A Decision Support System Software based on Multi-Criteria Analysis for the Selection of Urban Sustainability Scenarios

Maurizio Cellura, Giorgio Beccali, Marina Mistretta
Dipartimento di Energetica e Applicazioni di Fisica
Palermo University
Viale delle Scienze, 90128 Palermo
ITALY
Presenting Author's e-mail: mcellura@deaf.unipa.it
Web-page: www.deaf.unipa.it

Abstract

A correct technical approach to the innovative issues introduced by Agenda 21, requires innovative scientific tools able to analyze the current environmental profile of urban ecosystems and, at the same time, to start processes of energetic and environmental optimization, with regard to community daily needs and opportunities.
In the context of complex urban dynamics, data are necessary in policy making to provide objective measures of conditions and trends and to rethink ineffective strategies, but often the existing ones are inappropriate, inaccurate, incomplete or not consistent for specific purposes. There is a need to build collect useful and representative information on conditions and trends of the urban components, to translate such information to knowledge through appropriate analytic techniques and to apply that knowledge as retrofitting actions.
The aim of the present paper is to define a mathematical model to assess the whole environmental performance of urban systems and to control the developing trends towards sustainability, in consequence to different scenarios of human management. A user-friendly software is developed, as a decision support system for policy makers in the multi-criteria selection among different planning and management options.

1. INTRODUCTION

Sustainability goals involve the introduction of innovative scientific tools, in order to analyze the current urban factors and to optimize the energetic and environmental profile of urban systems, with regard to carrying capacity and territorial needs and vocations. In such context, it is necessary to introduce new methods and new informative systems for decision-makers, in order to express global effect of environmental management options in a synthetic way (Beccali *et al.*, 2001b).
As the Action Plan of Agenda 21 clearly suggests, an important precondition for the transformation of the guiding principle of sustainable development into practical environmental policy is the availability of indicators. In fact, indicators are synthetic and dynamic tools, which provide representative information about the environmental quality to decision-making (Schultink, 1992).
Addressing these needs requires two main elements: (1) public availability of transparent data; and (2) availability of interactive software designed to make easier exploration of data, models and results.
According to the previous tasks the Authors have started a research with the following aims:

- Definition of a Multi-criteria Decision Support System for the scenarios selection oriented to the urban sustainability. It represents a flexible model, which can address decision-makers to select suitable types and numbers of parameters according to the fixed objectives;
- A user-friendly software, as an operative tool of the decision support system (DSS) for the accomplishment of Agenda 21 and the planning of sustainable development strategies.

1.1 A brief description of DSS and the methodology employed

Data are necessary in policy making to provide objective measures of conditions and trends and to rethink ineffective strategies, but often the existing ones are inappropriate, inaccurate, incomplete or not inconsistent for peculiar purposes (Hardi & DeSouza-Huteley, 2000).

The complex collection and processing of the needed information on urban ecosystem and its energy and material flows require the definition of synthetic indices, which can exhaustively describe the environmental profile referring to the available scenarios. An urban sustainability index, which is based on dynamic and consistent models, could represent a useful predicting tool to assess the urban developing trend, and to aid decision-makers to select environmentally oriented strategies.

The proposed model defines a synthetic index, called as Urban Sustainability Index (USI), which is carried out by means of suitable processes of aggregation and weighting of some selected indicators.

In details, model framework can be divided in the following steps:

- Urban indicators database compilation according to the most common classification methodologies;
- Value Functions definition and assignment of quality levels to raw data. In particular, the score x_i of the chosen indicator is transferred to a proper unvarying scale, through suitable value functions $V_i(x_i)$;
- Assignment of weights to each $V_i(x_i)$, depending on its importance in the belonging environmental sector.
- Aggregation of weighted indicators in a sub-index SI_k, for each k^{th} sector;
- Assignment of weights to each SI_k;
- Aggregation of all the sub-indices in USI, for each alternative;
- Definition of the hierarchical priority among the options to be compared, that is a comparison among their different USI values;
- Sensitivity analysis to test the reliability of the performed choice and to determine the effects caused by input variation on USI. It controls the modification on USI, caused by a change of uncertainty parameters, such as indicators raw data, value function shape, indicators weights, value ranges, etc. It doesn't provide final and absolute results on sustainable development issue, but it aims to give the opportunity to compare different scenarios and identify the one that fulfils the sustainability goal, by varying the fundamental parameters of the examined process.

According to the previous requirements, the presented DSS is designed with the following characteristics:

1. Flexibility and expansibility;
2. Transparency;
3. Dynamic Database;
4. Capacity to be transferable in every urban context, as a support system for the accomplishment of Agenda 21.

The *DSS* model is a software system, characterized by a structural framework of mutually interacted modules. Each module, as a set of assembled types, data structures, procedures and algorithms, is a software sub-system, which contains and provides calculation resources and functions.

The main goal of the software is to provide a support tool to the management of sustainability at an urban level, in order to assess the whole environmental performance of urban systems and to control the developing trends towards sustainability, according to the policy options to be compared.

1.2 USI calculation

For each indicator a value function is defined according the following steps:

- Definition of the compared alternatives set **A**. Each alternative A_t is described by the vector $\mathbf{USI}_t$ that is function of $(SI_1,...SI_k,...SI_m)$, where m is the number of environmental sectors, which assemble the selected indicators, and SI_k represents the performance of A_t on the k^{th} sector;

- Selection of the significance range of each indicator referring to the available raw data x_i [$x_{i,min}$, $x_{i,max}$, i = 1,…,n_k];
- Definition $V_i(x_i)$ shape and its trend, convexity or concavity;
- Assignment of $V_i(x_i)$ to x_i: $x_i \rightarrow V_i(x_i)$ $\forall$ $x_i \in [x_{i,min}, x_{i,max}]$ e $V_i(x_i) \in [0,1]$;
- Consistence control for the obtained outcomes.

$V_i(x_i)=0$ and $V_i(x_i)=1$ are respectively the minimum and the maximum values, or quality levels, of the examined indicator and represent, respectively, the worst and the best values which x_i could be assumed. For sake of simplicity, attributes are assumed independent, so that an additive model can be applied to values $V_i(x_i)$. It follows that:

$$SI_k = \sum_{i=1}^{n} w_i V_{i,k}(x_i) \quad (1)$$

where:

- SI_k is the sub-index of k^{th} sectors C_k;
- n is the number of indicators belonging to the sector C_k;
- w_i is the weight to attribute to the i^{th} indicator of the k^{th} sector so that $\sum_{i=1}^{n} w_i = 1$. The Analytical Hierarchy Process is used (Saaty, 1990);
- $V_{i,k}(x_i)$ is the value function corresponding to the i^{th} indicator of the k^{th} field, $\forall x_i \in [x_{i,min}, x_{i,max}]$ $V_{i,k}(x_i) \in [0,1; 1]$;
- x_i is the raw datum of the i^{th} indicator in C_k.

The above procedure is extended to all sectors C_k and the following set **S** is obtained:

$$\mathbf{S} = \left\{ \mathbf{SI_k} : \quad SI_k = \sum_{i=1}^{n} w_i \cdot V_{i,k}(x_i); \quad k = 1,....m \right\} \quad (2)$$

Figure 1 shows the calculation module of weights, which is applied both for $V_i(x_i)$ and SI_k.
The aggregation model is applied to each alternative A_t. Therefore, $\forall A_t$ the m sub-indices SI_k can be aggregated to obtain USI:

$$USI_t = \sum_{k=1}^{m} w_k SI_k \quad (3)$$

where:

- USI_t is the final index of urban sustainability;
- w_k is the weight to assign to the k^{th} sub-index.
- SI_k is the sub-index corresponding to the k^{th} field.

The assignment of weights w_k is similar to the procedure applied for w_i (Figure 1). USI_t is calculated for each alternative, so that a decisional hierarchy among different A_t values is obtained.
Decision-maker can express his preference judgment on the alternative A_t, by selecting the USI_t which:

$$USI_t = \max \left\{ USI_t : USI_t = \sum_{k=1}^{m} {}_t w_k SI_k \right\} \quad (4)$$

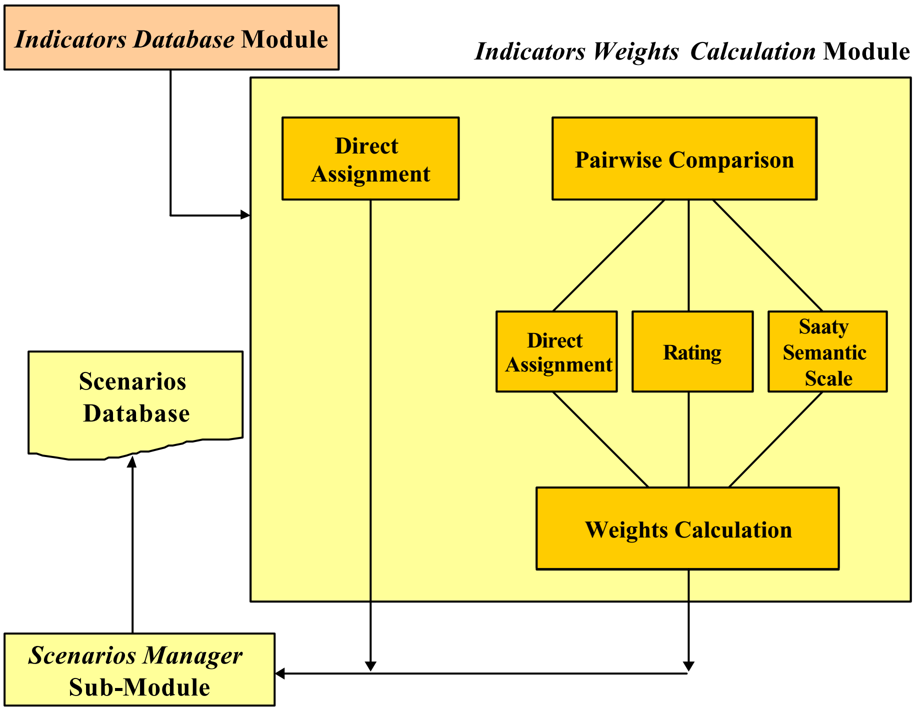

Figure 1. Indicators Weights Calculation Module

USI_t score is conditioned by the following factors:

- Uncertainty on raw data;
- Weights of attributes;
- Shape of V(x) for each attribute.

The proposed model allows carrying out a sensitivity analysis of previous factors and defines the corresponding variation of SI_k and USI for each of them (Figure 2).

Since the model has a linear structure, the effects of above factors can be estimated independently.

With regard to input data, uncertainty produces a variation in their value, expressed as range of confidence. The variation of USI, due to a modification on i^{th} attribute is given by the following equation:

$$\Delta USI_{i,t} = w_k \cdot w_i \Delta V_{i,k}(x_{i,t}) \tag{5}$$

The influence of i^{th} weight is given by the following range of USI values:

$$\left[USI\left(w_1 + \frac{\Delta w_i}{n-1},\ldots,w_i - \Delta w_i,\ldots,w_n + \frac{\Delta w_i}{n-1}\right); USI\left(w_1 - \frac{\Delta w_i}{n-1},\ldots,w_i + \Delta w_i,\ldots,w_n - \frac{\Delta w_i}{n-1}\right)\right] \tag{6}$$

The expert fixes can modify w_i inside a fixed range, while the other weights are decreased and increased by the same quantity in order to maintain their sum equal to 1. Then, USI has to be computed again.

The V(x) effect on USI_t is estimated by modifying the function shape of the selected attribute – in this particular case from linear to quadratic and vice versa – and by controlling the corresponding variation of *USI*. In the above cases, the model provides the oscillation range of USI_t, expressed in comparison with the primary value.

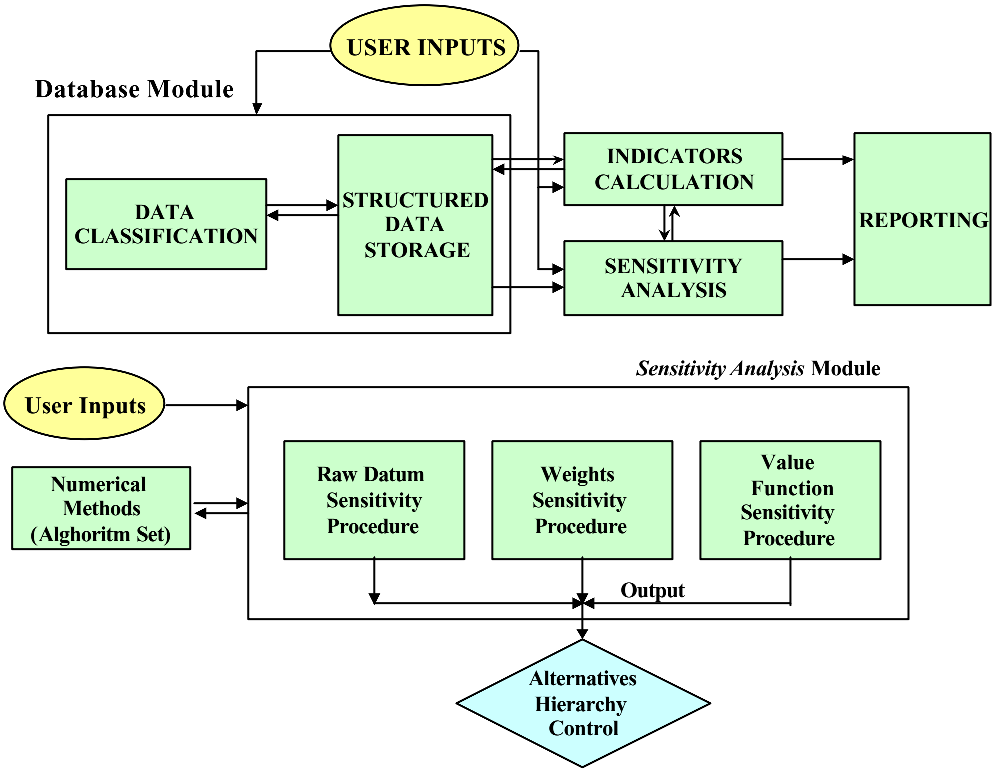

Figure 2. Sensitivity Analysis Module

1.3 DSS Software

The software user has to give the following inputs:

- Environmental sectors, that is energy consumption, waste management, urban mobility, etc.;
- Database construction: the user inserts the selected indicators and assigns them to the corresponding sector;
- Definition of the decisional alternatives set;
- Values function properties assignment to each indicator, such as shape, concavity or convexity; the equation of a linear increasing function is:

$$V_i(x_i) = 0,9 \cdot \frac{x_i - x_{i,min}}{x_{i,max} - x_{i,min}} + 0,1 \qquad (7)$$

while for the decreasing function, the equation results:

$$V_i(x_i) = 0,9 \cdot \frac{x_{i,max} - x_i}{x_{i,max} - x_{i,min}} + 0,1 \qquad (8)$$

For not linear value function, two numerical methods are employed to obtain the optimal function that is suitable to available experimental data: (1) Last Squares Method; (2) Lagrange Polynomials Method.

- Direct assignment of w_i and w_k , respectively, to $V(x_i)$ and SI_k, or direct assignment of Saaty matrix elements.

The dynamic structure of indicators database provides the following opportunities:

1. to update the qualitative and quantitative information for the indicators included in the database;

2. to extend or reduce both sectors number and indicators number for each them;
3. to modify the goals of the decisional process and/or the compared alternatives number.

1.4 Case study

The DSS previously shown is applied in the urban context of Palermo, where some suitable indicators are selected to define the energetic and environmental components and the developing trend of urban ecosystem, according to the following items: (1) Consumption of energy; (2) Municipal solid waste management; (3) Water consumption; (4) Mobility;(5) Urban structure. In each sectors the sustainability indicators are defined reflecting specific criteria. Particular attention is devoted to the resource and the environmental aspects. By looking at one particular sector proposed, for example MSW management, the following independent indicators are taken into a consideration for a set of three optional multiattribute profiles: (1) materials recovery rate x_1; (2) volume requirement for landfill x_2; (3) net energy consumption by the management system x_3; and (4) emission of greenhouse gases by the management system x_4. We have derived data by applying life cycle analysis of local MSW (Beccali *et al.*, 2001a). Table 1 shown the outcomes obtained by applying *DSS* software in the MSW sector. A_1, A_2 and A_3 represent three different optional multiattribute profiles. In particular:

- Option A_1 represents the current management system of municipal solid waste in Palermo, essentially characterized by disposal in landfill, without remarkable selection or recovery.
- Option A_2 is a hypothesis of integrated management system with sorted collection, assumed up to 35% of total waste, and recovery of energy by thermal treatment.
- Option A_3 is characterized by an increased sorted collection up to 50% of total waste, but thermal treatment is not included and biological treatment is assumed to produce quality compost.

The values of attributes in the range [0,1] suggest that the two integrated management alternatives A_2 and A_3 appear as sustainable strategies of reducing environmental releases and using municipal waste as alternative resources (Figure 4). Figure 5 shows the outcomes of weighting procedure, by applying the pairwise comparison to the indicators. By assuming that all weighting factors are equal to 0,25, that is the default scenario, it means that there isn't any numerical information about mutual relation among the weighting factors. In the analysis of the effect of individual criteria on the general index of urban sustainability, the following scenario is taken into consideration about the relationship among the weights on the decision-making process: $w_4 > w_3 > w_1 > w_2$ we have an ordinal information about weights of indicators.

1.5 Conclusions

USI, proposed in the paper, is obtained as flexible tool of multi-criteria selection, to define sustainability management scenarios at an urban scale and to choose those alternatives, which are more suitable to fulfil the goal of *Forum* local actors (Agenda 21). It can represent a tool of:

- Synthetic and exhaustive information, able to express the environmental profile of urban ecosystems and the corresponding developing trend, overloading the limit of the traditional sectorial indices;
- Addressing the decision-making processes. In fact it provides a useful and reliable help to definition of predicting scenarios of sustainability.

Therefore, the USIs can be usefully employed to analyze the developing trends of urban ecosystems and to plan sustainable development strategies, as tools of:

- analysis of the current environmental state in urban context;
- prediction, according to management scenarios assumed;
- decision-making support in the selection of the eco-sustainable options A_t.

Far from defining a circumstantial and unchangeable corpus of sustainability indicators, the proposed model represents a dynamic and transferable method, since it can be employed in any urban context, as support tools for the accomplishment of Agenda 21.

Table 1. Aggregation Outcomes for the Three Multiattribute Profiles Compared in MSW sector.

Options	$V_1(x_1)$	$V_2(x_2)$	$V_2(x_3)$	$V_2(x_4)$	SI_{MSW} ($w_1 = w_2 = w_3 = w_4$)	SI_{MSW} ($w_4 > w_3 > w_1 > w_2$)
A_1	0.1062	0.22	0.1008	0.388	0.243	0.229
A_2	0.7610	0.85	0.9102	0.881	0.851	0.863
A_3	0.9193	0.46	0.3756	0.915	0.668	0.709

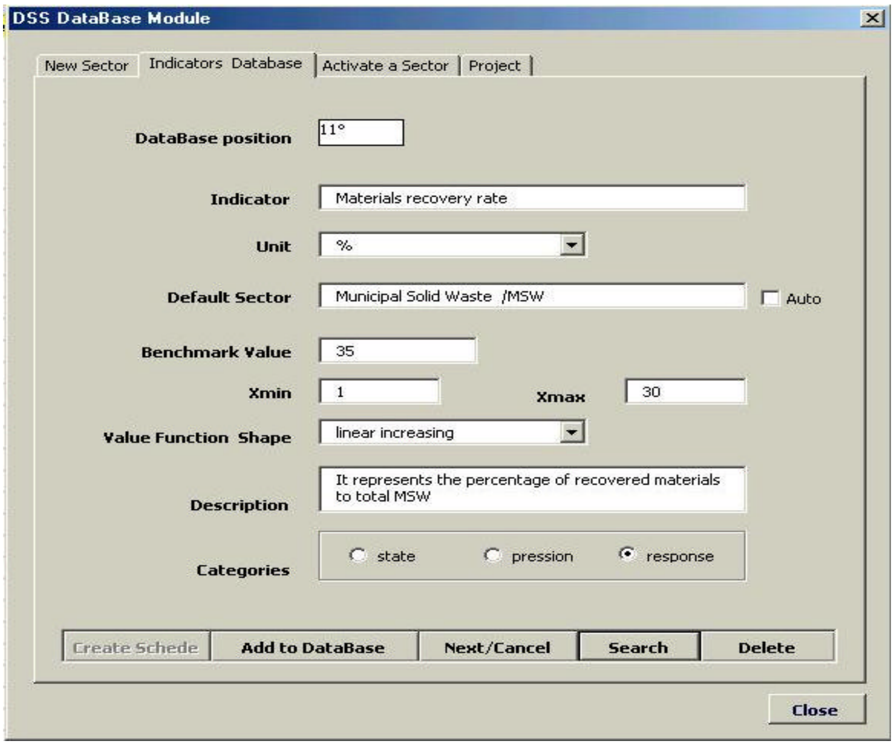

Figure 3. Indicators Database compilation

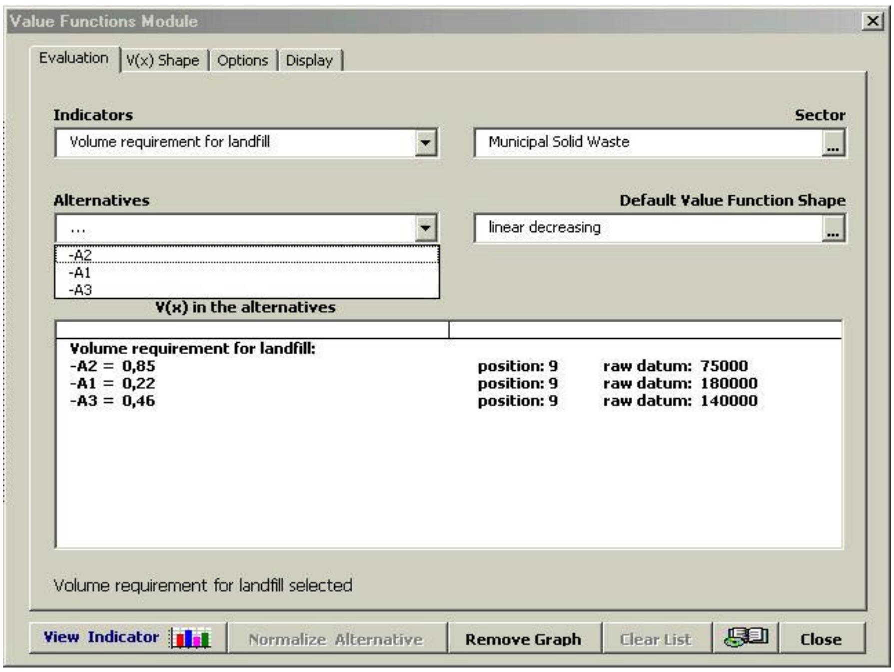

Figure 4. Assignment of value $V_i(x_{i,t})$ to the raw datum $x_{i,t}$.

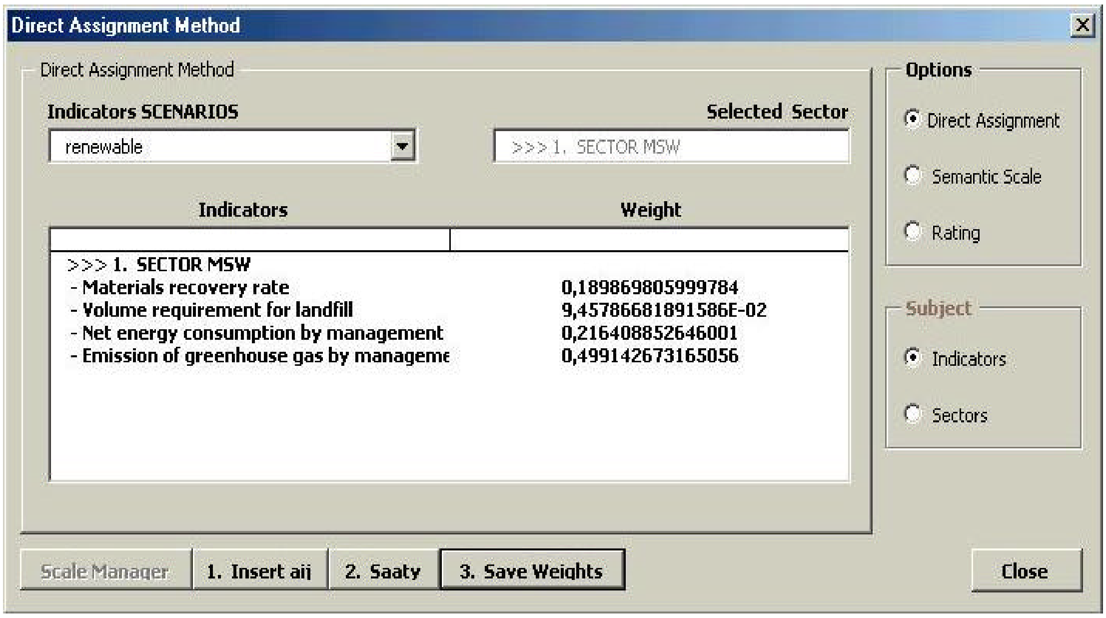

Figure 5. Application of Direct Assignment Method in the AHP Procedure for the weights calculation.

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