development is the subject of sustained ongoing research, carried on in many dedicated organizations, and there are already many remarkable references on this subject. There are not so many research activities and references dedicated to the sustainble development assessment. However, such an assessment is very useful, because it allows the decision makers to take scientifically grounded

[1] See also White (1999).

measures. Such a methodology allows, even if it is not perfect, to evaluate the evolution in time of the Sustainable Development and various comparisons.

This work has as purpose the presentation of a methodology for the Sustainable Development assessment.

The Sustainable Development may refer to the whole socio-economic activity, or just to some components of it. There are available works dedicated to the Sustained Development of a whole economy, or to various branches (such as the agriculture) or some enterprises.

The methodology presented in this work is dedicated to the entire socio-economical activity, but it can be adjusted to various components of it. This method relies on the possibilities offered by the aquisitions of the science and technology from the last decades, and these possibilities are well beyond the expectations from the past. Among these acquisitions the IT is particularly important, and especially the software dedicated to mathematical computation. Among such software applications there is Mathcad, which has particularly useful features, but still is rather seldom used. Another remarkable acquisition of the last decades is the Fuzzy Logic, which allows computers an improved use of the concepts involved in reasoning.

The basic unit for the currently presented Sustainable Development assessment methodology is the indicator. The most important problem is the establishing the contribution of each indicator to the final value which characterizes the Sustainable Development process as a whole. For establishing this contribution it is necessary especially to find an appropriate aggregation modality for these indicators. This operation is obviously difficult, due to the large number and variety of the Sustainable Development indicators. One should notice that such an aggregation involves numeric indicators such as the ones for characterizing the atmospheric pollution and the ones referring to health or education.

This aggregation requires two dedicated operations, which are to be presented below in this work. The first is the Indicators Normalization and the second is their Fuzzification, which is a major component of the Fuzzy Logic.

2. Indicators

Indicators are simple figures or other signs which help to simplify the information on a complex phenomenon like environmental pressure, rendering it into a most easily understandable format. This way information is more easier to explain also for those who are not experts or who need the information quickly.

Adriaanse 1 defines an indicator as a quantitative model and a form of information that makes perceptible a certain phenomenon that is not immediately detectable. Therefore, the indicators provide a simpler and more readily understand form of information than complex statistics or complex phenomena. The three main functions of the indicators are:

1) Quantification
2) Simplification
3) Communication.

Indicators also help to follow the change of phenomena in time scale and the development of phenomena in relation to the stated objectives. One of the important functions of an indicator used for decision making is its potential to show the trend, i.e. the course of development, in an early stage. In order to work with indicators one needs data, which comes from a monitoring process. Indicators should be objective and the results should be repeatable. In many cases indicators should also be internationally comparable, although those were mainly used nationally. The main risk for indicators use is the excessive simplifying and loosing of important information.

3. The Need of the sustainability indicators

A document of the Burtland Commission, called Agenda 21, states in the chapter 40 that "Indicators of sustainable development need to be developed to provide solid bases for decision making at all levels, and to contribute to a self-regulating sustainability of integrated environmental and development systems."

Sustainability indicators are primary needed, because complicated ecological, social, cultural and economical phenomena are wanted to be considered in decision making at all levels. Moreover, indicators are needed because there are no absolute measures, which could be applied. For example, there is lack of measures that could be used explicitly for socio-cultural causalities. There is also a lack of absolute measures for expressing the ecological and economical causalities. The ecological impact is typically indicated on the basis of induced harmful emissions, consumption of natural resources and loss of bio-diversity. However, the impact-effect-mechanisms are known and modelled somewhat better than is the case with regard to sociocultural causalities.

In relation to policy-making, environmental indicators are used for three major purposes:

1. to supply information on environmental problems, in order to enable policymakers to value their seriousness;
2. to support policy development and priority setting, by identifying key factors that cause pressure on the environment;
3. to monitor the effects of policy responses.

Indicators are not only needed in order to supply information about the state, condition and causalities, but also to assess the effectiveness of alternative responses.

4. The Employed Models

The main goal is the devising of a methodology for determining a quantitative value for the OSUS indicator, which is recommended for characterizing the whole Sustainable Development. Among the various models, there will be recommended and presented here two models, which are SAFE and PSR.

4.1. The SAFE Model

The SAFE model (Figure 1) is used to classify the parameters used to characterize the Sustainable Development in primary, secondary, tertiary and base indicators. Their name and notation is the following (Figure 1).

Primary indicators which contribute to the general indicator OSUS (ECOS, for Ecological Sustainability and HUMS, for Human Sustainability)

The ECOS primary indicator (for Ecological Sustainability) is formed with the contribution of four secondary parameters: AIR (Air quality), LAND (Land quality), WATER (Water quality) and BIOD (Biodiversity).

The HUMS primary indicator is formed with the contribution of four secondary parameters: POLIC: (Political system), BIOD (Biodiversity), WEALTH (Economic welfare) si KNOW (Educational system).

Each of the eight secondary indicators which are mention above are formed with the contribution of three tertiary parameters, which are: P (Pression), S (Status) si R (Response).

The tertiary indicators' forming requires the contribution of more based indicators, which have a notation indicated on the Figure 1. For example, I(Bip) specifies an indicator which contributes to the forming of the tertiary indicator P (Pression), and this last one contributes to the forming of the secondary BIOD (Biodiversity) indicator.

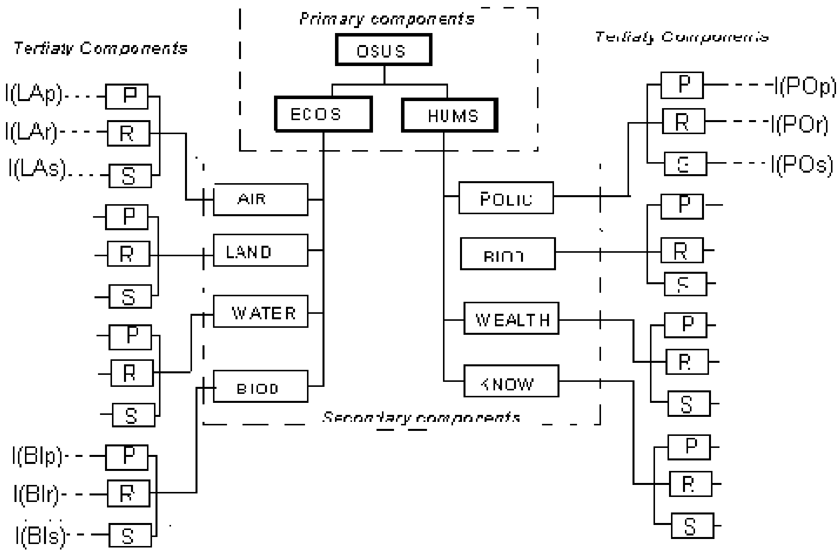

Figure 1. The SAFE Model

4.2. The Pressure - State – Response (PSR) Model

The PSR framework is based on the fact that human activities exert Pressures on the environment (such as pollution, land use change, or increased demand for livestock products). These result in changes in the State of the environment (e.g. changes in pollutant levels, habitat diversity, livestock production, etc.) which in turn result in Impacts. The Society's Response to changes in pressures or state is based then on environmental and economic policies or programs intended to prevent, reduce or mitigate the pressures and/or environmental and socio-economic damage that occurred as a result of the original pressures.

The structure of the PSR model is presented in the Figure 2.

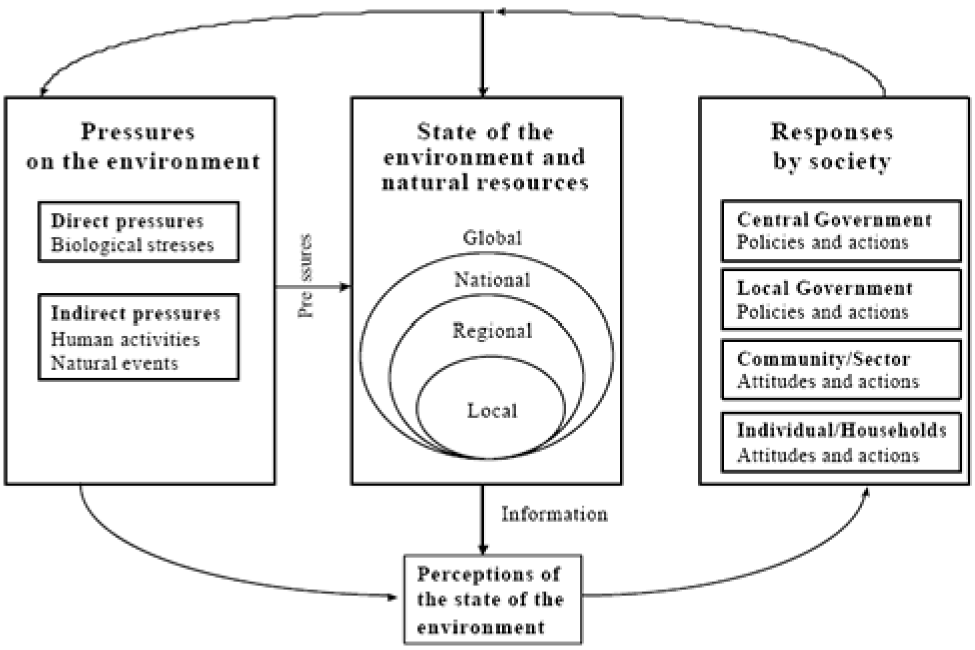

Figure 2 - The OECD Pressure-State-Response Framework

The PSR model considers that: human activities exert pressures on the environment and affect its quality and the quantity of natural resources ("state"). The society responds to these changes through environmental, general economic and sectoral policies and through changes in awareness and behaviour ("societal response"). The PSR model has the advantage of highlighting these links, and helping decision-makers and the public see environmental and other issues as interconnected (although this should not obscure the view of more complex relationships in ecosystems, and in environment-economy and environment-social interactions).

Depending on the purpose for which the PSR model is to be used, it can easily be adjusted to account for greater details or for specific features.

4.2.1 Pressures

Environmental pressures relate to pressures from human activities exerted on the environment, including natural resources. Indicators of environmental pressures are closely related to production and consumption patterns. They often reflect emissions or resource use intensities, along with related trends and changes over a given period. They can be used to show progress in decoupling economic activities from related environmental pressures. They can also be used to show progress in meeting national objectives and international commitments (e.g. emission reduction targets).

4.2.2 State

Environmental conditions relate to the quality of the environment and the related effects or impacts, and the quality and quantity of natural resources. They cover ecosystems and natural environment conditions as well as quality of life and human health aspects. As such they reflect the ultimate objective of environmental policies. Indicators of environmental conditions are designed to give an overview of the situation (the state) concerning the environment and its development over time.

Examples of indicators of environmental conditions are: concentration of pollutants in environmental media, exceedance of critical loads, population exposure to certain levels of pollution or degraded environmental quality, the status of wildlife and of natural resource stocks. In practice, measuring environmental conditions can be difficult or very costly.

4.2.3. Response

Societal responses show the extent to which society responds to environmental concerns through environmental, general economic and sectoral policies and through changes in awareness and behaviour. They refer to individual and collective actions and reactions that are intended to:

- mitigate, adapt to or prevent human-induced negative effects on the environment;
- halt or reverse environmental damage already inflicted;
- preserve and conserve nature and natural resources.

Examples of indicators of societal responses are environmental expenditure, environment-related taxes and subsidies, price structures, market shares of environmentally friendly goods and services, pollution abatement rates, waste recycling rates. In practice, indicators mostly relate to abatement and control measures. The indicators showing preventive and integrative measures and actions are more difficult to obtain.

5. Indicators aggregation

The indicators aggregation and the contribution of each one to the to the final value of the OSUS indicator is the most important and difficult problem. In this work there are used two aggregation methods recommended in the specialty references.

For the base indicators aggregation there will be used their Normalization, and for the others (primary, secondary and tertiary) there will be used the reasoning based on Fuzzy Logic.

The use of the reasoning based on Fuzzy Logic is justified by the following two basic features.

(a) Fuzzy logic has the ability to deal with complex and polymorphous concepts, which are not amenable to a straightforward quantification and contain ambiguities. In addition, reasoning with such ambiguous concepts may not be clear and obvious but rather fuzzy.

(b) Fuzzy logic provides the mathematical tools to handle ambiguous concepts and reasoning, and finally gives concrete answers (known as crisp ones) to problems wrought with subjectivity. Sustainability is, indeed, quite subjective. What appears unsustainable for an environmentalist may be sustainable for an economist.

Fuzzy logic is a scientific tool which allows to simulate the dynamics of a system without a detailed mathematical description. Knowledge is represented by "IF-THEN" linguistic rules, which describe the logical evolution of the system according to the linguistic values of its principal characters that we call linguistic variables. Real values are transformed into linguistic values by an operation called fuzzification, and then fuzzy reasoning is applied in the form of "IF-THEN" rules. A final crisp value is obtained by defuzzification, which is an operation opposite to fuzzification.

Accordingly, to assess sustainability, the following have to be defined:

- Linguistic variables which best represent the sustainability of the whole system,
- Linguistic rule bases and fuzzy logical operators which express qualitatively the knowledge and the key features of the overall system, and
- A defuzzification method to convert fuzzy statements into a single crisp value of overall sustainability.

6. Indicators normalization

The description of the base indicators normalization will be completed with a normalization example for an indicator referring to the life expectancy.

There will be considered a certain indicator I(x), where x is the variable it depends upon. Such an indicator could be the life expectancy, and the x notation would represent years in this case,

The general normalization relations of an I(x) indicator, whose value subject to normalization is x, are the following.

If the target T is a maximal value:

$I(x) = [x - xmin] / [T - xmin]$ if $x \leq T$

$I(x) = 1$ if $x = T$

If the target T is a minimal value

$I(x) = 1$ if $x < T$

$I(x) = [xmax - x] / [xmax - T]$ if $x \leq T$

c) If the target T is a range between Tmin si Tmax then

$I(x) = [x - xmin] / [Tmin - x min]$ if $x \leq Tmin$

$I(x\} = 1$ if $x \in [Tmin, Tmax]$

$I(x) = [xmax - x] / [xmax - Tmax]$ if $x \geq T max$

d) If the target T belongs to a YES/NO statement, then

$I(x) = 0.5$ if $x = T$ and

$I(x) = 0$ if $x \neq T$

The graphical representation of the normalization functions is shown below.

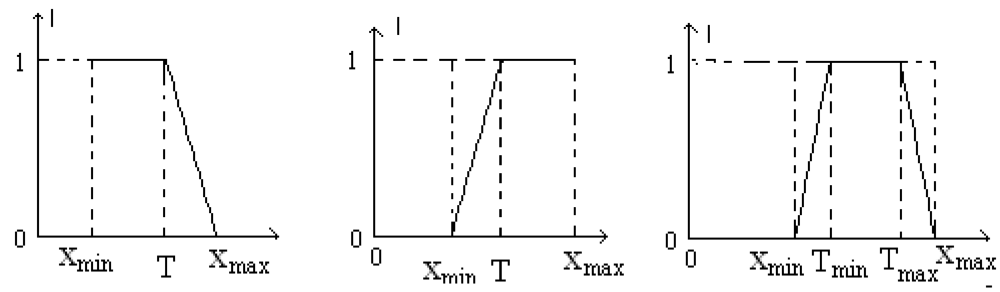

Figure 3- The Graphical Representation of the Normalization Function

An example of maximal target is the life expectancy, and one of minimal target is the atmospheric pollution with carbon dioxide CO2.

A proposed example is the normalization of the base indicator life expectancy. The target for this indicator is a maximal value which is desirable. The range selected for the analysis is between a minimum of 25 years and a maximum of 85 years.

The value given for life expectancy is of 65 years in this example.

There will be used the notation from the a) Figure and there will be (in Figure 4)

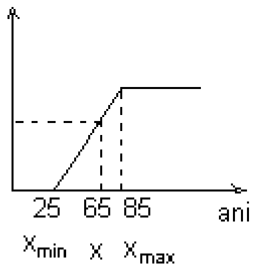

Figure 4 - The Normalization of the life expectancy indicator Framework

The normalization relation will be, in this case:

y = (x – xmin) / (xmax – xmin) (1)

for the values xmin = 25 years, x = 65 years, xmax = 85 years

By using the relation 1 there will be obtained the normalized value

y = (65 –25)/(85 – 25) = 40/60 = 0.66

In conclusion, in this case the normalized value of the life expectancy indicator is

y = 0.66

7. Statistical aggregation

The statistical aggregation of more inicators I m which refer to the same linguistic value will issue a resulting indicator I rez and it is based on the relation

$$I_{rez} = \frac{\sum_{i=1}^{m} w_i I_i}{\sum_{i=1}^{m} w_i}$$

where m is the number of aggregated indicators (Ii) and w i are the weights of these indicators, expressed as numbers within the range 0..1.

8 Aggregation based on the fuzzy logic

For the indicators aggregation based on Fuzzy Logic there will be needed a sequence of three operations (Fuzzification, Inference and Defuzzification) for each of the tertiary, secondary and primary components.

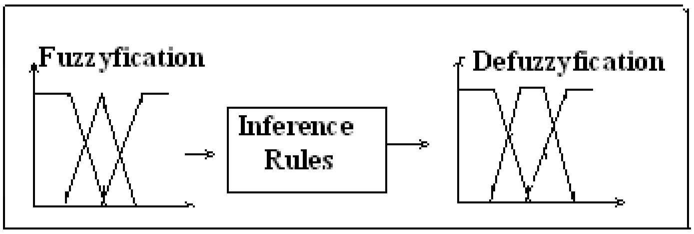

Figure 5 - The schematic diagram of an operations sequence for Fuzzy Logic-based aggregation

The functions and the numbers of linguistic values are decided for each case by the human expert and the knowledge engineer.

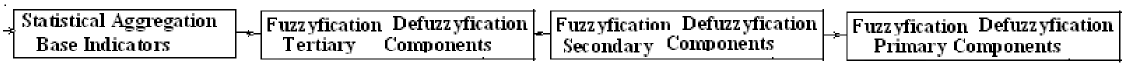

Figure 6 - Chaining of operation involved in Fuzzy inference

The fuzzy sets and the fuzzy logic are used for representing uncertainities which are very important in the Sustainable Development field.

9. Fuzzy Expert SysteM

The desired value of the OSUS indicators can be obtained with a Fuzzy Expert System.

The Fuzzy expert system is an Expert System which uses a set of membership functions and fuzzy rules for performing reasoning on the input data.

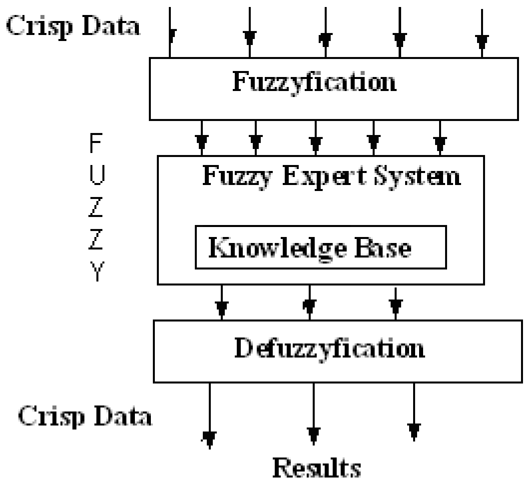

Figure 7 - Schematic diagram of a fuzzy expert system

10. Conclusions

It was described a methodology for assessing the indicator to characterize the socio-economic Sustainable Development using the Fuzzy logic.

There were described two component models: PSR and SAFE.

It was shown that for aggregation of the defined indicators are used two methods requiring either a normalization or a fuzzification.

For normalization it was presented an illustrative example referring to the life expectancy.

11. References:

1. Luc A. Andriantiatsaholiniaina, Vassilis S. Kouikoglou, Yannis A. Phillis, Evaluating strategies for

sustainable development: fuzzy logic reasoning and sensitivity analysis, 2004, Ecological Economics nr. 48 p. 149– 172

2. Zaccaï, Bauler, Dictionnaire du Développement Durable belge. Institut pour un Développement Durable – SSTC., Indicateurs pour un développement durable
3. M. G. Cornelissen, J. van den Berg, W. J. Koops. ERASMUS RESEARCH INSTITUTE OF MANAGEMENT REPORT SERIES, Eliciting Expert Knowledge for Fuzzy Evaluation of Agricultural Production Systems
4. Earl Cox, The Fuzzy Systems Habbook, AP Professional New York
5. Roefie Huetinga, Lucas Reijnders, "Broad sustainability contra sustainability: the properconstruction of sustainability indicators", 2004, Ecological Economics nr. 50 p. 249– 260