MODELLING THE URBAN SUSTAINABLE DEVELOPMENT BY USING FUZZY SETS

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Abstract
The sustainable urban development is a subject of interest for regional policy makers and it needs appropriate assessment based on futile instruments for research, and for practical reasonsl (planning and decision making). Even if the sustainability's attainment is a research topic field for academia and urban planners and managers and, as well, an ambitious goal for any resource administrator, yet there is no precise way of defining and measuring it. The sustainability of the urban development policy implies multiple and diversified aspects from rational exploitation of the local resources and well-structured workforce to environmental issues, endowment of modern urban facilities and infrastructure elements. As the urban sustainability is measured using a multitude of basic indicators, needing proper information to make long term management decision and planning, the subject is treated with fuzzy setsseen as an appropriate manner to deal with ambiguity, subjectivity and imprecision in the human reasoning when processing large volumes of data, eventually unstructured and complex. The paper proposed a modeling approach based on fuzzy sets inspired by the SAFE (Sustainability Assessment by Fuzzy Evaluation), a model which provides a mechanism for measuring development sustainability. The papers intends presenting a quantitative methodology in assessing the potential sustainability of urban development (in terms of adequacy) by pointing the failures in pursuing trends that are associated to a robust growth in the urban areas. The advantages of such approach are derived from taking into account the multi-criteria and uncertainty facets of the phenomenon; also, having in mind that the sustainability remains a non-straight-cut concept, being vaguely defined it implies a non-deterministic character by using the fuzzy set logic. The proposed model is designed to assess the divergence from desired trajectories, the weak point in reaching indicators' target (as they are commonly regardedd as appropriate in what is understood as a good practices), it may then be addressed for policy makers in indicating some action measures in urban administration as they intendenly strive towards increasingly sustainable development on the long term.

Keywords: sustainability, urban management, indicators, fuzzy approach.

1. INTRODUCTION

Urban lifestyles are nowadays characterized by very different developing trajectories, based on high consumption levels, exuberant use of natural resources, excessive production of waste, a widening gap between rich and poor, and rapid growth of the global human population. More and more, scientists and various experts in the field of human health and nature preservation emphasize on subjects as high speed of urbanization, the pressure of human activities on the city green spaces, the noisy and more increased traffic, the burden of air pollution in urban areas. The points of interest are reflected by continuous preoccupation of various international organizations and agencies toward the subject – such as the United Nations Population Division, World Health Organization, International Road Federation,

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World Resources Institute etc. Related to the future of cities and urban areas, the sustainability become crucially important but it is an inherently vague concept whose scientific definition and measurement still lack widely common understanding.

There are number of initiatives working on indicators and frameworks for sustainable development (Singh, 2009, Hernández-Moreno and De Hoyos-Martínez, 2010). Indicators and composite indicators are increasingly recognized as a useful tool for policy making and public communication in conveying information on countries' performance in fields such as environment, economy, society, or technological development. Those interested could be experts and scientists, to policy makers and central/local authorities to the general public. For economists, the notion of sustainable development has meant a new major challenge, as they were forced to broaden existing analytical frameworks and a rising interest in research moves away from global sustainability analysis towards empirical policy-relevant research at the regional and urban level (Nijkamp, 2000*).* Assessing sustainability and vulnerability implies provision of information to evaluate the consequences of development strategies, policies and actions on development process. It is necessary to define a pragmatic framework, based on what is known from theories and what is learned in practice, that can be used as a model to guide, define and use appropriate indicators for the system (i.e. structure/ functions, scales/levels, viability/integrity, goods/services) and the steps for decision and policy making (i.e. conditions, diagnosis, forecasts, responses and evaluation). Devuyst (2001) introduces "sustainability assessment", a new concept that aims to help in steering societies in a more sustainable direction, and applies this concept to cities. It deals with practical ways to reach a more sustainable state in urban areas through such tools as strategic environmental assessment, sustainability assessment, direction analysis, baseline setting and progress measurement, sustainability targets, and ecological footprint analysis (Devuyst, 2001). More specific, Gagliardi (2007) treats the topic of evaluation of fuzzy logic trough the fuzzy logic instruments, describing procedures to assign weights to expert criteria used to estimate the sustainability of a city (Naples, Italy).

According to some authors (Braat, 1991), the sustainability indicators, either in a direct (predictive) or indirect manner (retrospective), should provide information about the future sustainability of social objectives such as material welfare, environmental quality and natural system amenity. In order to be able to assess with a reasonable level of accuracy, the sustainable urban development one needs information that should provide:

- current state of the urban management configuration (such as consumption and infrastructure and logistics)
- the reflection of time dimension as the urban system evolves

- the distance in time in reaching the previously stated policy objectives.

Statistical data for the basic indicators can be obtained from many sources, such as United Nations organizations, World Bank, World Resources Institute, international federations, governmental and nongovernmental organizations, etc. The indicators are selected from authorized and reliable sources - from the World Bank – World Development Report (WDI), UNDP - Human Development Report (HDR), United Nations Population Division, World Health Organization, International Road Federation, World Resources Institute, and other sources. There are various statistical databases that provide information on the urban and city development: an example is the World Bank (WB) indicators – a specific chapter of the collection of World Development Indicators (WDI) covering over 200 countries in over 420 different indicators, grouped in various sectors. As an example of the richness of information available, in the Table 1 is presented the set of indicators given by the World Development Report in the subject of Urban Development (source: http://data.worldbank.org/indicator).

TABLE 1 - INDICATORS PROVIDED BY WORLD DEVELOPMENT INDICATORS

Improved sanitation facilities, urban (% of urban population with access)	Pump price for diesel fuel (US$ per liter)
Improved water source, urban (% of urban population with access)	Pump price for gasoline (US$ per liter)
Motor vehicles (per 1,000 people)	Road sector diesel fuel consumption per capita (kt of oil equivalent)
Passenger cars (per 1,000 people)	Road sector energy consumption (% of total energy consumption)
PM10, country level (micrograms per cubic meter)	Road sector gasoline fuel consumption per capita (kt of oil equivalent)
Population in the largest city (% of urban population)	Urban population
Population in urban agglomerations of more than 1 million (% of total population)	Urban population (% of total)
Poverty gap at urban poverty line (%)	Vehicles (per km of road)
Poverty headcount ratio at urban poverty line (% of urban population)	

2. THE FUZZY MODEL FOR ASSESSING URBAN SUSTAINABILITY

The urban sustainable development is difficult to define in pure quantitative terms, and during the past decades, the researchers recognize that it bears an imprecise and vague feature of being defined and tackled in many facets, with several ways of collecting data for indicators regarding the efficient and the effective usage of resources. Yet, there is an increasing need for using mathematical expressions on the sustainability issues as they are more appropriate to be related to the higher demand on software application in management (Hoffman, 2008). Under these circumstances, the fuzzy logic is well suited

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to handle such a vague, uncertain, and polymorphous concept (Lazim and Wahab, 2010, Colesca and Alpopi, 2010).

Fuzzy logic is justified because it is tolerant of imprecisely defined data, it can model non-linear functions of arbitrary complexity; and it is able to build on top of the experience of experts.

Sustainable development has also been described as fostering adaptive capabilities and creating opportunities (Winograd, 2007). The challenges for sustainable development are related to the improvement of resilience and adaptive capacities, take advantage of emerging opportunities and cope with the consequences of different processes of change. In this context, vulnerability (seen as function of risks and threats minus adaptive options and coping responses) is emerging as a critical component of any sustainable development strategy.

3. COLLECTION OF DATA

The SAFE model is used for the newly proposed model for assessing the urban sustainability and primarily it was introduced in Phillis and Andriantiatsaholiniaina (2001) and developed further (Andriantiatsaholiniaina and Kouikoglou, 2004) and (Phillis and Kouikoglou, 2011). SAFE is a hierarchical fuzzy inference system. It uses knowledge encoded into “if-then” rules and fuzzy logic to combine 75 inputs, called basic indicators, into more composite variables describing various environmental and societal aspects and, finally, provides an overall sustainability index in [0, 1].

Similar to the above mentioned SAFE methodology, the overall urban sustainability (*OUS*) of a certain urban area is appraised according to two major dimensions: the smooth dynamics (*SD*) and positive growth prospects (*PG*). These will be referred to as the crucial components of the overall urban sustainability. Both of them are regarded as depended on several dimensions of basic sustainability: current status (*STA*), evolving potential (*POT*), driven responses (coordinated interventions) (*RES*).

Figure 1 illustrates all the dependencies of urban sustainability components. To evaluate the secondary components, the newly proposed model follows the *Pressure – State - Response* approach [Organization for Economic Cooperation and Development (OECD), 1991], which was originally proposed to assess the general environmental component of sustainability.

STA describes the current overall state of an urban area; it is a function of a large number of indicators, acting as primitive determinants of the current living, economic and societal conditions of the urban areas; the *STA* variable is an aggregate measure of the basic indicators presented in the Table 2.

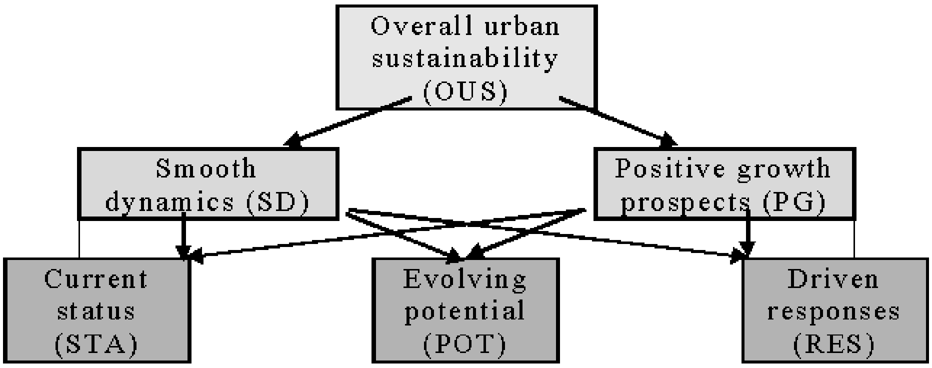

FIGURE 1 - DEPENDENCIES OF URBAN SUSTAINABILITY COMPONENTS

TABLE 2 - BASIC INDICATORS USED IN THE MODEL – THE *STA* VARIABLE

Secondary component	STA (current state of living conditions, population health and wealth, infrastructure, consumption behaviors)
SD and PG	PM10, country level (micrograms per cubic meter) (WB) Poverty gap at urban poverty line (%) (WB) Gross national income (GNI) per capita (HDR) Income Gini coefficient (HDR) Adjusted net savings (% of GNI) (HDR) Overall life satisfaction (0, least satisfied, 10, most satisfied) (HDR) Satisfaction with measures of well-being (% satisfied) (HDR) Urban population (% of total) (Eurostat) Total Number of Households (Eurostat) Number of dwellings (Eurostat) Average price per m^2 for an apartment (Eurostat) Average occupancy per occupied dwelling (Eurostat) Average living area in Urban Audit cities - m^2 per person (Eurostat) Ratio of first to fourth quintile earnings (Eurostat) Proportion of individuals reliant on social security (Eurostat) Prop. of residents exposed to air traffic noise >65 dB(A) at day time (Eurostat) Prop. of residents exposed to rail traffic noise >65 dB(A) at day time (Eurostat) Prop. of residents exposed to road traffic noise >65 dB(A) at day time (Eurostat) Consumption of water (cubic metres per annum) per inhabitant (Eurostat) Price of a m^3 of domestic water (Eurostat) Percentage of dwellings connected to potable drinking water supply infrastructure (Eurostat) % dwellings connected to sewerage treatment system (Eurostat) Percentage of the urban waste (Eurostat) Municipal waste generated (Kg per person per year) (Eurostat) Municipal waste generation and treatment, by type of treatment method (kg per capita) (Eurostat) Municipal waste by type of treatment (Kg per person per year) (Eurostat) Urban population exposure to air pollution by particulate matter (micrograms per cubic metre) (Eurostat) Urban population exposure to air pollution by ozone (micrograms per cubic metre day) (Eurostat) Registered cars in Urban Audit cities - number of cars per 1000 inhabitants (Eurostat) Number of registered motor cycles per 1000 population (Eurostat) Number of deaths in road accidents per 10000 population(Eurostat) Number of persons seriously injured in road accidents per 10000 population (Eurostat)

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The *POT* variable, as well, is an aggregate measure of the changing forces human activities exert on the state of the corresponding secondary component; the subcomponent indicators used in calculating the *POT* value are given in the Table 3. And, the third primary variable - *RES* - summarizes the indicators related to the policy response to the environmental, economic, and social current conditions (Table 4); they measures the benefits of the envisaged actions, taken to bring lower pressure to the undesired levels of some indicators – it should indicate the efforts that might result in a better state (quality of life for the inhabitants and the operating business climate for the economic actors in the local urban area) and the potential triggers to bring more benefits in the urban area development.

TABLE 3 - BASIC INDICATORS USED IN THE MODEL – THE *POT* VARIABLE

Secondary component	**POT (demographic tendencies, investments in developing and upgrading infrastructure,**
SD and PG	Improved sanitation facilities, urban (% of urban population with access) Improved water source, urban (% of urban population with access) Moves to city during the last 2 years/moves out of the city during the last 2 years (Eurostat) Live births per 1000 residents (Eurostat) Crude death rate per 1000 residents (Eurostat) Available hospital beds in Urban Audit cities - per 1000 inhabitants (Eurostat) Number of practising physicians per 1000 residents (Eurostat) Number of practising dentists per 1000 residents (Eurostat) Total number of recorded crimes per 1000 population (Eurostat) Number of murders and violent deaths per 1000 population (Eurostat) Car thefts in Urban Audit cities - number per 1000 inhabitants (Eurostat) Number of domestic burglary per 1000 population (Eurostat) Annual average change in employment over approx. 5 years (Eurostat) Number of unemployed (Eurostat) Proportion of unemployed who are under 25 (Eurostat) Employment/Population (of working age) Ratio (Eurostat) Percentage of households with Internet access at home (Eurostat) Local units providing ICT services per 1000 companies (Eurostat) Proportion of employment in culture and entertainment industry (Eurostat) Number of tourist overnight stays in registered accommodation per year per resident population (Eurostat) Tourist overnight stays per 1000 population at low season (Eurostat)

Some representative indicators used in the sustainability model are given in 2-4 (yet, there are not describes in terms of power on influence, which is still an uncovered subject, posiible to be more explored conceptually).

Recently, fuzzy logic has been proposed as a systematic tool for the assessment of sustainability. Fuzzy logic is capable of representing uncertain data, emulating positive reasoning habits of skilled humans, and handling vague situations where traditional mathematics is ineffective. The fuzzy logic is addressed as a convenient way to treat the sustainability dimension as it allow considering the complexity and the scarce determination of the knowledge captured in the human experts reasoning on the subjects related to urban development. It may combine the imprecise pieces of information (often in linguistic variables) with objectives that are stated with ambiguous terms and expressions, difficult to be computed mathematically; still, under such circumstances, the fuzzy logic can give solid answers to problems posed in subjective or metaphorical formulations. In this way by using words and imprecise information in fuzzy logic mechanisms, the weaknesses of some traditional methods (such as the cost-benefit analysis) that rely heavily of numerical data and quantification may be overpassed.

TABLE 4 - BASIC INDICATORS USED IN THE MODEL – THE *RES* VARIABLE

Secondary component	RES (greening policies, triggers for proper development)
SD and PG	Economic activity rate in Urban Audit cities - % (Eurostat) Employment per 100 of residents aged 15-64 (Eurostat) New businesses registered in proportion of existing companies (Eurostat) Median disposable annual household income (Eurostat) Number of elected city representatives per 1000 residents (Eurostat) Percentage of elected city representat. who are men (Eurostat) Students in upper and further education (ISCED level 3-4) per 1000 resident pop. (Eurostat) Students in higher education (ISCED level 5-6) per 100 resident population aged 20-34 (Eurostat) Collected solid waste in Urban Audit cities - tones per inhabitant and year (Eurostat) Total land area (km^2) according to cadastral register (Eurostat) Green space (in m^2) to which the public has access, per capita (Eurostat) Population density in Urban Audit cities (Eurostat) Net residential density - pop. per land area in housing (Eurostat) Average time of journey to work (Eurostat) Length of public transport network / land area (Eurostat) Length of public transport network per inhabitant (Eurostat) Length of public transport network on flexible routes per 1000 pop (Eurostat) Number of buses (or bus equivalents) operating in the public transport per 1000 pop (Eurostat) Cost of a monthly ticket for public transport (for 5-10 km) Accessibility by air (EU27=100) (Eurostat) Accessibility by rail (EU27=100) (Eurostat) Accessibility by road (EU27=100) (Eurostat) Multimodal accessibility (EU27=100) (Eurostat)

The fuzzy logic allows making correct and precise analysis of some linguistic formulations by involving the sequential process of fuzzyfication – making inferences – defuzzyfication. As a start, the real values are transformed into linguistic variables; these are processed according to some IF-THEN rules, resulting in the fuzzy output that allows decoding it in a crisp value. The proposed model is described in the Figure 2, by indicating the sequence of steps.

Normalization step: Data of each basic indicator are normalized on a scale between zero (lowest level of preference) and one (highest level of preference sustainability) to allow further arithmetical computations (aggregation) and to facilitate fuzzy computations. Instead of using the data for each indicator directly, they are normalized in order to allow summation and ignoring the specific units of measurement. To each basic indicator, v, some values are assigned: a target vt_i, a minimum, v_{min}, and a maximum value v_{max}. The target can be a single value or, in general, any interval on the real line of the form $[vt_{\min}, vt_{\max}]$ representing a range of desirable values for the indicator. The maximum and minimum values are taken over the set of available measurements of the indicator. It does this as it do not refer some well established or even, commonly agreed reference values for the involved statistical indicators, but rather uses the "best" values (in some particular views) or the average values as they are registered nowadays.

Knowledge base	Steps
Statistical indicators and empirical raw data	Collecting indicators
	Normalization
Input variables	Fuzzyfication module
Set of rules	inference engine module
Output variables	Defuzzyfication module

FIGURE 2 - THE MODEL CONFIGURATION IN STEPS

Let the v_i be the data value for the i indicator and the v_{max} and v_{min} the maximum and minimum values for all units in the sample, the vt_i is the target value for the same indicator, then the vn_i is computed according to the optimized direction corresponding to the indicator's description –Table 5.

TABLE 5 - NORMALIZATION PROCEDURES ACCORDING TO THE SPECIFIC TYPE OF BASIC INDICATOR

The maximum target value	$vn_i = \begin{cases} \dfrac{v_i - v_{\min}}{vt_i - v_{\min}} & v_i \le vt_i \\ 1 & v_i \ge vt_i \end{cases}$
The minimum target value	$vn_i = \begin{cases} \dfrac{v_{\max} - v_i}{v_{\max} - vt_i} & v_i \ge vt_i \\ 1 & v_i \ge vt_i \end{cases}$
The inclusion the interval $[vt_{\min}, vt_{\max}]$	$vn_i = \begin{cases} \dfrac{v_i - v_{\min}}{vt_i - v_{\min}} & v_i \le vt_{\min} \\ 1 & v_i \in [vt_{\min}, vt_{\max}] \\ \dfrac{v_{\max} - v_i}{v_{\max} - vt_{\max}} & v_i \ge vt_{\max} \end{cases}$

The fyzzy model consists of: linguistic variables, the linguistic rules and the specification on the defuzzyfication method. Any linguistic variable is descried by: the name, by its linguistic values, by the membership values and the admissible domain for its values. The overall sustainability – the output variable - can be seen as a function of the subsystems' quality, devised by the fuzzy logic input variables. The function is the result of a set of dependence rules (treated as *IF – THEN* rules) derived from the experts reasoning.

Fuzzyfication step. The fuzzyfication module transforms the crisp, normalized value, vn_i, of a indicator, into a linguistic variable in order to make it compatible with the rule base. A linguistic variable is a variable whose values are expresses as qualitative attributes - words or phrases. A linguistic value, *LV*, is represented by a fuzzy set using a membership function $\mu_{LV}(vn)$. The membership function associates with each normalized indicator value, vn_i, a number, $\mu_{LV}(vn_i)$, in [0, 1] which represents the grade of membership of y_s in *LV* or, equivalently, the truth value of proposition "indicator *v* is *LV*".

In the model, the linguistic values of each basic indicator are weak (*W*), medium (*M*), and strong (*S*), each of them being expressed using a trapezoidal function of membership involved in the computation – Figure 3. The trapezoidal functions are chosen for the secondary and primary variables to represent an increased uncertainty; they are quite simple and the sustainability assessment results obtained from the model agree with widely held opinions. In representing the membership functions, the horizontal axis is composed by the normalized values for each variable (with values ranked from 0 to 1) and the vertical axis depict the membership degrees (with the domain of [0, 1]).

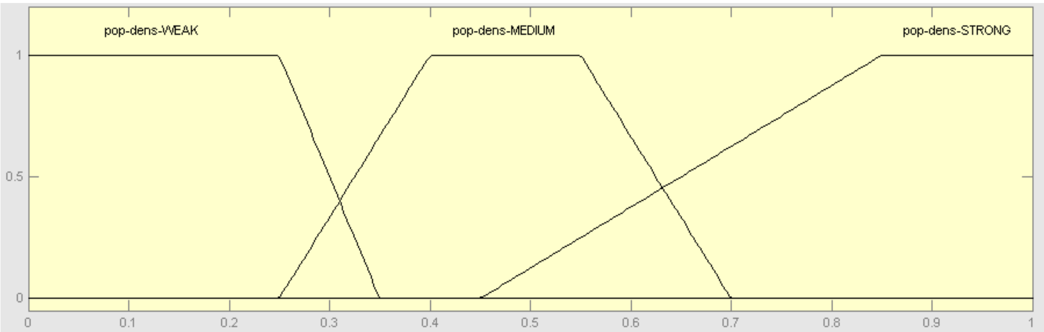

FIGURE 3 - EXAMPLE OF LINGUISTIC VALUES OF A BASIC INDICATOR (POPULATION DENSITY)

For the secondary composite indicators (such as *SD* or *PG*), five linguistic values are used: very poor (*VP*), poor (*P*), intermediate (I), satisfactory (*S*), and very satisfactory (*VS*) – figure 4 and 5. For the output indicator (OUS), five linguistic values are used: very bad (*VB*), poor (*B*), intermediate (I), good (*G*), and very good (*VG*) - figure 6.

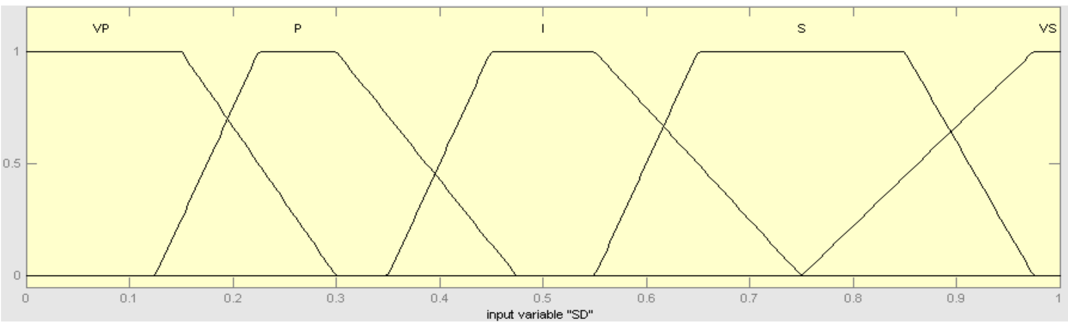

FIGURE 4 - LINGUISTIC VALUES AND FUZZYFICATION OF INPUT VARIABLE (SD)

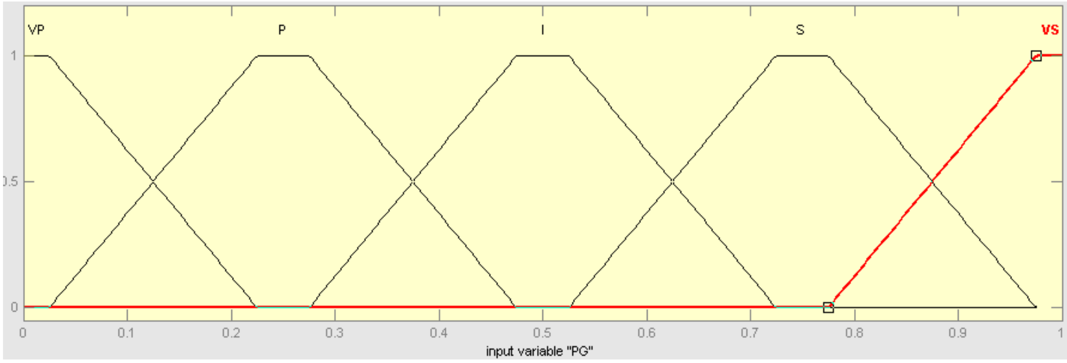

FIGURE 5 - LINGUISTIC VALUES AND FUZZYFICATION OF INPUT VARIABLE (GP).

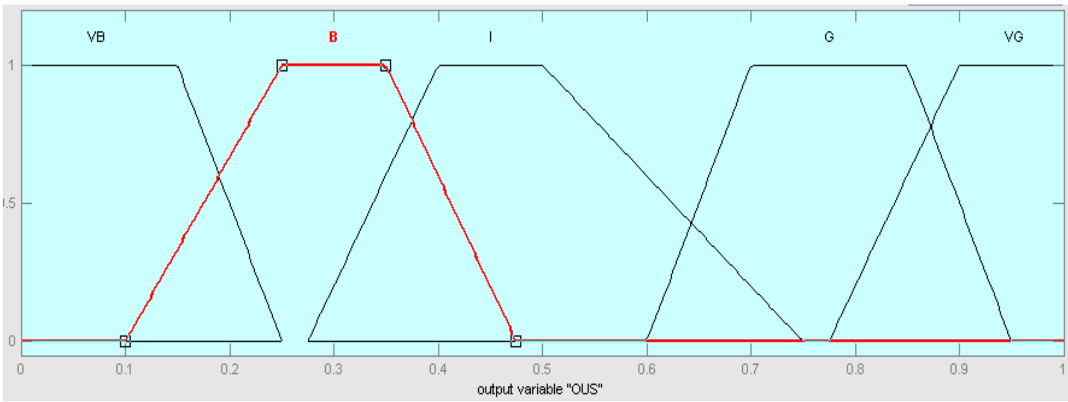

FIGURE 6 - LINGUISTIC VALUES AND FUZZYFICATION OF OUTPUT VARIABLE (OUS)

The rules are represented in the Mamdani implication, so, the statement "*if x=A then y=B*" or "$A \to B$" results in a rule R such that: $\mu_R(x,y) = \min\{\mu_A(x), \mu_B(y)\}$. In general, a rule base may contain several rules assigning subsets of the same linguistic value, LV_v, to indicator s. For example, the rule base of the secondary component *SD* contains the following rules:

IF STA is medium AND POT is week AND RES is strong, THEN SD is intermediary.

IF STA is weak AND POT is strong AND RES is strong, THEN SD is very satisfactory.

The "*IF – THEN*" rules are expressions of the current and multidisciplinary understanding on the influence-impact mechanisms among a set of factors. Consider the secondary variable *SD* and its components *STA*, *POT* and *RES*. For simplicity, only three fuzzy sets are used: weak (*W*), medium (*M*), and strong (*S*), to represent the primary variables and five fuzzy sets for *SD*: very poor (*VP*), poor (*P*), intermediate (*I*), satisfactory (*S*), and very satisfactory (*VS*). Table 6 shows the corresponding rule base which consists of 33=27 rules.

TABLE 6 - THE SET OF RULES FOR THE COMPUTATION OF SD OR PG

Rule R	If STA is	And POT is	And RES is	Then ….. (SD) or … (PG)… is
1	weak	strong	strong	very satisfactory
2	weak	medium	strong	very satisfactory
3	weak	weak	strong	satisfactory
4	weak	strong	medium	very satisfactory
5	weak	medium	medium	satisfactory
6	weak	weak	medium	average
7	weak	strong	weak	satisfactory
8	weak	medium	weak	intermediary
9	weak	weak	weak	bad
10	medium	strong	strong	very satisfactory
11	medium	medium	strong	satisfactory
12	medium	weak	strong	intermediary
13	medium	strong	medium	satisfactory
14	medium	medium	medium	intermediary
15	medium	weak	medium	bad
16	medium	strong	weak	intermediary
17	medium	medium	weak	bad
18	medium	weak	weak	very bad
19	strong	strong	strong	satisfactory
20	strong	medium	strong	intermediary
21	strong	weak	strong	bad
22	strong	strong	medium	intermediary
23	strong	medium	medium	bad
24	strong	weak	medium	very bad
25	strong	strong	weak	bad
26	strong	medium	weak	very bad
27	strong	weak	weak	very bad

Table 7 consists of set of rules describing the inference *OUS=Function(SD, PG)* – figure 7.

DEFUZZIFICATION STEP. DEFUZZYFICATION IS THE FINAL OPERATION ASSIGNING A NUMERICAL VALUE IN [0, 1] TO THE COMPOSITE INDICATOR *S*. AS DEFUZZYFICATION METHOD, THE CENTER-OF-GRAVITY FORMULA WILL BE USED; $def(Ov) = \frac{\sum_j y_j \cdot \mu_{Ov}(y_j)}{\sum_j \mu_{Ov}(y_j)}$ WHERE: Y_J IS THE VALUE FOR THE *J* INDICATOR IN THE OUTPUT FUZZY SET O_V WITH THE MEMBERSHIP FUNCTION OF $\mu_{Ov}(y_j)$.

TABLE 7 - THE SET OF RULES FOR THE COMPUTATION OF OUS

PG \ SD	VP	P	I	S	VS
VP	VB	VB	VB	VB	VB
P	VB	B	B	B	B
I	VB	B	I	I	I
S	VB	B	I	G	G
VS	VB	B	I	G	VG

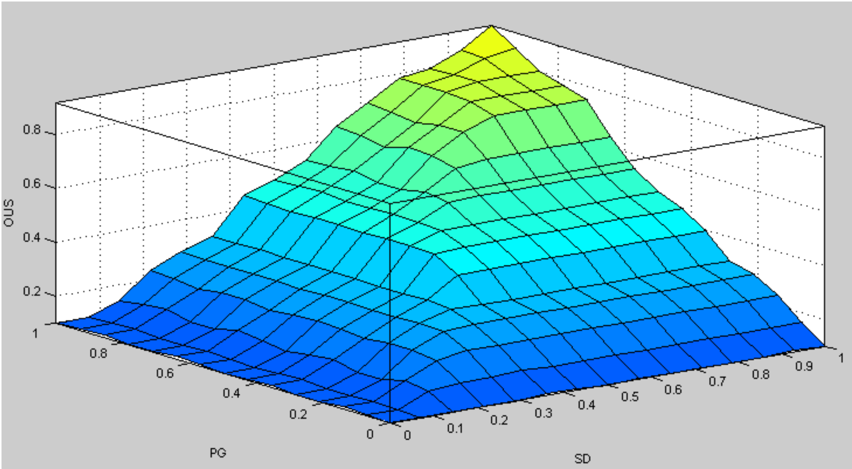

FIGURE 7. THE SURFACE OF OUS=FUNCTION (SD, PG)

In using numerical values, based on a selection of indicators for a sample of 40 countries from around the world (mainly, those of European Union, also, some additional ones representative on the international climate), the model was applied to calculate and assess the urban sustainability of the Romanian urban areas, in general terms – as opposed to other countries). As a minimum indicator to be normalized it was described the "*Population density (people per sq. km of land area)*" and as a maximum one –"*GDP per capita, PPP (current international $)*" – Table 8.

TABLE 8 - EXAMPLE OF INDICATORS USED TO COMPUTE SD AND PG

Population density (people per sq. km of land area)	Population density is midyear population divided by land area in square kilometers. Population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship--except for refugees not permanently settled in the country of asylum, which are generally considered part of the population of their country of origin. Land area is a country's total area, excluding area under inland water bodies, national claims to continental shelf, and exclusive economic zones. Source: *WDR* data.worldbank.org/indicator/EN.POP.DNST
GDP per capita, PPP (current international $)	GDP per capita based on purchasing power parity (PPP). PPP GDP is gross domestic product converted to international dollars using purchasing power parity rates. An international dollar has the same purchasing power over GDP as the U.S. dollar has in the United States. GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant 2005 international dollars. Source: WDR http://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD

The selection of indicators (Table 9) in the normalized form (according to the formulas from Table 5, see TableS 10-12 for examples of applying the normalization stage in the case of two indicators) is fuzzyfied (according to the set of membership functions displayed in Figure 3).

TABLE 9 - SELECTION OF SD AND PG INDICATOR (THE SIMPLIFIED MODEL)

Indicator	STA	POT	RES
SD	GDP per capita, PPP (current international $) Ratio of first to fourth quintile earnings PM10, country level (micrograms per cubic meter) Total Number of Households	Improved sanitation facilities, urban (% of urban population with access) Improved water source, urban (% of urban population with access) Proportion of unemployed who are under 25 Employment/Population (of working age) Ratio	Employment per 100 of residents aged 15-64 Collected solid waste in Urban Audit cities - tones per inhabitant and year Total land area (km^2) according to cadastral register
PG	Urban population (% of total) Population density (people per sq. km of land area) Percentage of the urban waste	Moves to city during the last 2 years/moves out of the city during the last 2 years Live births per 1000 residents Percentage of households with Internet access at home Number of tourist overnight stays in registered accommodation per year per resident population	New businesses registered in proportion of existing companies Green space (in m^2) to which the public has access, per capita

TABLE 10 - VALUES FOR THE SAMPLE FOR TWO INDICATORS

Country	**Population density (people per sq. km of land area)**		**GDP per capita, PPP (constant 2005 international $)**	
	2009 actual values	*2009 normalized values*	*2009 actual values*	*2009 normalized values*
Australia	2.8474	0	34259,08429	0,477912
Austria	101.4445	0.076199	34673,09305	0,48416
Belgium	356.2999	0.27316	32394,66025	0,449775
Bulgaria	105.2629	0.07915	11455,75274	0,133771
Canada	3.7103	0.000667	34567,05803	0,48256
China	142.7460	0.108118	6200,209383	0,054456
Croatia	79.1994	0.059008	16337,85623	0,20745
Cyprus	94.2680	0.070653	25758,99864	0,349631
Czech Republic	135.7925	0.102745	22097,60544	0,294374
Denmark	130.3151	0.098511	32251,92288	0,44762
Estonia	31.6194	0.022236	16132,49744	0,204351
Finland	17.5663	0.011375	30784,45863	0,425474
France	114.3346	0.086161	29577,58519	0,40726
Germany	234.8621	0.179309	32254,75434	0,447663
Greece	87.5352	0.06545	26482,28211	0,360547
Hungary	111.8436	0.084236	16896,26778	0,215877
Iceland	3.1827	0.000259	33980,22094	0,473703
Ireland	0.0000	0.00749	36277,85903	0,508379
Italy	204.7366	0.156027	26577,56781	0,361985
Japan	349.9588	0.26826	29692,40681	0,408993
Latvia	36.2619	0.025824	12846,5138	0,15476
Liechtenstein	224.4438	0.171257	0	0
Lithuania	53.2879	0.038982	15010,68974	0,187421
Luxembourg	192.2216	0.146355	68853,45655	1
Malta	1296.7844	1	21987,23322	0,292709

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Country	Population density (people per sq. km of land area)		GDP per capita, PPP (constant 2005 international $)	
	2009 actual values	2009 normalized values	2009 actual values	2009 normalized values
Moldova	109.5624	0.082473	2591,892021	0
Netherlands	489.6710	0.376234	36358,00405	0,509588
Norway	15.8020	0.010012	47675,9603	0,680395
Poland	125.4023	0.094715	16705,03356	0,212991
Portugal	116.2356	0.08763	21369,824	0,283391
Romania	**93.4423**	**0.070015**	**10793,95398**	**0,123783**
Russian Federation	8.6616	0.004493	13611,38119	0,166303
Serbia	82.8397	0.061821	9966,737375	0,111299
Slovak Republic	112.6436	0.084854	19202,48351	0,250682
Slovenia	101.4519	0.076205	24806,41844	0,335255
Spain	92.0792	0.068961	27066,05755	0,369357
Sweden	22.6693	0.015319	32314,13539	0,448559
Switzerland	193.2792	0.147172	36953,7398	0,518579
United Kingdom	255.6035	0.195339	32147	0,446037
United States	33.5621	0.023737	41761	0,591129

TABLE 11 - VALUE DISTRIBUTION IN THE RANGE OF [0,1] - POPULATION DENSITY (PEOPLE/PER SQ. KM LAND AREA)

From	*To*	*Number of value in the sample*	*Relative frequency*	*Cumulative frequency*
0	0.1	26	0.43	0.43
0.1	0.2	19	0.32	0.75
0.2	0.3	7	0.12	0.87
0.3	0.4	2	0.03	0.90
0.4	0.5	2	0.03	0.93
0.5	0.6	2	0.03	0.97
0.6	0.7	1	0.02	0.98
0.7	0.8	0	0.00	0.98
0.8	0.9	0	0.00	0.98
0.9	1.01	1	0.02	1.00

TABLE 12 - VALUE DISTRIBUTION IN THE RANGE OF [0, 1] - GDP PER CAPITA, PPP

From	*To*	*Number of value in the sample*	*Relative frequency*	*Cumulative frequency*
0.0	0.1	3.0	0.08	0.08
0.1	0.2	6.0	0.15	0.23
0.2	0.3	8.0	0.20	0.43
0.3	0.4	5.0	0.13	0.55
0.4	0.5	12.0	0.30	0.85
0.5	0.6	4.0	0.10	0.95
0.6	0.7	1.0	0.03	0.98
0.7	0.8	0.0	0.00	0.98
0.8	0.9	0.0	0.00	0.98
0.9	1.0	1.0	0.03	1.00

Further they are aggregated (using equal weights) in computing the *STA, POT* and *RES* variables (also, in fuzzy form – Figure 4 and 5). Afterwards, the output of the model is a degree (%) of sustainability of the system under examination, meaning an urban area – using the corresponding set of linguistic varibles (figure 7). The three fuzzy variables are subject to inference rules (Table 6)so the new secondary variables *SD* and *PG* are computed (following the rules in Table 7), and, finally, the *OUS* crisp value (equal to 0,569) is generated (Figure 8).

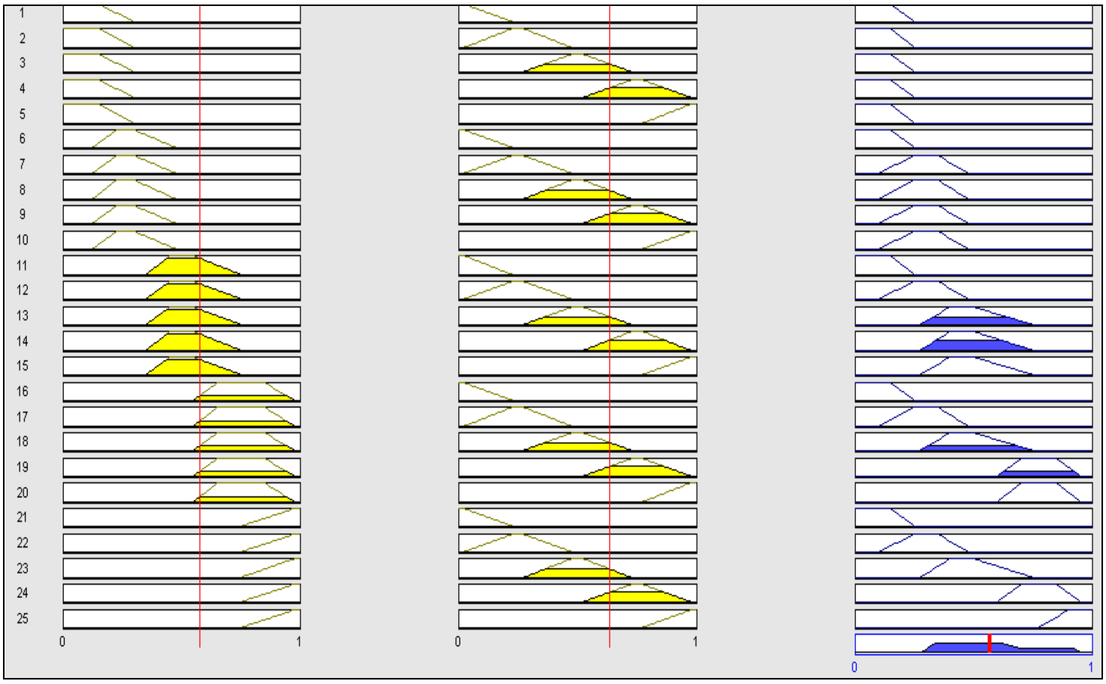

FIGURE 8 - THE CALCULUS FOR OUS= 0.569 IF SD=0.576, PG=0.635 ACCORDING TO THE INVOLVED INFERENCE RULES

The model is flexible in the sense that users can choose the set of indicators and adjust the rules of any knowledge base according to their needs and the characteristics of the socio–environmental system to be assessed. The model is open to new inputs as reality described by extended base of statistical indicators and it may include a temporal dimension for including the experience change – involving a sensitivity analysis.

4. CONCLUSIONS

Sustainable decision-making should have two simultaneous goals: achievement of human development to secure high standards of living and protection and improvement of the environment now and for the generations to come.

Policy makers need a tool based on scientific information to forecast the effects of future actions on sustainability and establish policies for sustainable development. In general, policy makers should be able to identify the factors that promote or impede progress towards sustainability and obtain quantitative information about them. Each sustainability variable is a function of a number of basic indicators. Decision makers have a multitude of considerations to make before they decide on a strategy such as availability of resources, money and people, political priorities, etc. A possible way to expand the analysis for urban sustainability management is to engage the sensitivity analysis which can emphasize the attention on those parameters that affect sustainability critically.

According to the results of sensitivity analysis and the target for each indicator, then, the interested parties may design policies to advance ecological, human, and overall sustainability by • proposing mechanisms and projects to improve promoting indicators or maintain them, if their values are optimal, taking precautionary measures to correct impeding indicators or maintain them, if their values are optimal, and adopting conservative actions for neutral indicators.

REFERENCES

Andriantiatsaholiniaina, L.A., Kouikoglou, V.S., Phillis, Y.A. (2004). Evaluating strategies for sustainable development: fuzzy logic reasoning and sensitivity analysis, *Ecological Economics* 48, pp. 149–172

Braat, L. (1991). *The predictive meaning of sustainability indicators*, in Kuik, O. and Verbruggen, H (eds.), In Search of Indicators of Sustainable Development, Kluwer Academic Publishers, Dordrecht, pp. 57-70

Colesca S.E., Alpopi C. (2010). Quality of electronic government services. A fuzzy analysis, *Quality – Access to Success*, Vol. 7-8, pp. 88-95

Devuyst, D., Hens, L. and De Lannoy, W. (2001). *How Green Is the City*? Published by Columbia University Press

Gagliardi, F., Roscia, M. and Gheorghe Lazaroiu, G. (2007). Evaluation of sustainability of a city through fuzzy logic, *Energy*, Volume 32, Issue 5, May 2007, pp. 795-802.

Hernández-Moreno S. and De Hoyos-Martínez J. (2010). Indicators of urban sustainability in Mexico, *Theoretical and Empirical Researches in Urban Management*, 7(16), pp. 46-60

Hoffman, T. (2008). Vulnerability Assessments: Guidelines to Maximize Performance, The 9 hottest skills for '09, *Computerworld*

Lazim A. and Wahab N. (2010). A fuzzy decision making approach in evaluating ferry service quality *Management Research and Practice*, Vol. 2, Issue 1, pp. 94-107

Nijkamp, P. and Vreeker, R. (2000). Sustainability assessment of development scenarios: methodology and application to Thailand, *Ecological Economics* 33 (2000), pp. 7–27.

Phillis, Y.A. and Andriantiatsaholiniaina, L.A. (2001). Sustainability: an ill-defined concept and its assessment using fuzzy logic, *Ecological Economics*, Volume 37, Issue 3, June 2001, pp. 435-456.

Phillis, Y.A., Grigoroudisa. E. and Kouikoglou, V.S. (2011). Sustainability ranking and improvement of countries, .*Ecological Economics*, Volume 70, Issue 3, 15 January 2011, pp. 542-553.

Singh, R.K., Murty, H.R., Gupta, S.K. and Dikshit, A.K. (2009). An overview of sustainability assessment methodologies, *Ecological Indicators* 9 (2009), pp. 189 – 212.

Winograd, M. (2007). Sustainability and vulnerability indicators for decision making: lessons learned from Honduras, *International Journal of Sustainable Development*, Vol. 10, Nos. 1-2