Multi-Criteria Evaluation

Overview

Decision making on alternatives for risk reduction planning starts with an intelligence phase for recognition of the decision problems and identifying the objectives. Development of the alternatives and assigning the variable by decision makers to each alternative are employed to the design phase. The final phase evaluates the optimal choice by comparing the alternatives, defining indicators, assigning a weight to each and ranking them [4]. This process is referred to as Multi-Criteria Decision Making analysis (MCDM), Multi-Criteria Evaluation (MCE) or Multi-Criteria Analysis (MCA). MCDM is performed by choice and prioritization and is defined based on Alternative, Value, Criteria and the Weights on the Criteria. MCDM can be classified as Multi Objective Decision Making (MODM) and Multi Attribute Decision Making (MADM). Sometimes it can be referred to as Single or Group decision making and be based on these methods, and it can be achieved by certainty or uncertainty [1]. Malczewski [2] stated that the most projects using MCDM are based on single decision making. Nevertheless, group decision will give us benefits in the SDSS. It depends if each group has different choices of decisions [3]. The MCDM module is implemented for Multi-Criteria Decision Making analysis (MCDM) incorporating monetary and non-monetary criteria in the analysis for the optimal alternative. The MCDM module consists of several components. The first step is to define criteria (or Indicators) which are subdivided into disadvantages (criteria that indicate the difficulty for implementing the risk reduction strategy, also referred to as costs) and advantages (criteria that indicate the favourability, also referred to as benefits). In the next step the stakeholders can use the developed web-based tool for prioritizing criteria and setting up the decision matrix

MCE methods

There are many methods available for MCDM. These methods can be divided to deterministic, fuzzy and stochastic. When there is certainty in the alternatives, we go for deterministic and if uncertainty is apparent, fuzzy and stochastic models are useful. MCDM are introduced by different methods like [1] Weighted sum Model (WSM), Weighted Product Model (WPM), Analytic hierarchy process (AHP), Revised AHP, Elimination and Choice Translating Reality (ELECTRE), TOPSIS (for the Technique for Order Preference by Similarity to Ideal Solution) etc. The SDSS applies the most common and easiest way of MCDM known as WSM. In a later version of the SDSS, we might integrate TOPSIS and Fuzzy methods to the study and compare the results. The output of the Cost Benefit Analysis and the Risk Analysis will be used for the Multi-Criteria decision making and for comparison between alternatives.

$$A_i^{\text{WSM-score}} = \sum_{j=1}^{n} w_j a_{ij}, \text{ for } i = 1, 2, 3, \ldots, m.$$

Figure 1 WSM: w is weight and a is value for each criteria

PROBLEM DEFINITION

A multi-criteria decision problem can be defined by the set of alternatives (or other objectives) that a solution of the problem should attain. Whether an alternative reaches the objectives can be measured by a set of criteria. In this work, the performances of the alternatives are non-spatial, so the impact of one alternative for a certain criterion can be measured by one value. Then the total impact of all alternatives for all criteria can be presented in a table called the decision matrix. A decision problem is considered as defined, if the objectives, the criteria and the alternatives are defined.

- Alternatives: The alternatives represent the possible solutions to the problem. It is important that all relevant alternatives are taken into account: all alternatives, because adding new alternatives in a final stage of the policy-making process will cause serious delays.
- Decision variables (scale): Decision variables can be classified into three categories: binary, discrete and continuous. The simplest scale can be assigned to discrete values called as ratio which is for example the number of people injured in an event.
- Objectives: Objectives are direction of preference expressed in a given decision context.
- Goals: Goals are the basic reason for action, and describe, qualitatively or quantitatively, what we want to achieve.
- Constraints: A constraint indicates the minimum requirement that an alternative should have.

CRITERIA DEFINITION

The values of alternatives for each indicator have to be standardized. This process can be called criteria definition. In the end, all the results will have a value ranging from 0 to 1. There are various standardization methods:

- Maximum standardization: the scores are standardized with a linear function between 0 and the highest absolute score. For a benefit effect the absolute highest score is indicated with 1, for a cost effect the lowest score becomes 1.

- Interval standardization: the scores are normalized with a linear function between absolute lowest score and the highest score. In a benefit effect the absolute highest score is indicated with 1, and the absolute lowest with a 0. For a cost effect this is the other way round.

- Goal standardization: this is somewhat similar to interval and maximum standardization. Here, instead of using the highest and lowest values in the matrix, specific reference points are specified (ideal or goal value and a minimum value). The scores are normalized with a linear function between the end points of the range. For a benefit effect the maximum of the range is indicated with a 1, and the minimum with a 0. For cost effect this is the other way round.

PRIORITIZE CRITERIA

A typical weights approach is directly assigning weights to criteria using a scale such as 0 to 10 or 0 to 100. The decision maker is asked to determine the least important criterion and then give that a value of 10, then compare the importance of the other criterion with the worse one and give it a desirable value, and finally normalize so that they all add up to one. The SDSS implements two ways to prioritize criteria:

- Ranking
- Direct weight

FUNCTIONALITY AND WORKFLOW OF MCDM IN THE SDSS

The multi-criteria evaluation can only be carried out after the definition of alternatives.

The idea is that a decision matrix is created in which the different alternatives appear in the right side.

The Indicators (or Criteria) are separated into:

- Cost related indicators: all indicators that make it difficult to implement the risk reduction alternative. These can also be called the disadvantages.
- Benefit related indicators: all indicators that make it favourable to implement the risk reduction alternatives.

And furthermore separated in:

- Factual indicators (System indicators): these are the indicators that were calculated in the system before. They refer to the costs of construction, the risk reduction, number of exposed population etc. The system should still find a good way of obtaining these indicators.
- Perception indicators (User Indicators): these are user defined, and can be extended. These come from the various stakeholders, either by letting the stakeholders uses the system individually and then compares the scores and weights, or doing this in a workshop.

The stakeholders then:

- Prioritize each of the indicators. This can be done using the ranking or direct weight methods which the users use to prioritize the indicators.
- Weight the importance of the indicators.
- The system will then show the total score and give a priority.

		Indicators		Alternatives		
		Indicators	Weight	1 (click to view)	2(click to view)	3(click to view)
Costs disadvantages	Factual	Construction cost in monetary values		3000000	5000000	10000000
		Maintenance costs, yearly		30000	50000	150000
		Implementation time		5	2	8
	Perception	Resistance by population		low	mod	high
		Political support		high	mod	low
		……				
		……				
		……				
Benefits Advantages	Factual	Risk reduction in monetary value		100000	400000	600000
		Risk reduction : in people killed		150	300	250
		Risk reduction : in people injured		600	800	900
		Internal Rate of Return		+	++	-

		Remaining number of exposed buildings				
		Remaining number of exposed people				
	Perception	Safety		mod	high	high
		Environmental effects		mod	low	high
		Economic opportunities		mod	mod	high
		…….				
Final score						
Priority				3	1	2

Figure 2 Decision Matrix for Multi-Criteria Evaluation including Indicators, Weights and Alternatives

During the definition of the scenarios it might therefore be required to go again through the steps of Hazard data and Assets data as described earlier in this document. After the Hazard data and Assets data have been adapted to the particular scenario, then the user can again run the Risk Module for each of the alternatives. This will result in new risk estimations that include the effect of the alternatives. The user can then decide whether the evaluation will be done at the level of exposure, economic risk or societal risk.

In this excample the user is only interested in evaluating the economic risk of the different alternatives.

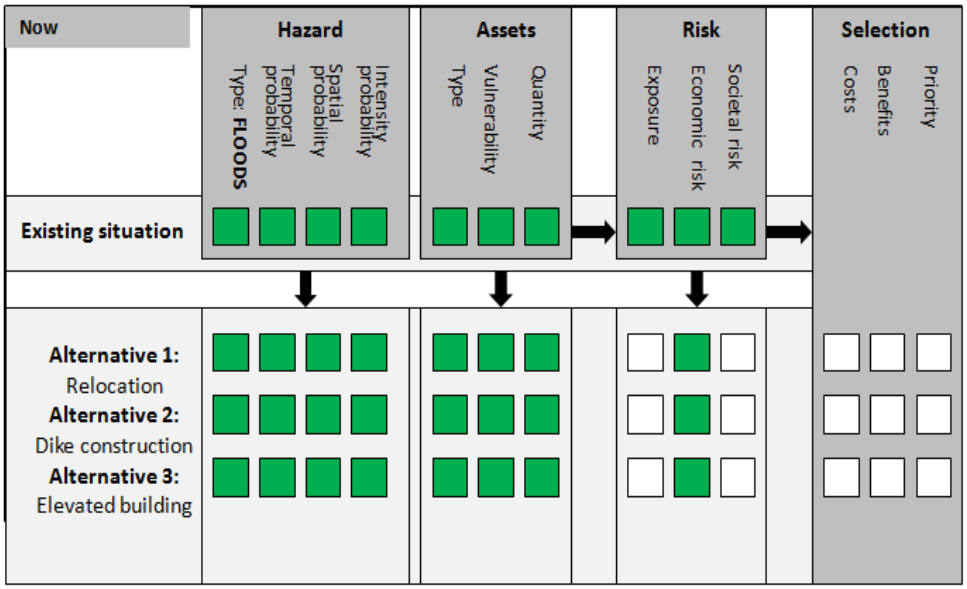


Figure 3 after entering the relevant hazard, assets and vulnerability data for each scenario, the user can analyse the new risk level. He can choose to do it for different types of risk

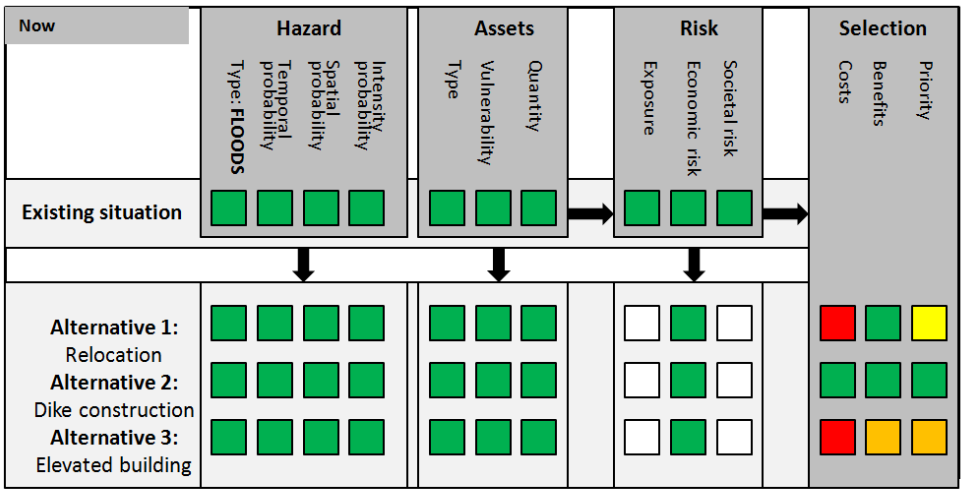
After completing this procedure the user can then analyze the costs and benefits. The costs for each scenario can be entered as actual monetary values (with information on investment period, initial costs, maintenance costs etc. within a spreadsheet) or as indicative weight values (if no actual costs are available or if it is difficult to express the costs in monetary value).

The benefits of the various alternatives are then evaluated by comparing the reduction in risk resulting from the implementation of the alternative with respect to the risk in the existing situation. This could be done in a simple way as the reduction in number of exposed elements at risk. Or it can be more complicated by calculating the reduction in terms of economic risk (e.g. annualized risk) or in terms of individual or societal risk.

The costs and benefits can then be compared. Depending on the quantification of the costs and the benefits, the user can then select one of the following options:

- Both costs and benefits are expressed in monetary values: the use of quantitative cost benefit analysis methods by calculating the Net Present Values and Internal Rate of Return.
- Only costs can be quantified but risk reduction is expressed in relative terms: cost-effective analysis, showing a prioritization of the alternatives by ranking.
- Both costs and benefits cannot be quantified: the multi-criteria evaluation procedure should then be applied by incorporating a number of indicators for each alternative, which may also be related to non-quantifiable aspects (e.g. the willingness of local population to adopt the measure, other environmental effects of implementing the measure etc).

Eventually the various measures can be prioritized and the best alternative can be visualized.



Prioritization of different alternatives

	Alternative 1	Alternative 2	Alternative 3
NPV 5%			
NPV 10 %			
IRR			

Risk calculation for different alternatives

Return period	Existing situation	Alternative 1	Alternative 2	Alternative 3
10	34.4	0	19	15
25	100.0	65	34.	40
50	199.0	164	100	80
100	510.0	475	199	150

Cost benefit analysis for different alternatives

Year	Alternative 1			Alternative 2			Alternative 3		
Year	Investment	Risk reduction	Benefit	Investment	Risk reduction	Benefit	Investment	Risk reduction	Benefit
1									
2									
3									
4									
etc									

Figure 4 after analysing the risk after implementing the alternatives, the user can analyse the costs of the alternatives, and make a cost-benefit analysis, leading to a prioritization of the alternatives

Following Figure demonstrates the flowchart of MCDM module and the input and the output in the system.

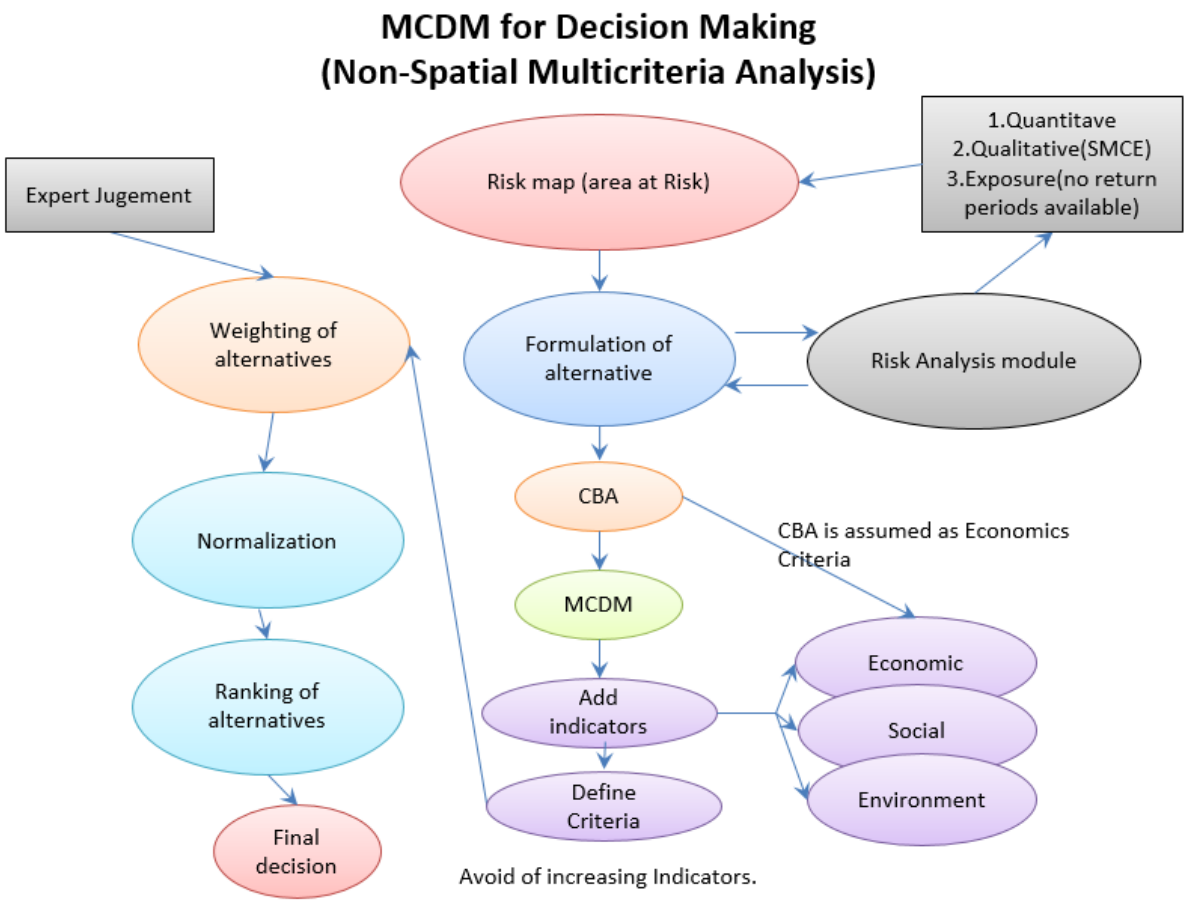


Figure 5 flowchart of MCDM: After analysing the risk after implementing the alternatives, the user can analyse the costs of the alternatives, and make a cost-benefit analysis, leading to a prioritization of the alternatives

MCE RESULTS

The following Figure shows the MCDM menu in the main toolbar. Under this main menu there are four sub menus: 'Multi-Criteria Dashboard', 'Alternative View', 'Indicators and Criteria' and 'Decision Matrix and Ranking'. At first, the only activated sub-menu is the Multi-Criteria Dashboard to lead the user to Multi-Criteria dashboard. The rest will be activated after the user opens the MCDM dashboard. This section introduces the user interface designed for each MCDM analysis and how the functionalities are implemented in detail.

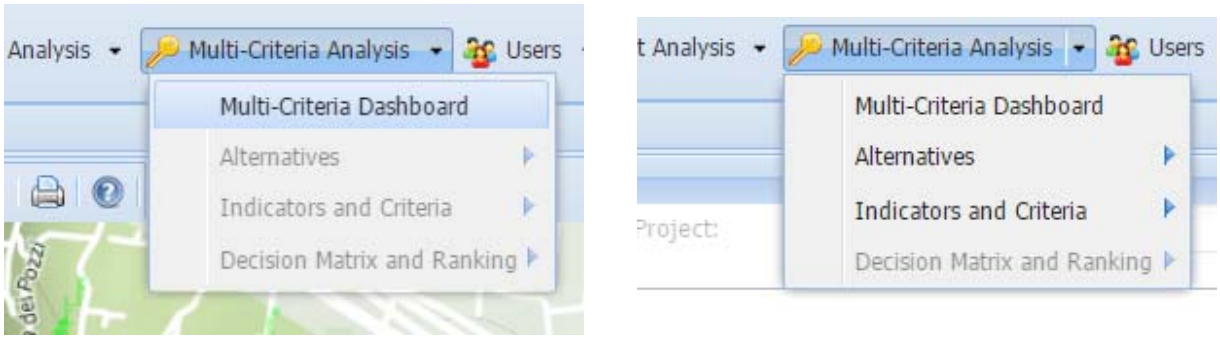


Figure 6 MCDM menu in the main toolbar

After clicking the Multi-Criteria Dashboard, a dashboard will be opened as shown in following figure. The rest of the sub menu will be activated as is shown in the previous figure. In this section, it is important to select Study area and Project. There are three types of input selections for MCDM. These can be linked to the Risk, Cost Benefit or user indicators (ADD Indicators button). The user has to be aware that a Decision Session has to be created or selected if Multi Criteria evaluation has to be done.

The Decision Matrix includes: Indicator name, Alternatives values under different indicators.

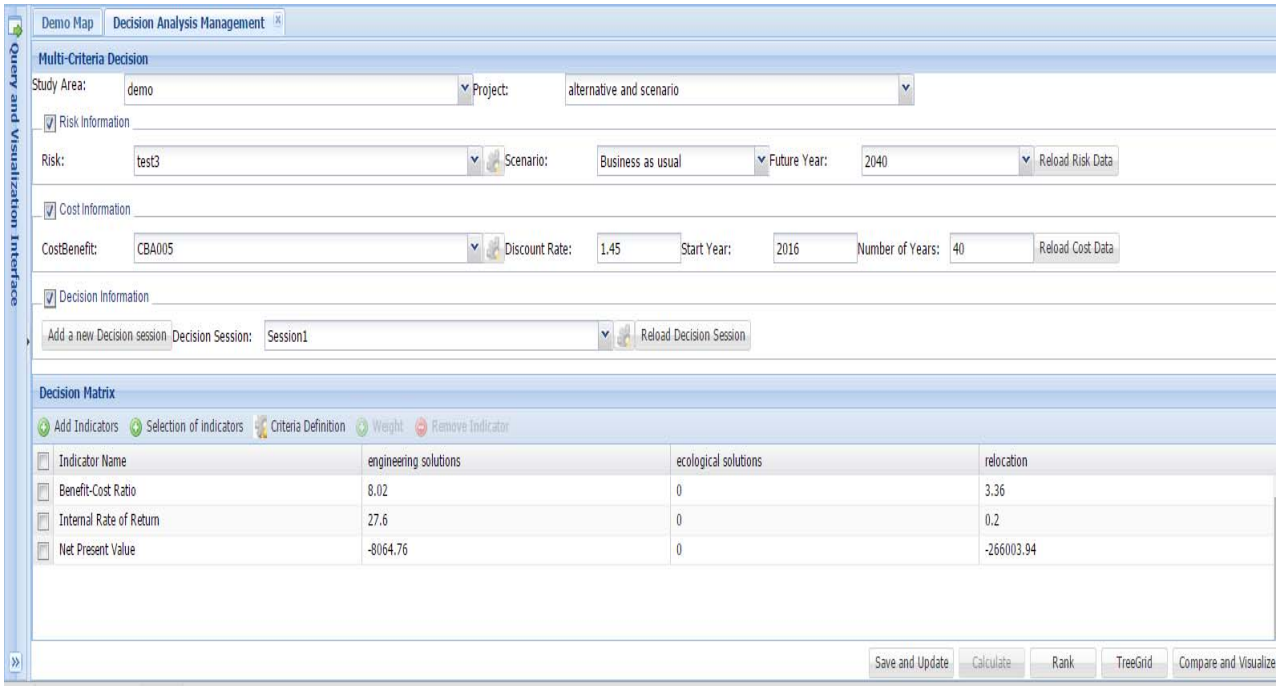


Figure 7 the MCDM Dashboard

The next figure shows the Risk information, such as Risk name/Scenario and future years under that risk analysis name. It also demonstrates the available cost information from the Cost Benefit Analysis under that risk name and some other information such as discount rate and number of years. The user can also link to the Risk Management UI or Cost Benefit Management UI if access to that part is necessary.

Remember that the Reload button is designed to reload the data to the decision matrix from different inputs such as the Risk, Cost or Decision parts if needed.

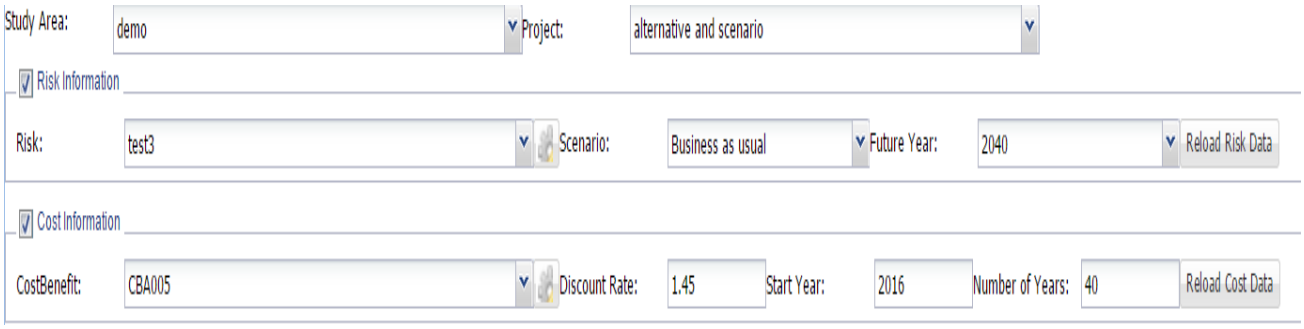


Figure 8 Risk Information and cost information

The figure below shows the Decision Session information. It is important for the user to fill out the session name and the description of decision making to save and compare the results. Session Management can be accessed under Decision information using Delete, Edit or Add. The risk name should be selected in most of the time that results can be calculated and seen in decision matrix. However if the user directly clicks on “compare and visualization” button or “decision session management”, the selection of the risk name is not necessary.

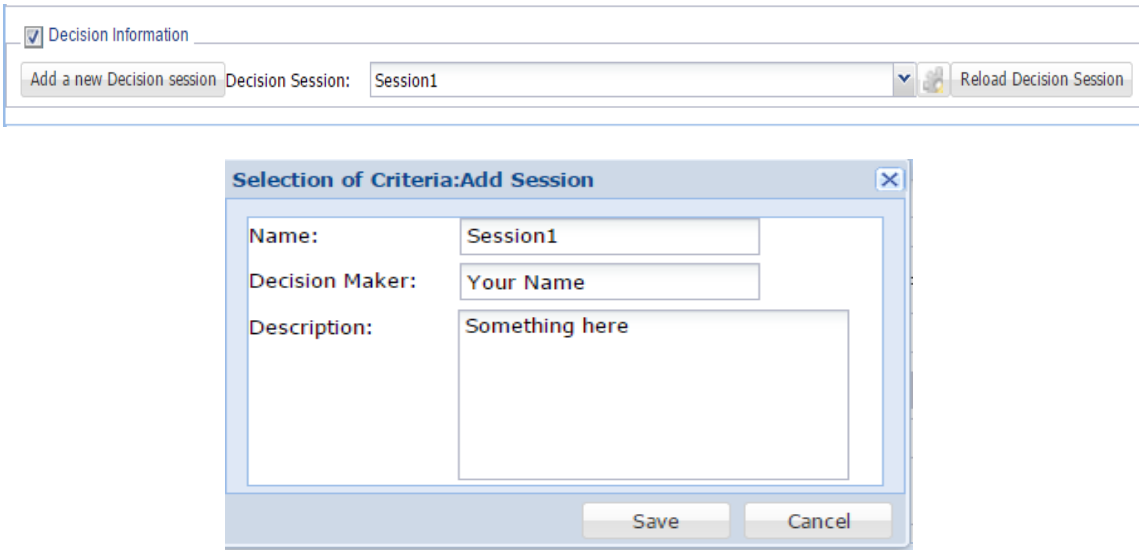


Figure 9 session information: the Goal of Decision Making

As mentioned before, in the decision information it is also possible to link to the Decision session management as shown in the next figure. The user can add session, edit session and delete any session.

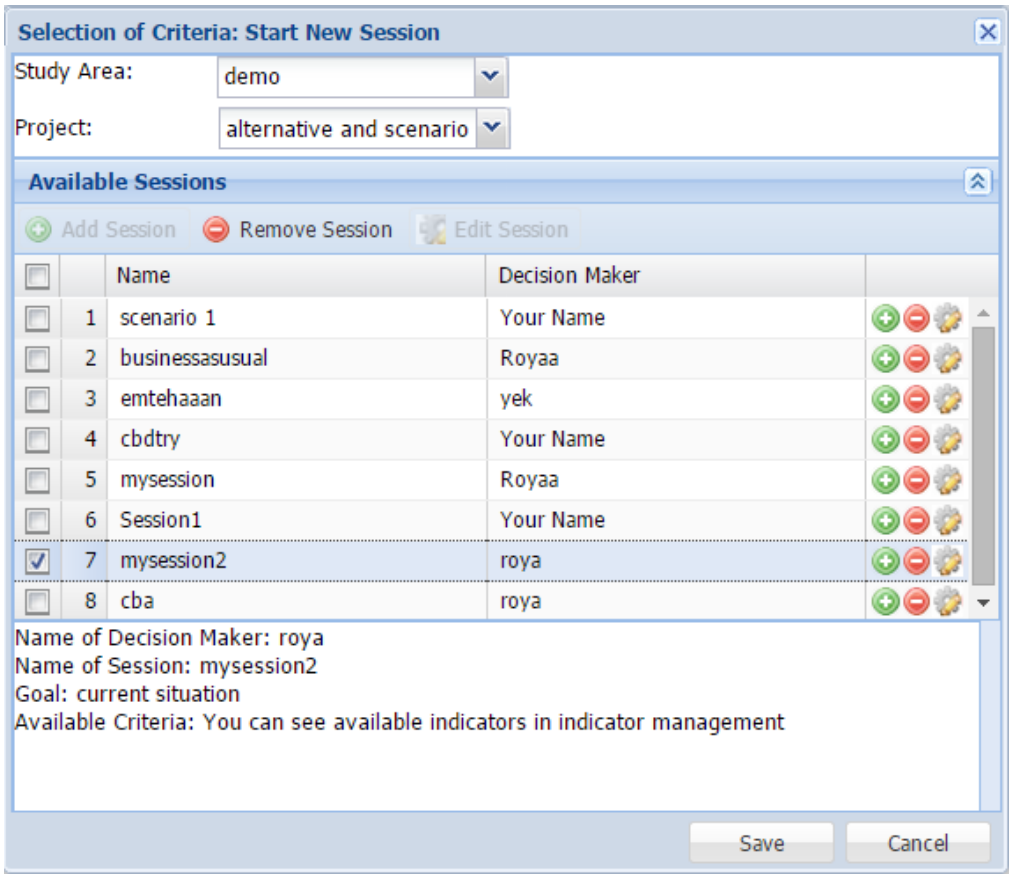


Figure 10 the Decision session definition window

DECISION SESSION MANAGEMENT

As you can see in the Decision Matrix, there are some parameters which need to be defined before going to the analysis. These are referred to as the problem definition for Multi-Criteria. The next figure shows the problem definition for the decision analysis. The steps are as follows:

- Add Indicators
- Selection of indicators
- Criteria Definition (can be referred to Value function and standardization as well)
- And weight or prioritizing

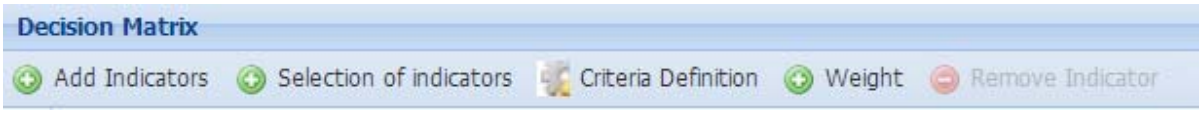


Figure 11 session information: the Goal of Decision Making

So after selecting the proposed risk name and defining the session, now it is time to go to the next step which is called the problem definition. It is possible to add more indicators to the decision matrix besides the system indicators. The following figures show what is needed to be entered when adding an indicator by the user or the system. The first figure shows the step to add system indicators from Risk and Cost by "Selection of indicators". The next window will be opened when the user clicks "Add Indicators" button to add user indicators. In decision analysis the source of the data or indicators are really important so this field cannot stay blank. The scale for each indicator also is defined in this step. After adding all the indicators by the different users, there is still the opportunity to select which of the indicators will be used by the decision analysis.

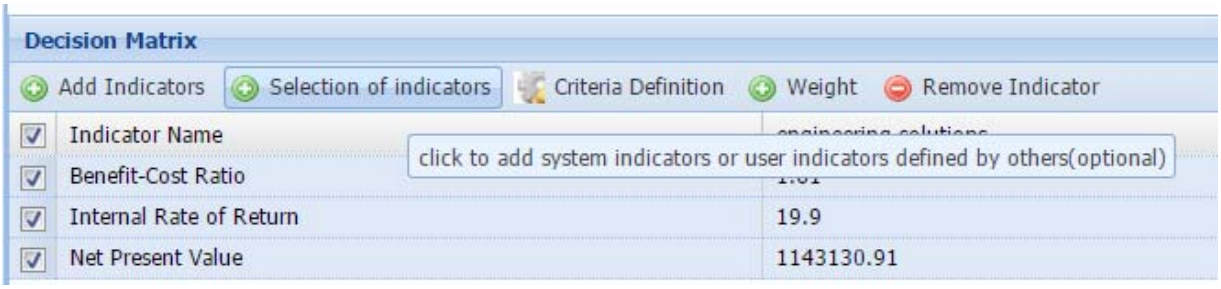


Figure 12 the selection of indicators

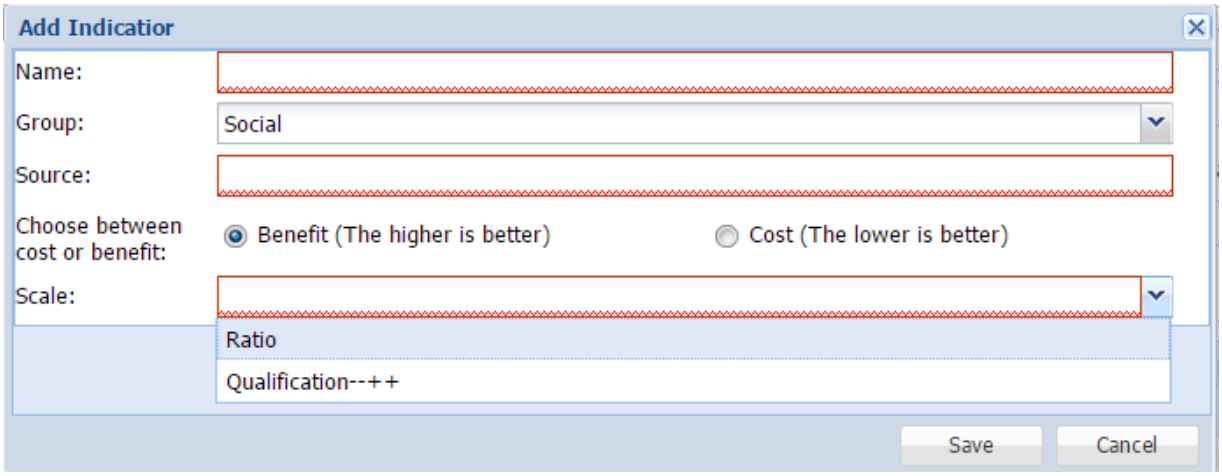


Figure 13 Add indicator: Scale can be Ratio, Qualification

After adding the user indicators, the value will be 0 for all alternatives. The user values should be added by clicking on each cell and then to use the "Save and Update" button. If the edited values are not saved by this button, the calculation will be done by 0 and the result won't be correct. So make sure that they are saved before going to the next step.

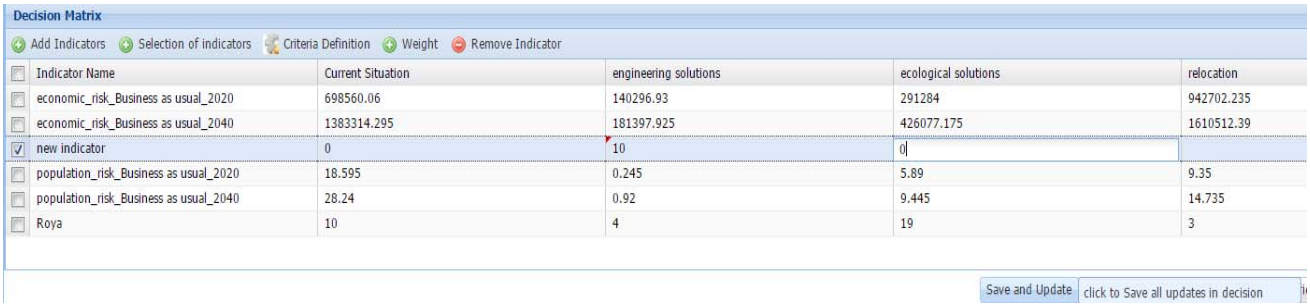


Figure 14 edit new indicator value and save the results before other steps

Before going to "Weight", the Criteria have to be defined. This can also involve standardization. In this step, value functions are selected for each indicator plus the maximum and minimum of the indicator value and constraints. As shown in following figure, the indicator has to be selected and then the lowest and highest value will be displayed from the available data. Three types of standardization are available: Maximum, Interval and Goal. It is really necessary to enter Minimum value and goal value if Goal

standardization is selected. If this step is omitted all the data will be transferred to zero. The value function can be visualized in a line chart, or saved into a JPG format picture.

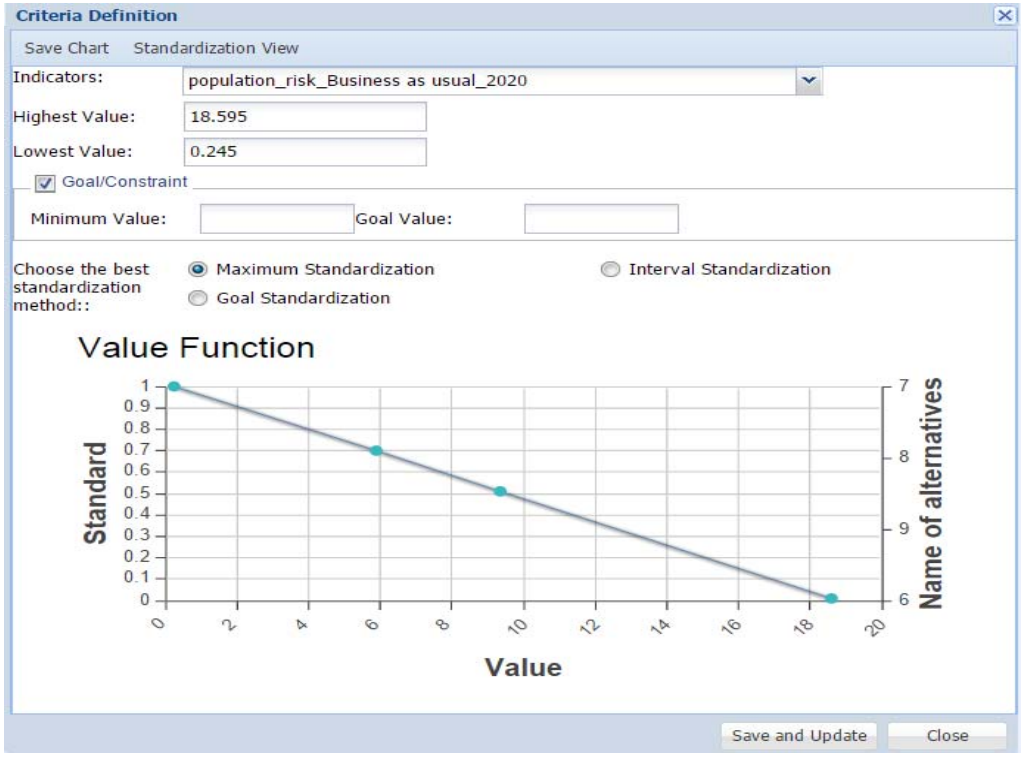


Figure 15 the Criteria Definition window

If you want to see the Criteria Matrix and their value functions, you have to click on “Standardization view” button on the previous window. Then following window will open.

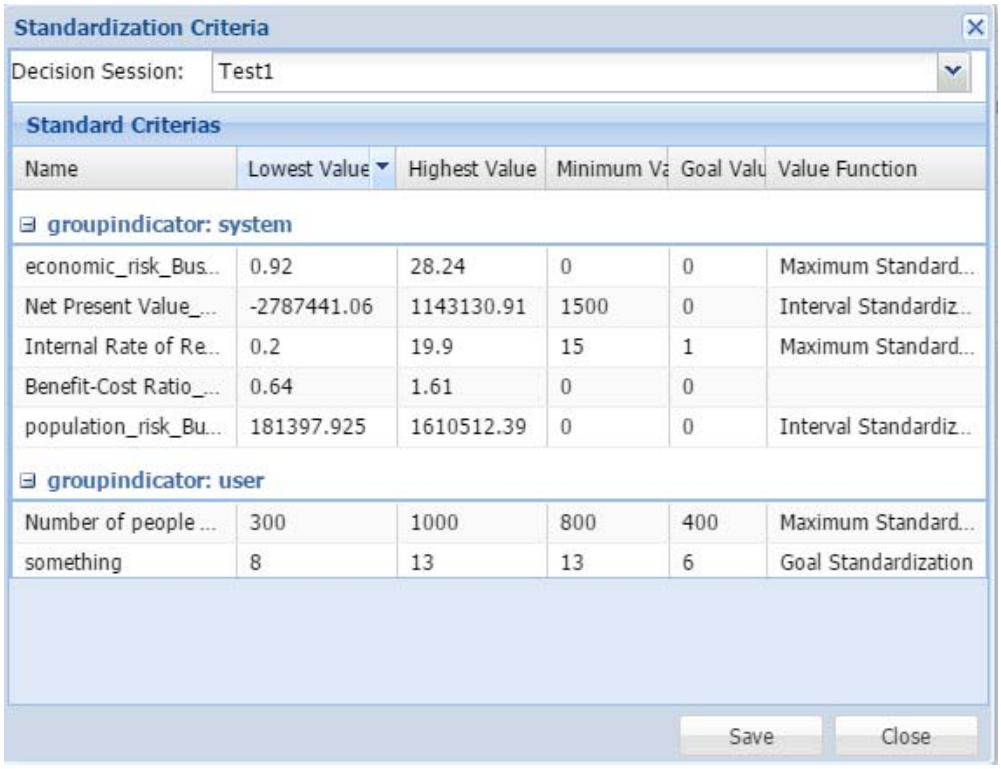


Figure 16 the Criteria Matrix including the current value function

The last step is to give a weight to each criteria. Next picture shows the interface for doing that. There are two ways of prioritizing Criteria: Ranking and Direct Weight. The next figures show the two types of weighting. Make sure when ranking selected, only an integer number will be accepted if you are going to rank between 1 to 10 or 1 to 7 for instance.

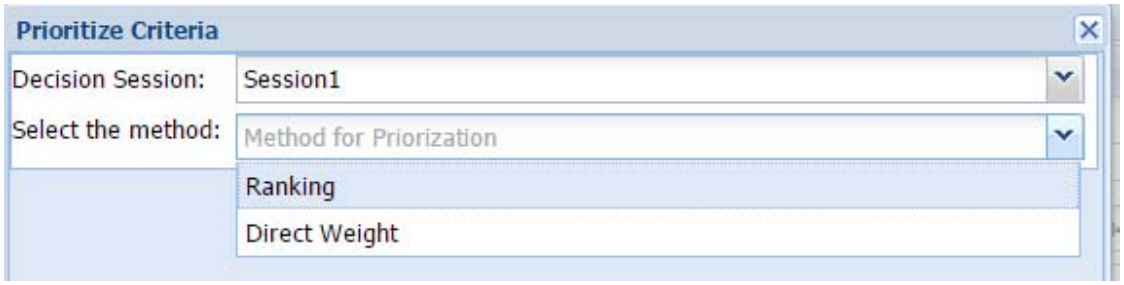


Figure 17 two types of prioritizing criteria: Ranking and Direct Weight

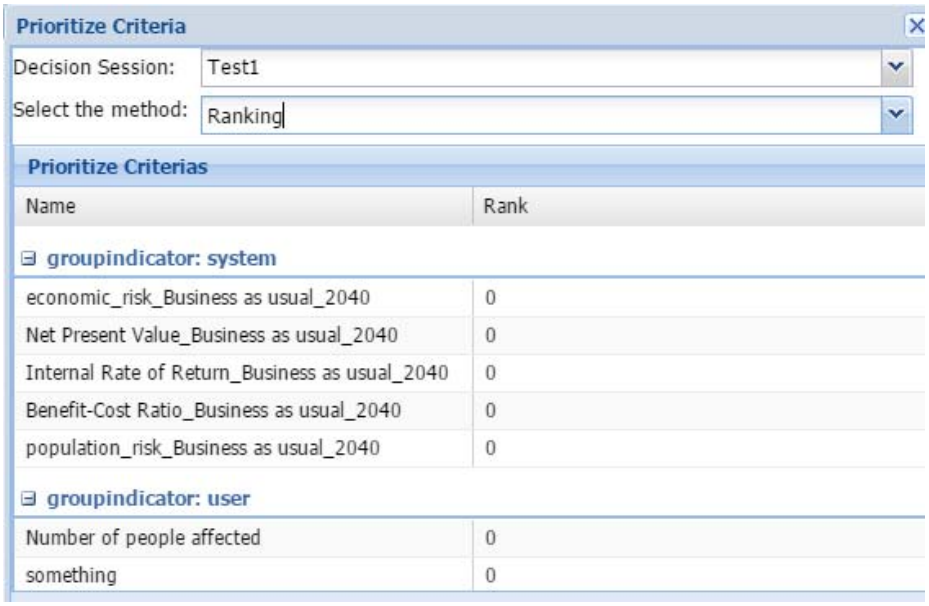


Figure 18 Prioritize Criteria (Weighting): Ranking Method

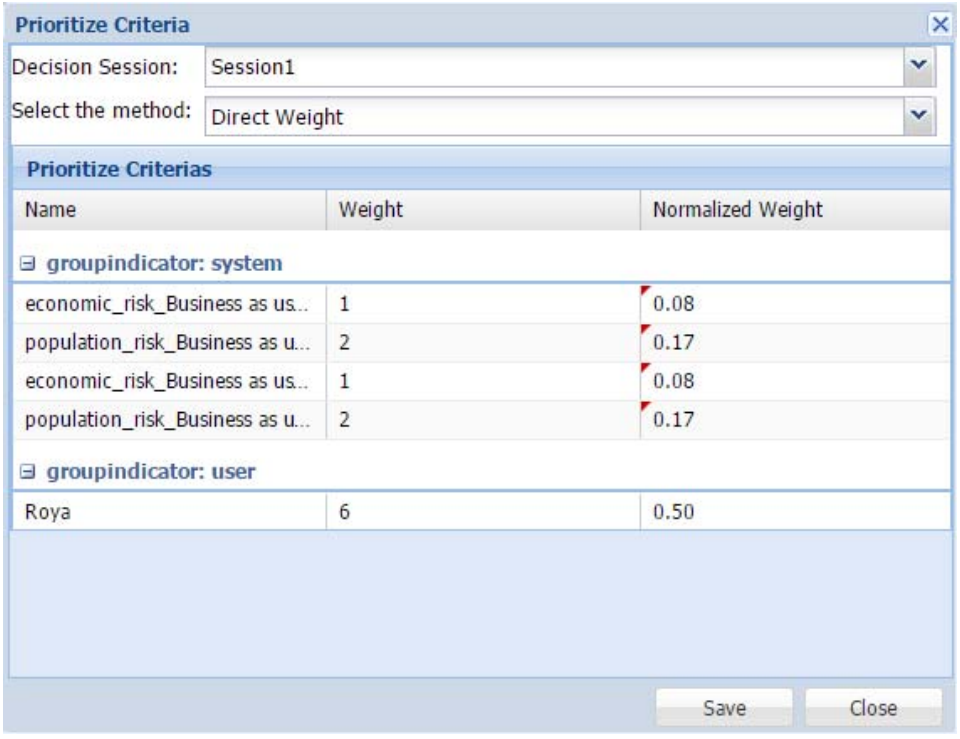


Figure 19 Prioritize Criteria (Weighting): Direct Weight, User weight and normalized weight

If your weights are not normalized, the system will ask confirmation to normalize the weights.

Figure 20 confirm normalization

The final step is to click on "Calculate" button. The system will ask confirmation to calculate the final results. Please make sure that all values and weights are inserted correctly and criteria definitions are done for all indicators.

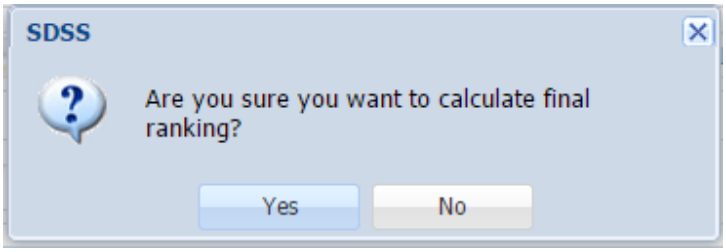


Figure 21 calculate the final result

After calculation, the visualization of results and comparison can be done. Comparison between different results and also under different Scenarios and future years can be displayed in this part. The following figure illustrates the window for the ranking. Ranking of alternatives can be displayed as a list in a grid or in bar chart as shown in next two figures. The weights of criteria are demonstrated by a pie chart.

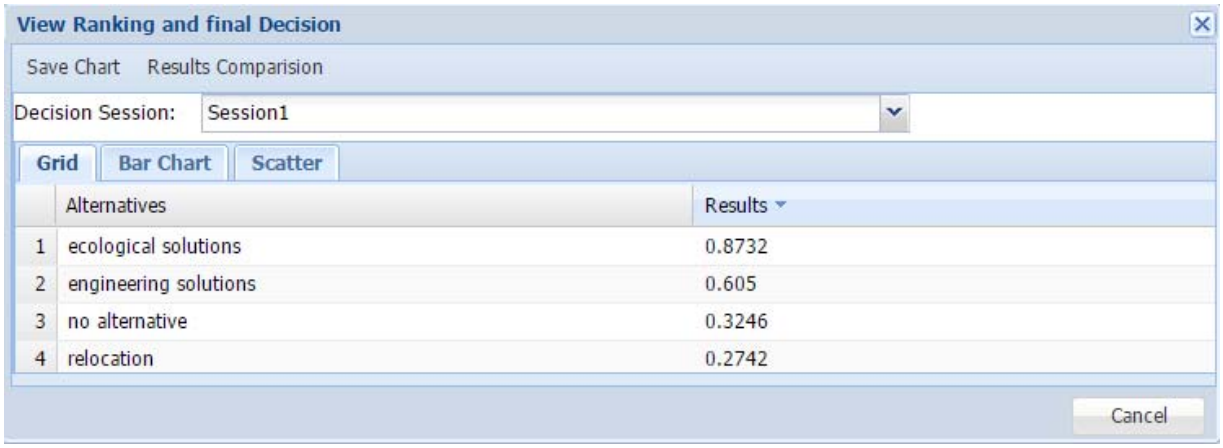


Figure 22 listing the Results of Ranking Alternatives

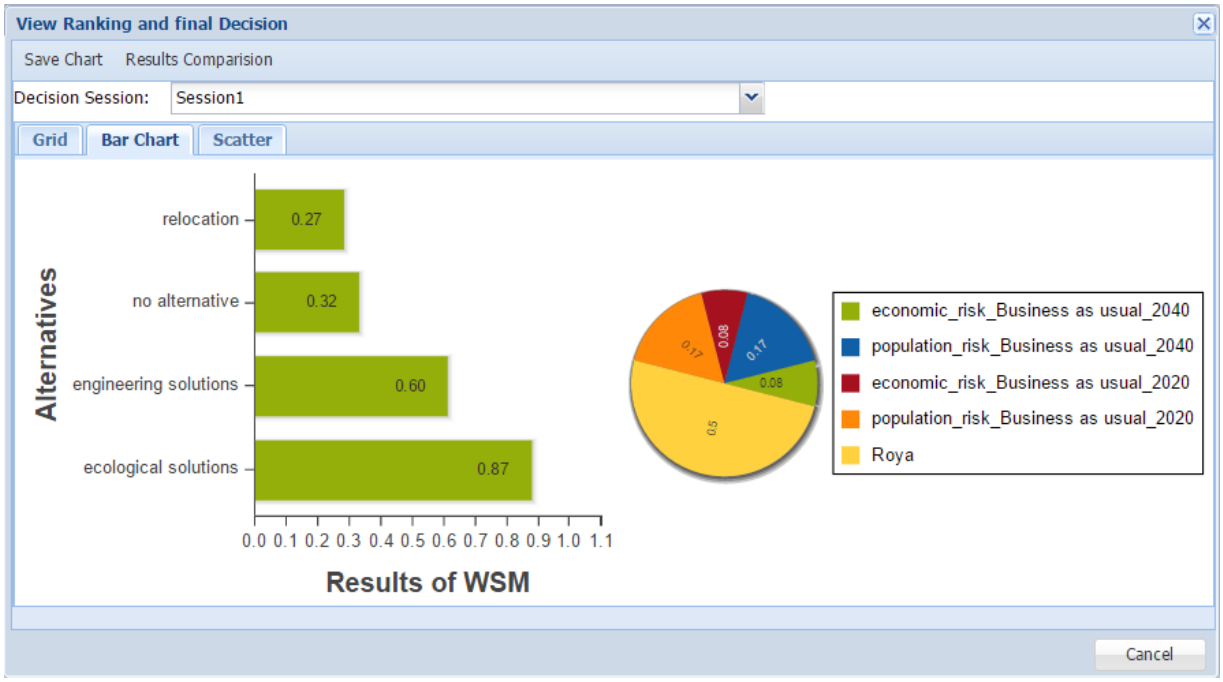


Figure 23 Results of Ranking Alternatives in a Bar Chart

The comparison session focuses on the results for different MCDM sessions under the same project. The sessions can be selected in the combo box and the results will be automatically updated and shown as a list in a grid (see next figure). It is also possible to see the results in multiple bar charts as shown in the figure after. If the user wants to compare the results under different scenario or future years, different sessions for each scenario or future year have to be created and added here.

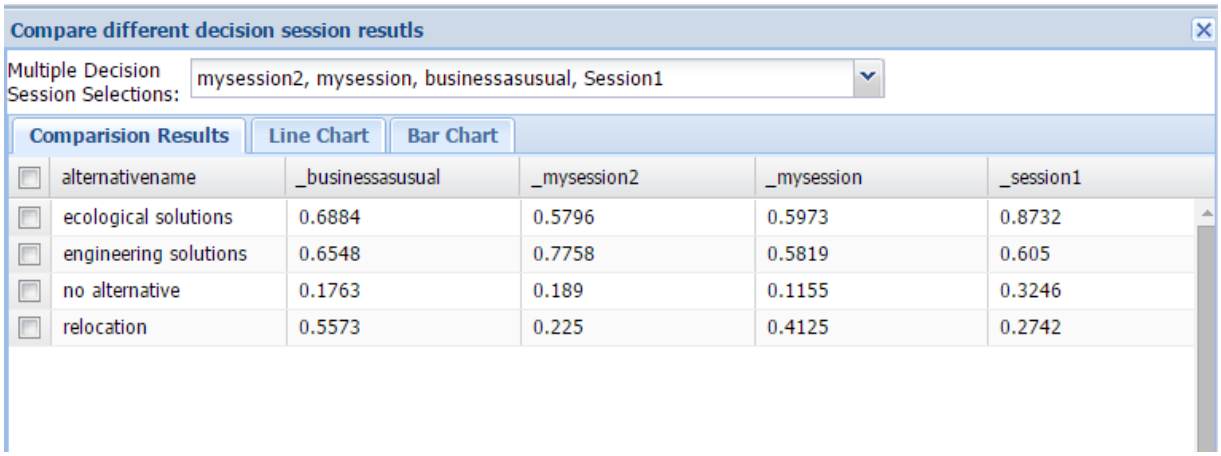


Figure 24 Comparison Results of Ranking Alternatives: Grid

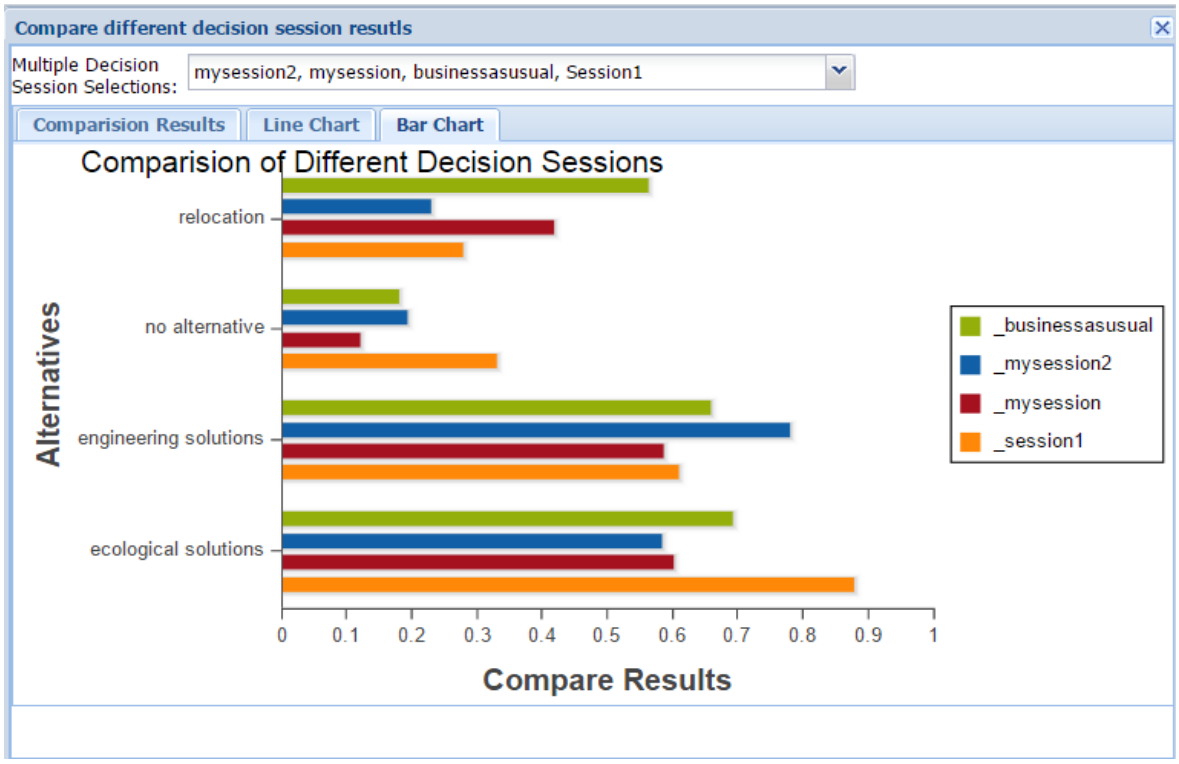


Figure 25 Comparison Results of Ranking Alternatives: Multiple Bar Charts

Users might wonder how it is possible to add changes such as deleting, editing or adding, or even viewing other Alternatives and Indicators or Sessions (Decision making session). These are added to the Multi-Criteria Analysis Menu for easy access. As it was mentioned before, in the main menu of Multi-Criteria Analysis there were other sub menus that were deactivated in the beginning. Now, after working with the

MCDM dashboard, they are activated and the user can easily access (if he/she has the right to access) these. The two following figures show the alternative view which is linked to the visualization and input data part.

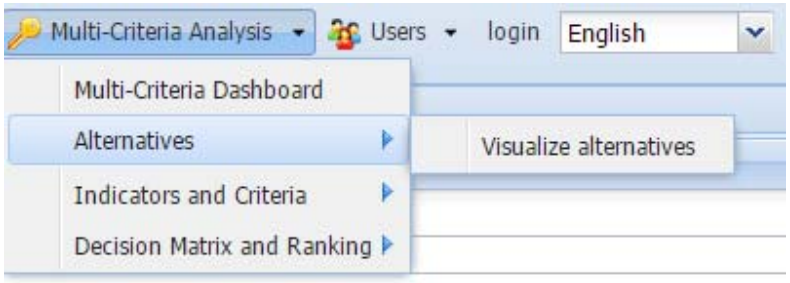


Figure 26 Visualize Alternative sub menu

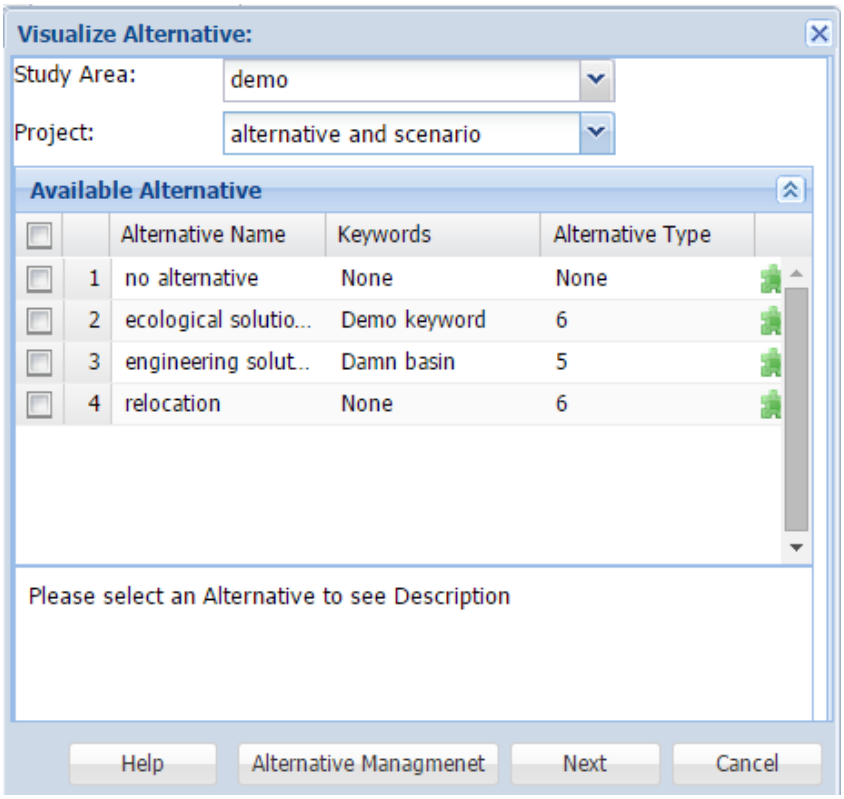


Figure 27 Visualize Alternative: linked to visualization and alternative management in input data

The next figure indicates the sub menu for Indicator Management, Session Management, Criteria Definition and Prioritize Criteria, and the following figure demonstrates how easy it is to check all

available indicators under a session, to add or delete or edit, view description and details of each session. The rest was already explained in previous sections.

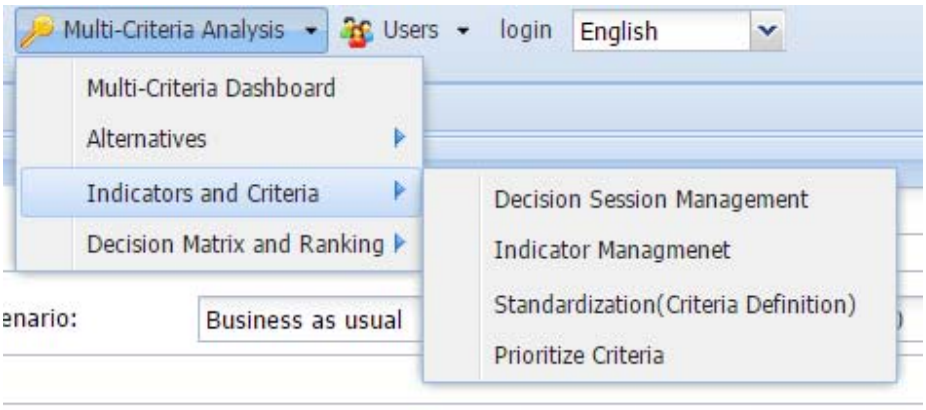


Figure 28 Indicator Management and Decision Session Management sub menu (Easy access)

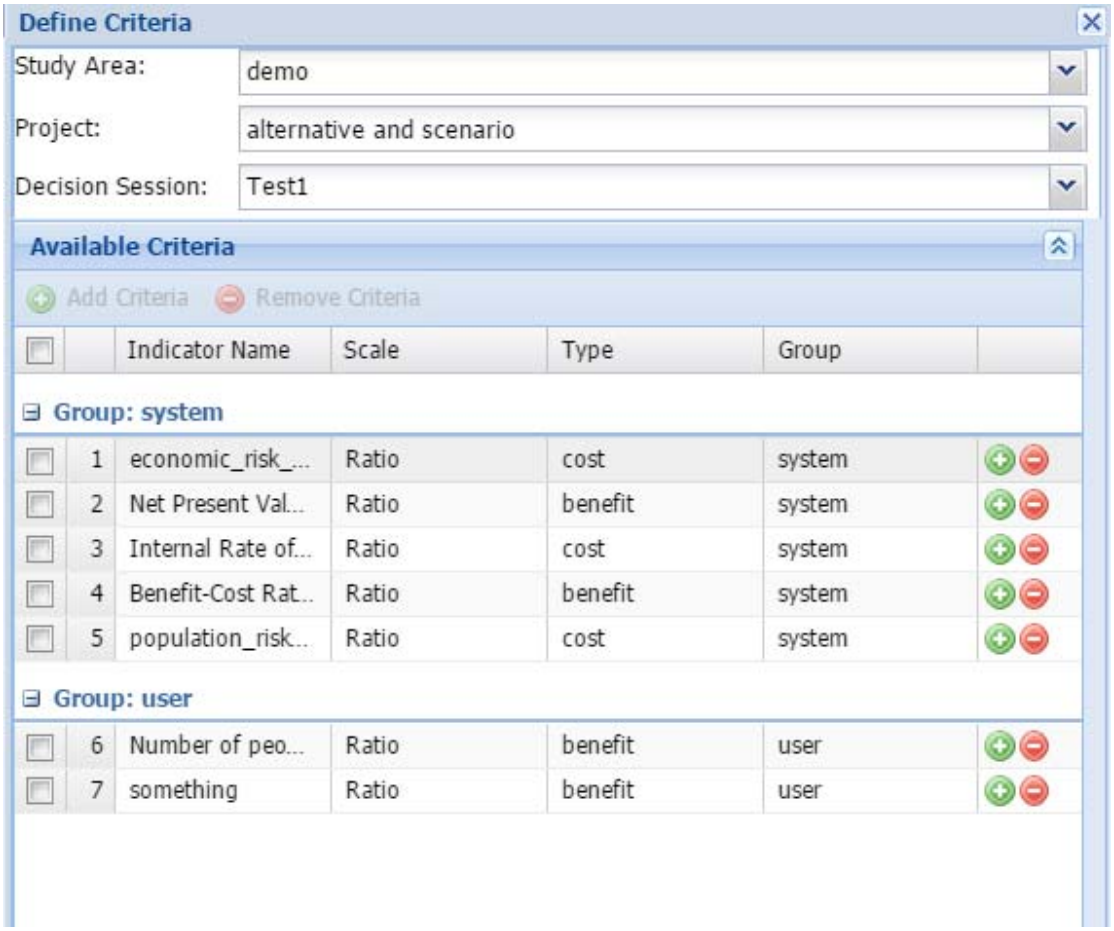


Figure 29 Indicator Management: Edit/Add/Delete

The last part of Multi Criteria analysis is to see the results and compare different decision sessions. The easy way to access to this part from the menu is shown in the following figure.

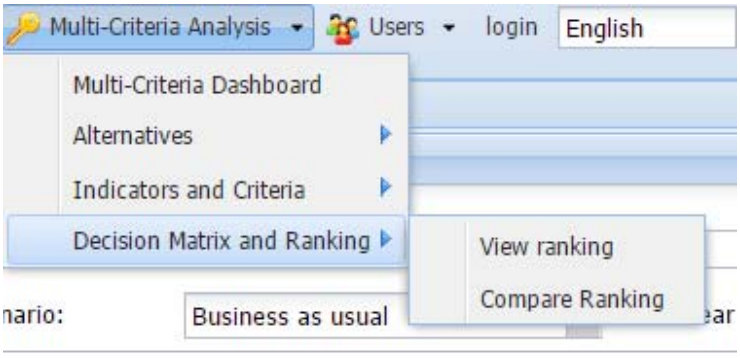


Figure 30 Visualize and comparison results sub menu (Easy access)

REFERENCES

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