A Decision Support System based on Multi-criteria Analysis for the selection of Urban Sustainability Scenarios

AUTORI:
Giorgio Beccali
Maurizio Cellura
Marina Mistretta

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INDICATORS AND INDEX

- In general, indicators describe complex phenomena in a quantitative way by simplifying them in such a way that communication is possible with specific target groups.

- Indicators can be seen as succinct expressions of information or as tool to deliver information to decision makers in a useable, understandable form.
- Ideally, an indicators framework provides an overview for considering environmental problems and the associated interconnections between them.
- Desirable characteristics of indicators include: quality of data and data collection; sensitivity to human-induced variations in space and time; policy relevance with a scientific base; recognizability and clarity.

INDICATORS AND INDEX

- Most models do not include the next logical step, i.e. addressing the balancing of pros and cons of possible impacts in order to reach a decision related to given policies or assessment objectives.
- This latter function is usually left for the political process, which often means that all information about possible impacts is processed informally in the mind of those individuals making the decision.
- This is the unique point where environmental indicators and indices can be particularly beneficial-that is, by reducing complexity.
- It is clear that environmental indicators and indices are important tools for converting quantities of environmental data and output of environmental models into succinct information that can be readily understood and used by decision-makers and the general public.

GOALS

- *A mathematical model to assess the whole environmental performance of urban systems and to control the developing trends towards sustainability*
- *definition of a synthetic index, called Index of Urban Sustainability (USI), determined by means of suitable processes of aggregation and weighting of some selected indicators.*
- *employment of USI in decisional processes on sustainability management at an urban level in order to aid to define suitable developing plans (Forum of Agenda XXI)*

TASK FULFILLED BY *USI*

- To describe the current status and the developing trend of the system in study, by means the analysis of its main components and cause-effect relationships among sequential events;
- To support the definition of quality targets and of environmental management objectives and strategies;
- To help inform and educate the public about the environmental situation;
- To support multi-attribute decisional procedures in the assignment of priority among the available alternatives.

METHODOLOGY

- Selection of representative indicators, as a reliable informative "corpus" and a dynamic and controllable tool to select the available options in decision-making processes.
- Normalization of indicators, by means of suitable value functions.
- Assignment of weights to each indicator
- Aggregation of normalized indicators in a sub-index, SI_k for each field examined
- Aggregation of all the sub-indices in *USI*
- Definition of the hierarchical priority among the options to be compared
- Sensitivity analysis to test the reliability of the performed choice and to determine the effects caused by input variation on *USI*.

METHODOLOGY

There is a possibility to choose any kind of field and/or indicators referring to preference of decision makers

Definitions of value functions:

Assumption:

- **Range of Normalization: [0, 1]**
- **0 and 1 represent respectively the minimum and maximum values of the normalised indicator.**
- **Attributes are assumed to be independent, so that it is possible to apply additive value functions.**
- **The shape of a value function doesn't depend on the min-max range of the selected parameter.**

METHODOLOGY

Weightings

Analytical hierarchy process methodology

- The local actors will express a judgement on the relative importance of each pair of attributes x_1, x_2,... x_n.
- If w_1,...,w_i,...,w_n are the unknown weights to be assigned to n attributes of the i^{th} fields, so that

$$\sum_{i=1}^{n} w_i = 1$$

the following quantities are guessed:

$$a_{ij} = \frac{w_i}{w_j} \qquad i = 1,\ldots, n\text{-}1 \text{ and } j = i\text{+}1,\ldots, n.$$

METHODOLOGY

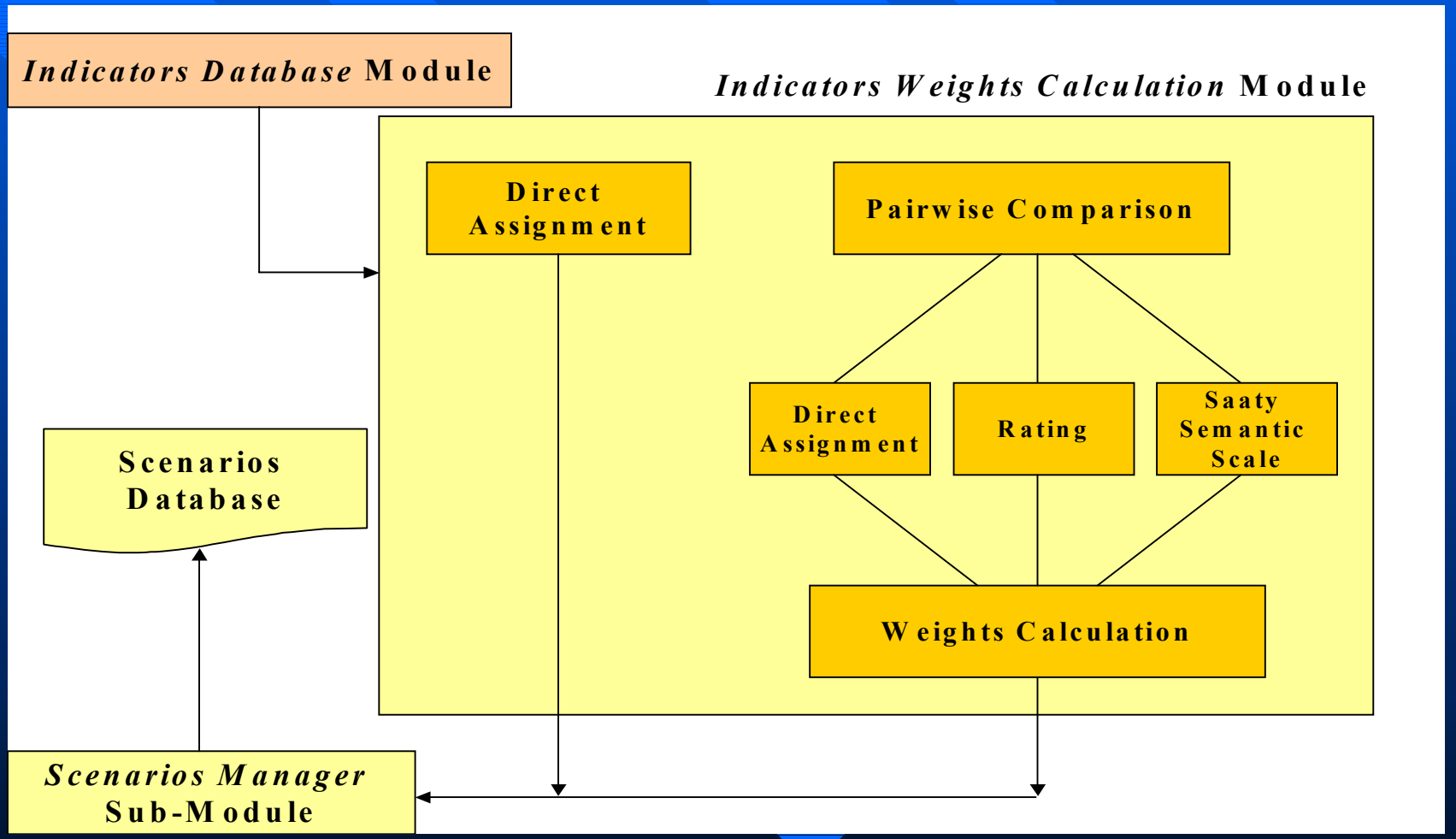


Figure 1. Indicators Weights Calculation Module

METHODOLOGY

Scale of the Relative Preference

DEFINITION	a_{ij}
Equally important	1
* intermediate value *	2
Weakly more important	3
* intermediate value *	4
More important	5
* intermediate value *	6
Much more important	7
* intermediate value *	8
Absolutely more important	9

METHODOLOGY

Aggregation of the criteria $VF(x_i)$:

- **The sub-index Si_k corresponding to the k^{th} field is computed by aggregation of the criteria $VF(x_1)$,... $VF(x_i)$,... $VF(x_n)$:**

$$SI_k = \sum_{i=1}^{n} w_i VF_{iSI_k}(x_i)$$

- **n is the number of the selected indicators;**
- **w_i is the weight assigned to the i^{th} indicator of the k^{th} field;**
- **$VF_{iSIk}(x_i)$ is the value function corresponding to the i^{th} indicator of the k^{th} field;**
- **x_i is the value of the raw indicator.**

METHODOLOGY

Aggregation of the *m* sub-indices Si_k

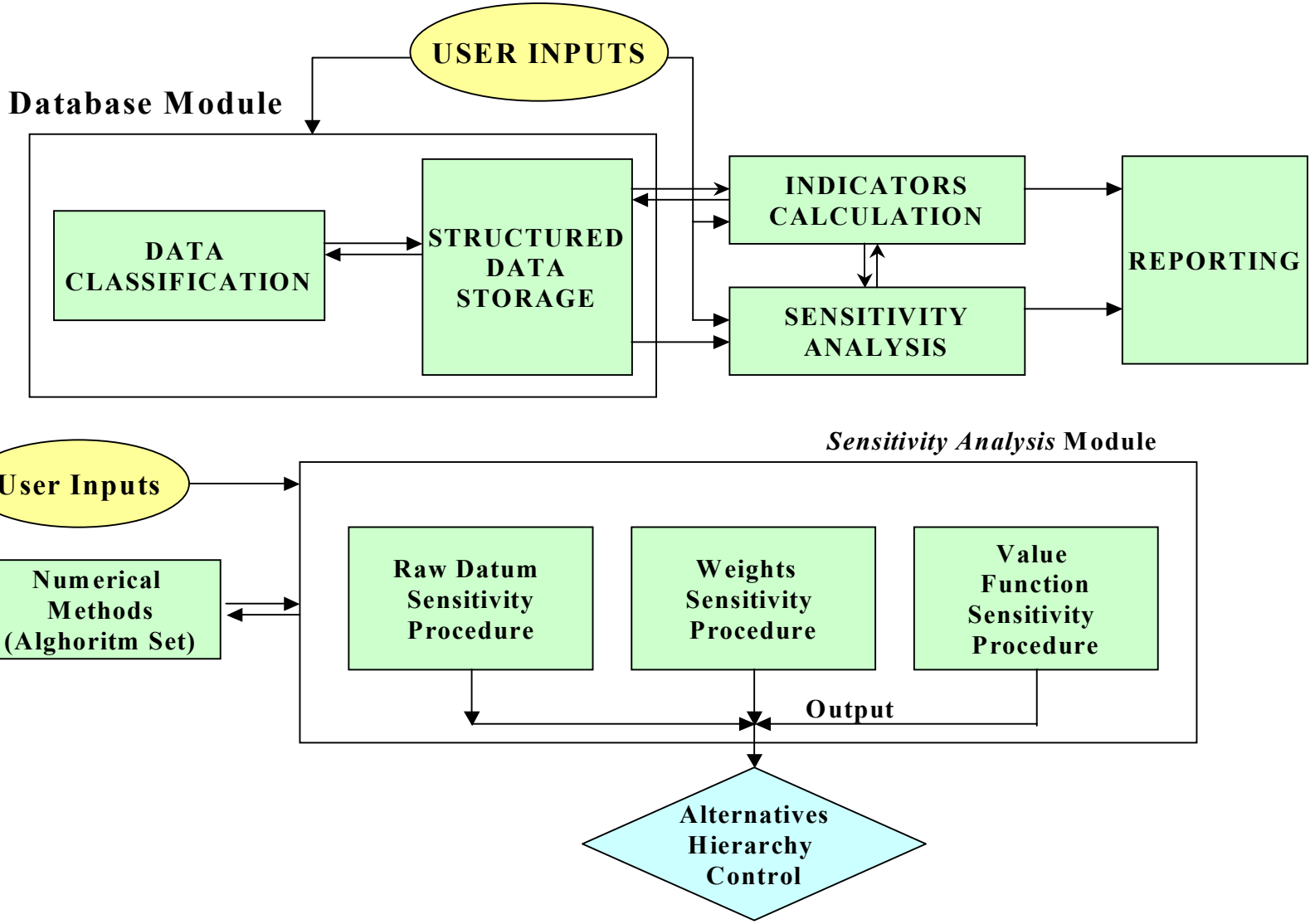
$$USI = \sum_{k=1}^{m} w_{SI_k} SI_k$$

- ***USI*** **is the final index of urban sustainability**
- w_{SIk} **is the weight to assign to the** k^{th} **sub-index**
- SI_k **is the sub-index corresponding to the** k^{th} **field.**
- **If** θ_α e θ_β **are two generic management alternatives in comparison**

$$USI_\alpha > USI_\beta \Rightarrow \theta_\alpha \succ \theta_\beta$$

SENSITIVITY ANALYSIS

- *USI* score is conditioned by the following factors:
- Weights of attributes
- Shape of *vf* for each attribute
- Uncertainty on input data
- Since the model has a linear structure, the effects of above factors can be estimated independently.



Sensitivity Analysis Module

CASE STUDY

At the moment the proposed model is applied to carry out a pilot experience in Palermo.

Steps of research activity:

- Constitution a dynamic database on material, energetic and ecological flows in order to characterize the urban ecosystem examined and to set up an observatory;
- Definition of synthetic index to describe energetic and environmental profile of the ecosystem;
- Analysis of historical events and definition of the predicting scenarios;
- Guidelines for carrying out eco-balance;
- Modelling sustainability isles.

CASE STUDY

By looking at MSW management, the following aspects must be pointed out in the definition of level hierarchy:

- MSW are a relevant pollution source if they are dumped unselected in landfill;
- MSW represent secondary resources, if sorted collection and recycling are performed, resulting in a savings of virgin materials;
- MSW represent renewable resources if thermal treatment and recovery of energy occur before the final disposal.

CASE STUDY

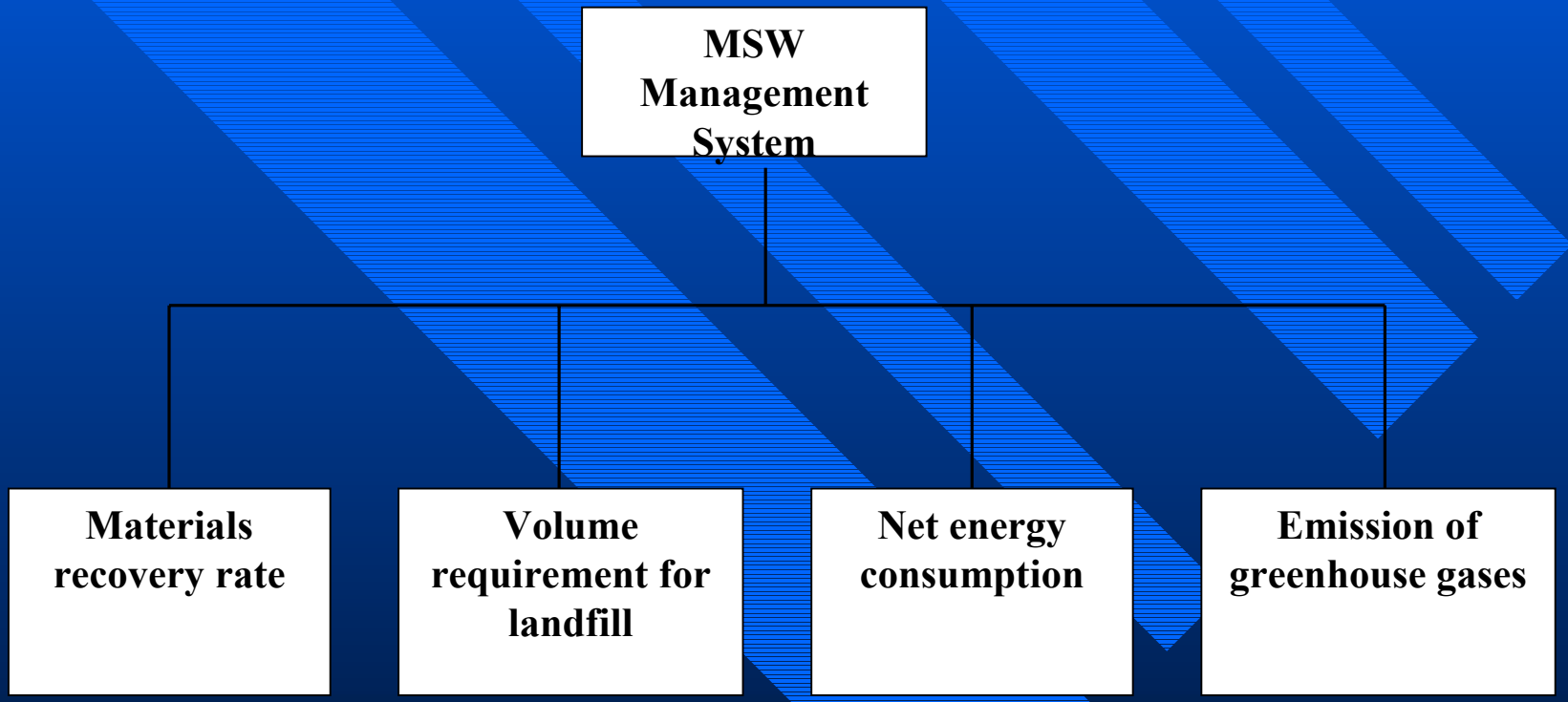
Sustainability indicators

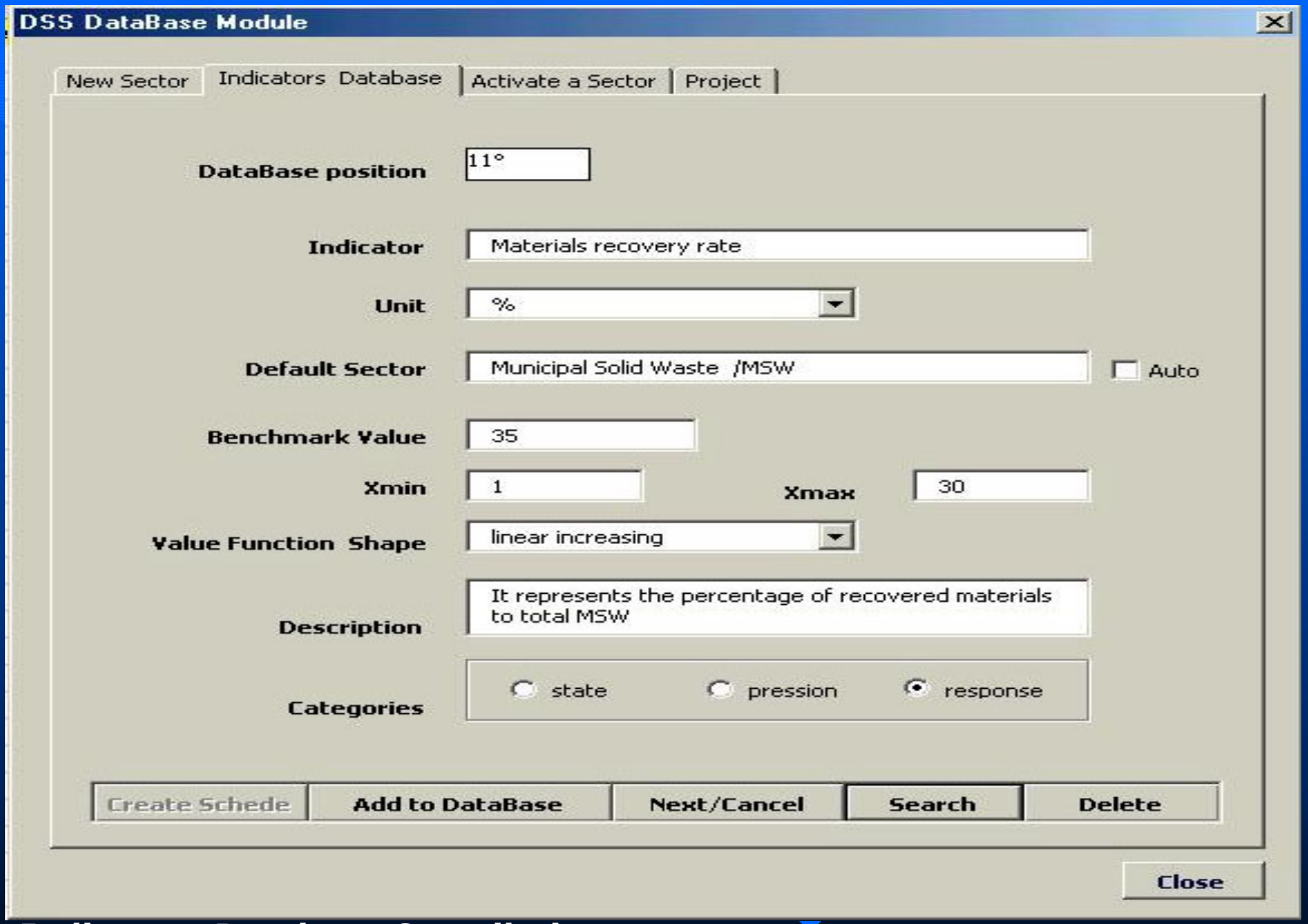
- **materials recovery rate x_1;**
- **volume requirement for landfill x_2;**
- **net energy consumption by the management system x_3;**
- **emission of greenhouse gases by the management system x_4.**

Data are derived by applying life cycle analysis of local MSW.

The selected indicators have been calculated for all the different alternatives of management assumed for the examined city

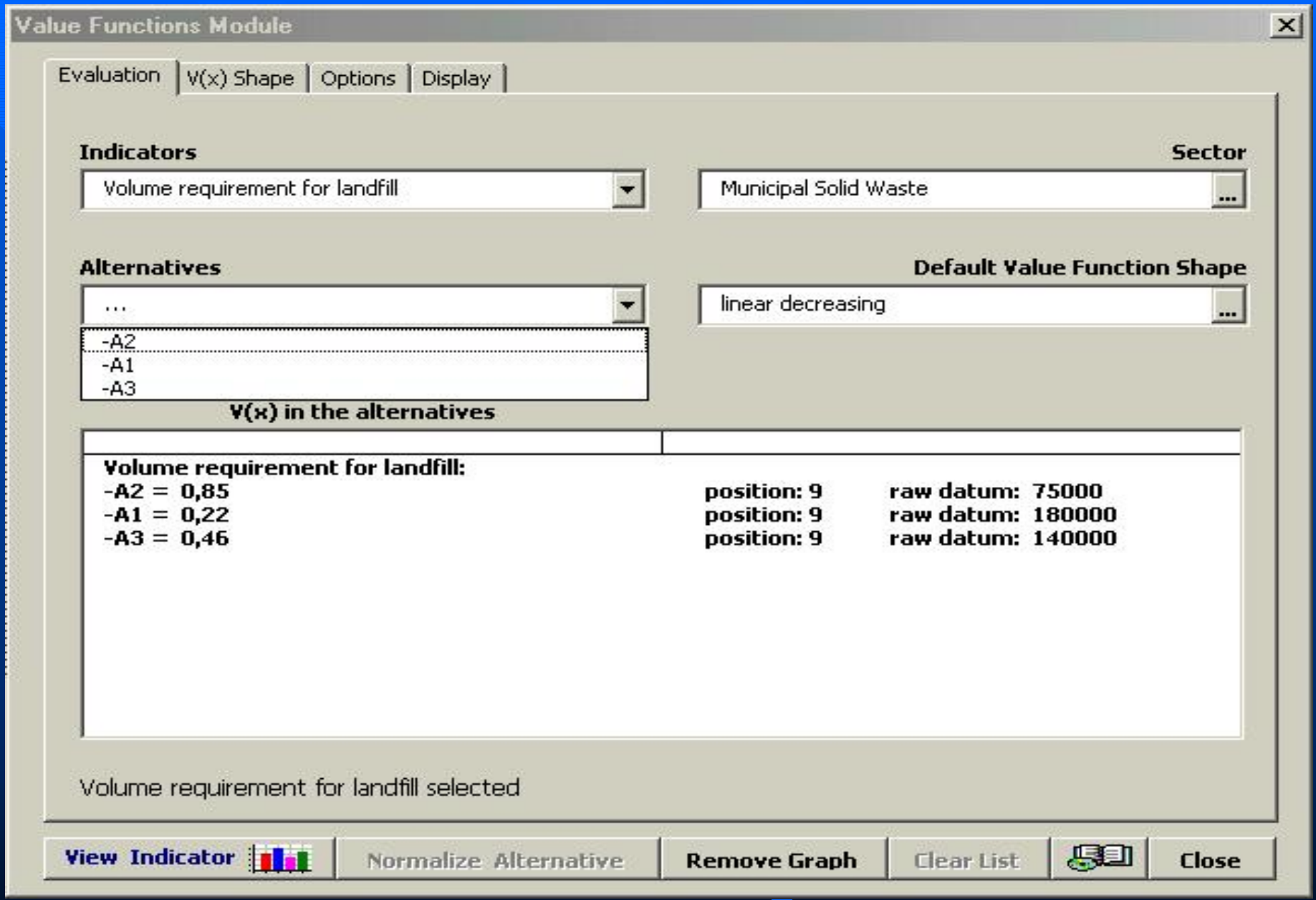
CASE STUDY


MSW Management System
Materials recovery rate
Volume requirement for landfill
Net energy consumption
Emission of greenhouse gases



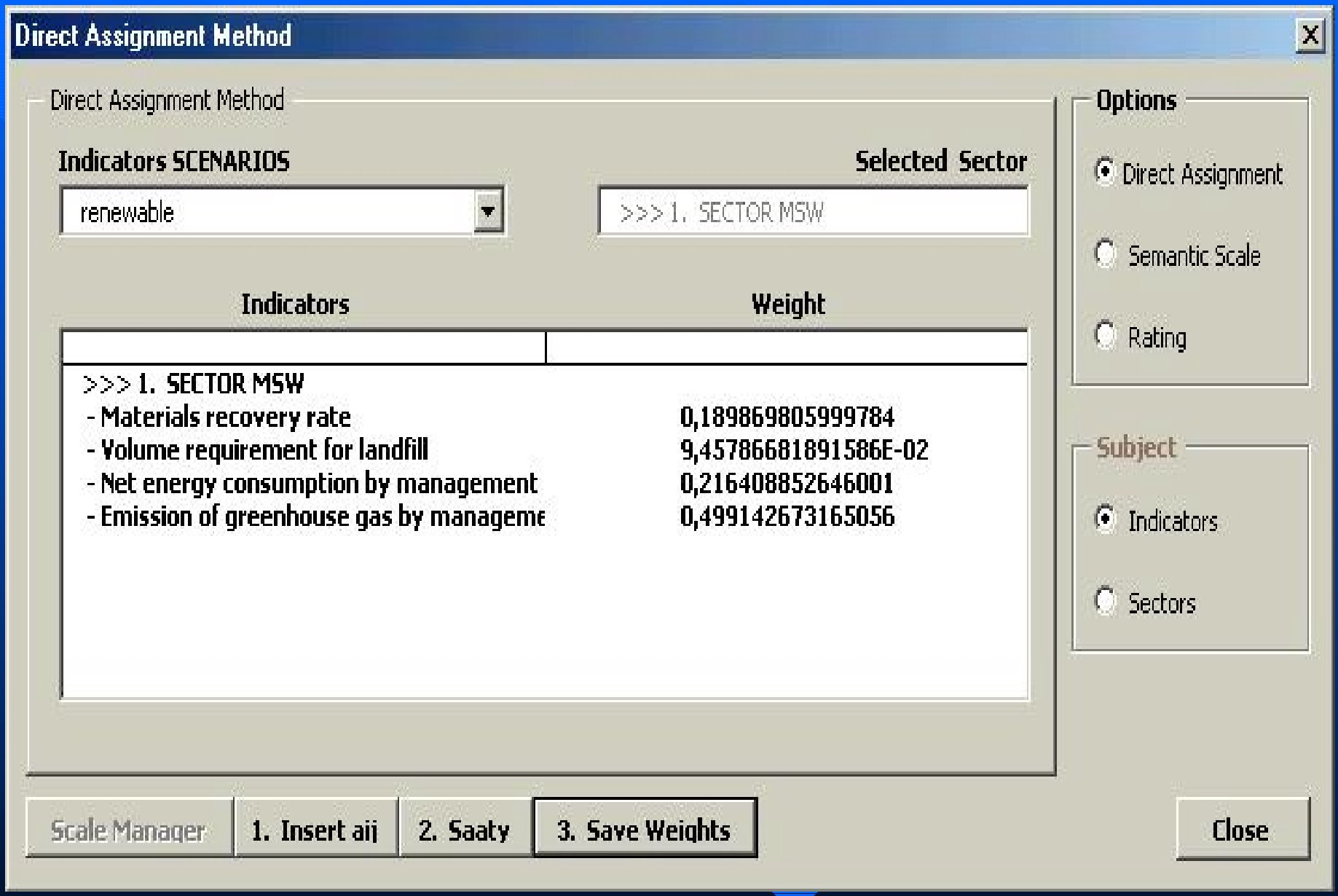
Indicators Database Compilation

- RIO 02, World Climate & Energy, January, 6-11 2001



Assignment of value $V_i(x_{i,t})$ to the raw datum $x_{i,}$

- **RIO 02, World Climate & Energy, January, 6-11 2001**



Application of Direct Assignment Method in the AHP Procedure for the weights calculation.

CASE STUDY

- Optional multiattribute profiles:
- Option A_1, which represents the current municipal waste management system in Palermo. It is essentially characterised by disposal in landfill, without remarkable selection or recovery.
- Option A_2, which is an hypothesis of integrated management system with sorted collection, assumed up to 35% of total waste, and recovery of energy by thermal treatment [Italian Legislative Decree 1997, February 5-N.22].
- Option A_3, in which sorted collection is increased up to 50% of total waste, but thermal treatment is not included and biological treatment is assumed to produce quality compost.

CASE STUDY

- ***Multiattribute profiles in the three decision alternatives compared.***

	A_1	A_2	A_3
x_1 [%]	1,2	22,3	27,4
x_2 [m^3/y]	$18 \cdot 10^4$	$7,5 \cdot 10^4$	$14 \cdot 10^4$
x_3 [GJ/y]	$1,8 \cdot 10^3$	$-18 \cdot 10^5$	$-6,1 \cdot 10^5$
x_4 [tonCO_{2eq}/y]	$4,4 \cdot 10^8$	$1,66 \cdot 10^8$	$1,47 \cdot 10^8$

- **since data derive from LCA, the minus sign means a saving of energy**

RESULTS

- For each indicator:
- The raw datum $x_i \rightarrow VF_{iw}(x_i)$ in the range [0,1].
- To fix a range of variation of x_i $[x_{i,MIN}, x_i, x_{i,MAX}]$, where $x_{i,MIN}$ and x_i, $x_{i,MAX}$ are, respectively, the minimum score and the maximum score for the indicator x_i;
- To indicate that $VF_{i,w}(x_i)$ is decreasing or increasing with argument x_i increasing
- To choose the exponent of $VF_{i,w}(x_i)$.

RESULTS

- **For the α^{th} alternative:**

$$SI_W^{(\alpha)} = \sum_{i=1}^{n} w_i VF_{i,W}(x_i)$$

- ***SI*$_w$ is computed as index of contribution of individual criteria to the sustainability assessment in MSW management system.**

Options	VF_1	VF_2	VF_3	VF_4	$SI_W^{(d)}$	$SI_W^{(w)}$
A_1	0.106	0.22	0.101	0.388	0.243	0.229
A_2	0.761	0.85	0.910	0.881	0.851	0.863
A_3	0.919	0.46	0.376	0.915	0.668	0.709

RESULTS

- For the α^{th} alternative:
- Default Scenario $SI_W^{(d)}$
- $w_1 = w_2 = w_3 = w_4$
- No information is available about preference on criteria and admissible weight coefficients
- Scenario with ordinal information about weights $SI_W^{(w)}$ $w_4 > w_3 > w_1 > w_2$
- The user can modify them during the interactive procedure, always referring to the condition that their sum has to be equal to 1. He has to pay attention to use always the same weights in the same decisional process of comparison among different alternatives in order to avoid inconsistent eco-hierarchies among such alternatives.

RESULTS

considerations

- current local management is absolutely defaulting:
- integrated management alternatives appear as sustainable strategies of reducing environmental releases and using MSW as alternative resources
- $VF_{4,A2}(x_4)= 0.881$
- $VF_{4,A3}(x_4)= 0.915$
- Since the indicator x_4 is assumed as the most important (according to the critical issue of Kyoto protocol), there isn't a very great difference between $SI_W^{(A2)}$ e $SI_W^{(A3)}$. Changing the ordinal preference between indicators, SI_W takes on different scores in the sustainability assessment of the compared options.

CONCLUSIONS

- far from defining a circumstantial and unchangeable corpus of sustainability indicators, the proposed model represents a flexible decision support system for local actors (the *Forum* of the Agenda XXI), as tool of:
- analysis of the current environmental state in urban context
- prediction according to management options assumed;
- decision-making support in the selection of the eco-sustainable options q_i;