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Evaluation of sustainability of a city through fuzzy logic

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Abstract

The sustainable indicators are characterized by a low degree of aggregation and a high amount of information. An indicator must show a synthetic representation of a real environmental, by using a value or a parameter, so that they can be easily used by policy makers. It is necessary to connect, therefore, the various systems in an appropriately integrated sustainable system. The indicators need to be aggregated based on the structure of the data. Each indicator must to be defined through a weight with reference to another weighted indicator.

In this paper is illustrated the calculation of the assigned weights that uses a procedure based on fuzzy logic and to define a model that allows us to estimate the sustainability of a city.

The final result is, therefore, a combination of values assigned by expert opinion for the various criteria, processed using fuzzy logic to obtain a weight with significant objectivity and as it is possible to estimate the sustainability of the city through the weights.

Keywords: Sustainability; Fuzzy logic

1. Introduction

The sustainability (or un-sustainability) is not easily measurable: in fact it is not directly indicated as a natural or direct consequence of the reading of the environmental indicators.

One of the environmental observation methods that is increasingly prominent proceeds by the use of indicators, which concur "to read" the state of environment in its several aspects, selecting—among all information available—those characterized as meaningful to explain a particular situation, with a descriptive, valuable, predictive or decisional aim [1].

To this point, the problem is to define the meaning of an environmental indicator: an indicator furnishes a synthetic description of an environmental reality, by a value or a parameter. However, the information that follows is wider than the value itself and it must be specified in relation to the type of indicator and to the context in which it is placed.

The indicator must be dynamic and in continuous evolution, because the environment is a complex system that cannot be completely observed from a single perspective.

Generally, three categories of users can be identified:

- the public in a generalized manner;
- policy makers and the authorities;
- experts and scientists [1].

Some essential terms for the predisposition of environmental indicators are the following [1]:

(a) identification of the space and temporal context that is taken as reference for the survey of the data base;
(b) decision on the type of information that it must be transferred and choice of a synthesis method of the information;
(c) check of some property that would characterize the definition of an environmental indicator.

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Therefore, it will be possible to equip the policy maker with information for "ready consultation", to provide him the information that puts him in a situation to attend and to estimate the effects of the intervention.

2. Sustainable indicators weight through fuzzy logic

The indicators arranged by the scientific community are commonly characterized by a low degree of aggregation and a high amount of information, while an increase in the degree of aggregation and a lessening of the amount of information would be necessary to policy makers. Since the different indicators are not homogeneous, as a result of their various structures, it is possible to assign a weight to each indicator to allow for possible aggregation. This assignment can be made by means of a combination of values assigned from different judges and different criteria, calculated using a procedure based on the "fuzzy logic".

The daily natural language consists of indefinite, inaccurate and polyvalent concepts, that can make approximate decision processes. The theory of "fuzzy logic", or "fuzzy set theory", resembles human reasoning in its use of approximate information and uncertainty to generate decisions. It was specifically designed to mathematically represent uncertainty and vagueness and provide formalized tools for dealing with the imprecision intrinsic to many problems [2]. The scope of this work is to assign, by fuzzy logic, the weights to the different indicators that can be taken in consideration in an environmental impact, so to obtain a significant homogeneity and objectivity.

Typically the base structure for an environmental plan is a matrix expressed with:

$$\begin{array}{cccc} & G_1 & \dots & G_J \\ A_1 & \varphi_{11} & \dots & \varphi_{1J} \\ \vdots & \vdots & & \vdots \\ A_I & \varphi_{I1} & \dots & \varphi_{IJ} \end{array}, \tag{1}$$

where G_j indicates an objective or an environmental characteristic; $G = \{G_1, G_2, \dots, G_J\}$ is a set of J environmental characteristics, A_i is an alternative or option and $A = \{A_1, A_2, \dots, A_J\}$ is a set of mutually exclusive plans; φ_{ij} indicates the result of the plan A_i regarding the objective G_j. Generally weights $\{w_1, w_2, \dots, w_J\}$ are introduced to represent the different value of various opportunities.

The following method allows for the assignment to m alternatives $A_1, \dots, A_m$ their weights. Therefore, *n experts* or *judges* $J_1, \dots, J_n$ are used to provide information based on the $C_1, \dots, C_k$ criteria. The informations assigned by judges are fuzzy trapezoid numbers [1] given by

$$(\alpha/\beta, \gamma/\delta), \tag{2}$$

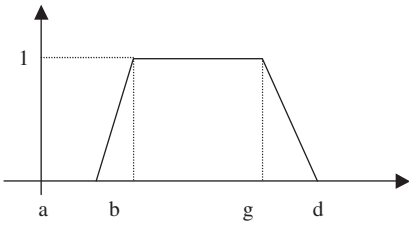

Fig. 1. Typical membership of fuzzy number.

where a, b, g, d are real numbers that satisfy the relation $a \leqslant b \leqslant g \leqslant d$, shown in Fig. 1 [3].

The weights of the indicators are given by the followings steps :

1. The judges express their opinion both in terms of the criteria of evaluation of the indicators and in terms of indicator's importance relative to every criteria in the interval of values [0, L]. The *matrix of criteria* obtained is

$$\begin{array}{cccccc} & & J_1 & J_2 & \dots & J_n \\ & C_1 & & & & \\ T = & C_2 & & & & \\ & \vdots & & \overline{b}_{kj} & & \\ & C_k & & & & \end{array}, \tag{3}$$

where

$$\overline{b}_{kj} = \left(\varepsilon_{kj}/\zeta_{kj}, \eta_{kj}/\theta_{kj}\right) \tag{4}$$

and the alternatives matrix is

$$\begin{array}{cccccc} & & J_1 & J_2 & \dots & J_n \\ & A_1 & & & & \\ & A_2 & & & & \\ T_k = & \vdots & & \overline{a}_{ij}^k & & \\ & A_m & & & & \end{array} \tag{5}$$

for every criteria C_k ($1 \leqslant k \leqslant K$), and where $\overline{a}_{ij}^k$ is expressed as

$$\overline{a}_{ij}^k = \left(\alpha_{ij}^k/\beta_{ij}^k, \gamma_{ij}^k/\delta_{ij}^k\right) \tag{6}$$

2. The weight can be determined in two ways:

(a) For every judge J_i the indicator weight is obtained by criteria shown as [2]

$$\overline{w_{ij}} = \left(\frac{1}{KL}\right) \otimes \left[\left(\overline{a}_{ij}^1 \otimes \overline{b}_{1j}\right) \oplus \dots \oplus \left(\overline{a}_{ij}^K \otimes \overline{b}_{Kj}\right)\right] \tag{7}$$

[1] The fuzzy number trapezoid are used because they are more comprehensible by the expert-judges. In fact, to say "about 7", can be indicated with notation (6/7, 7/8), while "included between 6 and 7" it can be indicated by notation (6/6), 7/7).

[2] The symbol $\otimes$, $\oplus$ represent a multiplication and addition fuzzy, respectively. For example if A = (1, 2, 3, 4) and B = (2, 3, 3, 4): A$\otimes$B = (1·2, 2·3, 3·3, 4·4) = (2,6,9,16) and A$\oplus$B = (1+2, 2+3, 3+3, 4+4) = (3,5,7,8).