Chapter 5

Comprehensive Evaluation of Transportation Projects

5.1 Introduction

The aim of transport planning, in practice, is the identifying of transport projects which are needed to fulfill the forecasted demands from land use and activity patterns (Sun, Jia, & Lv, 2007). Prioritizing candidate projects is also an important issue in the transportation planning process, not only due to budget constraints, but also implementing all candidate projects at the same time is impossible, and may cause insufficient transport supply during the construction period. Thus, a comprehensive assessment of transportation projects allows the decision maker to decide the funds and the investments schedule.

Conventional transport planning decision-making methods often require detailed economic analysis (Macharis, De Witte, & Ampe, 2009) (A Awasthi & Omrani, 2009). They tend to focus on a limited set of criteria; such as infrastructure costs, operating costs, travel time saving, and accident damage costs. They overlook many non-monetised impacts, and disregard indirect impacts. Otherwise, these methods are not sufficient for evaluating transportation projects from all viewpoints, and there is no need in an economic analysis to include stakeholders into analysis.

In developing countries, the economic analysis of transportation projects is more complicated due to lack of a reliable database (Hasibuan, Soemardi, Koestoer, & Moersidik, 2014). The economic analysis is by nature complex and strongly interrelated with socio-economic and environmental systems, which cannot be easily monetized. In addition, economic analysis is always associated with risks and uncertainties regarding variations in inflation, foreign exchange, and interest rates (i.e. instable economy). Furthermore, large scale public transport projects in developing countries are nonprofit and depend mainly on public funds. The transport tariff is not economic, but social and subsidized. Therefore, the application of some economic evaluation tools, such as cost/effectiveness and benefit/cost ratio, may be accompanied by some assumptions and the results will be inaccurate and unreliable.

MCDA embodies a suite of methods that provide a composite index (an overall project score) to identify the most preferable project (winning solution from different options) based on scientific analysis. Specifically, MCDA is used as a developing guidance to decision makers in dealing with multiple criteria; instead of utilizing a common single attribute such as cost-benefit ratio. Additionally, MCDA approaches have been clearly applied to integrate sustainability into transport planning processes (Hickman, Saxena, Banister, & Ashiru, 2012) (Tefe, Jones, & Appiah-Opoku, 2014). Knowledge generated by MCDA is derived subjectively based on comparative analyses of various elements.

However, MCDA may lead to doubt the results, due to the complexity nature of the methodology and the large amounts of data and information that must be “stored and operated”. It can be described as “an exercise in data handling” which may lead to non-transparent results.

Meanwhile, the use of local knowledge in scientific analysis is limited and often ignored in developing countries. The local knowledge is restricted only to setting the criteria weights. Recent studies, such as (McAdoo, Moore, & Baumwoll, 2009) (Mercer, Kelman, Suchet-Pearson, & Lloyd, 2009), documented a series of studies to demonstrate the growing importance for the integration of scientific and local knowledge for evaluation and prioritization of transportation projects in developing countries. (Stuart & Thompson-Fawcett, 2010) describe the lessons that could be learned from combining local knowledge with scientific knowledge related to sustainable urban design. Combining knowledge can be achieved by employing the Analytical Hierarchy Process (AHP). AHP is a decision-making tool used to organize various criteria into a relative hierarchy that allows for comparisons among these criteria relevant to their contributions to a common goal(Saaty, 2008).

The main advantages of applying AHP for evaluating alternatives can be summarized as follows:

- The process is carried out in successive steps, so that data management is not complicated as in the MCDA.
- AHP is based on pairwise comparison and the participation of stakeholders at each step.
- It is supported with a mechanism to insure the consistency of the stakeholder weights at each step.
- The judgment is established on preference relative linear scale that is practically attractive, user-friendly and more common than numbers.

If a large number of evaluation criteria and project options exist in an evaluation process, AHP will suffer hard debates during allocation of weights for pairwise comparison. The pairwise comparison should be conducted for the different options regarding all criteria.

In this Chapter, a new approach for Comprehensive Evaluation of Transportation Projects (CETP) is proposed. CETP can be applied for screening alternative project options and arranging them regarding to their importance to city sustainability. It is based on the integration between Multi-Criteria Decision Analysis (MCDA) and the Analytical Hierarchy Process (AHP). Thus, it can compose benefits of both techniques. The proposed approach considers the four essential sustainable criteria (economic, social, environmental, and transport efficiency). It can deal with quantitative criteria (in monetary unites or performance values), qualitative criteria, and either with "less is better" or "more is better" criteria. It takes also direct and indirect impacts into consideration. The proposed approach brings a process that highlights efficient decision making through a systematic, step-by-step procedure.

5.2 The Proposed Approach CETP

The main objective of the proposed approach is the comprehensive analysis of candidate transportation project options and arranging them regarding their importance to sustainable criteria. It is based on integration between Multi-Criteria Decision Analysis (MCDA) and the Analytical Hierarchy Process (AHP). These two techniques are chosen because of their capability to deal with preference-based decisions over a lot of alternative options based on criteria that are characterized by multiple, usually conflicting, attributes.

What is “The Comprehensive Evaluation of Transportation Projects”?

- Investigating the role of each project in achieving the community goals.
- Screening the candidate transportation projects regarding their importance to city sustainability, i.e. economic, social, environmental sustainability.
- Evaluating the project alternatives according to their direct and indirect impacts.
- The procedure should allow a trade-offs analysis between advantages and disadvantages of each project option.

The way to “The Comprehensive Evaluation of Transportation Projects”

- The evaluation should compose quantitative and qualitative criteria.
- The evaluation should deal with “less is better” and “more is better” criteria.
- The evaluation should highlight an efficient decision making tool through a logic systematic, step-by-step process, to facilitate data management and testing the consistency of allocated weights by stakeholders.
- The evaluation should allow group decision making by setting of weights.
- The evaluation should capture the scientific knowledge of system providers and experts and the local knowledge of other stakeholders (Jones, Tefe, & Appiah-Opoku, 2014).
- The evaluation should facilitate the decision making by introducing a visual presentation of the result to test the sensitivity in situations where uncertainties exist.

The CETP contains seven phases:

- Hierarchy structure of the decision problem
- Importance of the sustainable criteria
- Importance of the indicators
- Priorities of the project alternatives and their rating
- Priorities Aggregation
- Visual Composite Sustainability Level
- Visual Sensitivity Analysis

5.2.1 Hierarchy Structure

The approach organizes the decision-making problem into a relative hierarchy structure of four levels (Jones, Tefe, & Appiah-Opoku, 2013). The hierarchy structure allows criteria comparisons related to their importance from the viewpoint of multiple stakeholders with different interests step-by-step, through a logical systematic manner. Thus, it helps decision-makers facing a complex problem with multiple conflicting and subjective criteria, and understanding the internal complications in the process. It facilitates also data management and testing the consistency of allocated weights by stakeholders at each process level. Figure 6 presents the hierarchy structure that composes four successive levels, starting from the top level I (the goal), passing through the intermediate level II (criteria) and level III (indicators) to the lowest level IV (alternatives).

The approach begins at level I the community vision for the sustainability goals of the metropolitan region. A vision describes policies and actions needed to achieve the community concerns, and identify issues to measure the progress**.** A successful vision should include a future that balances economic, environmental and social needs.

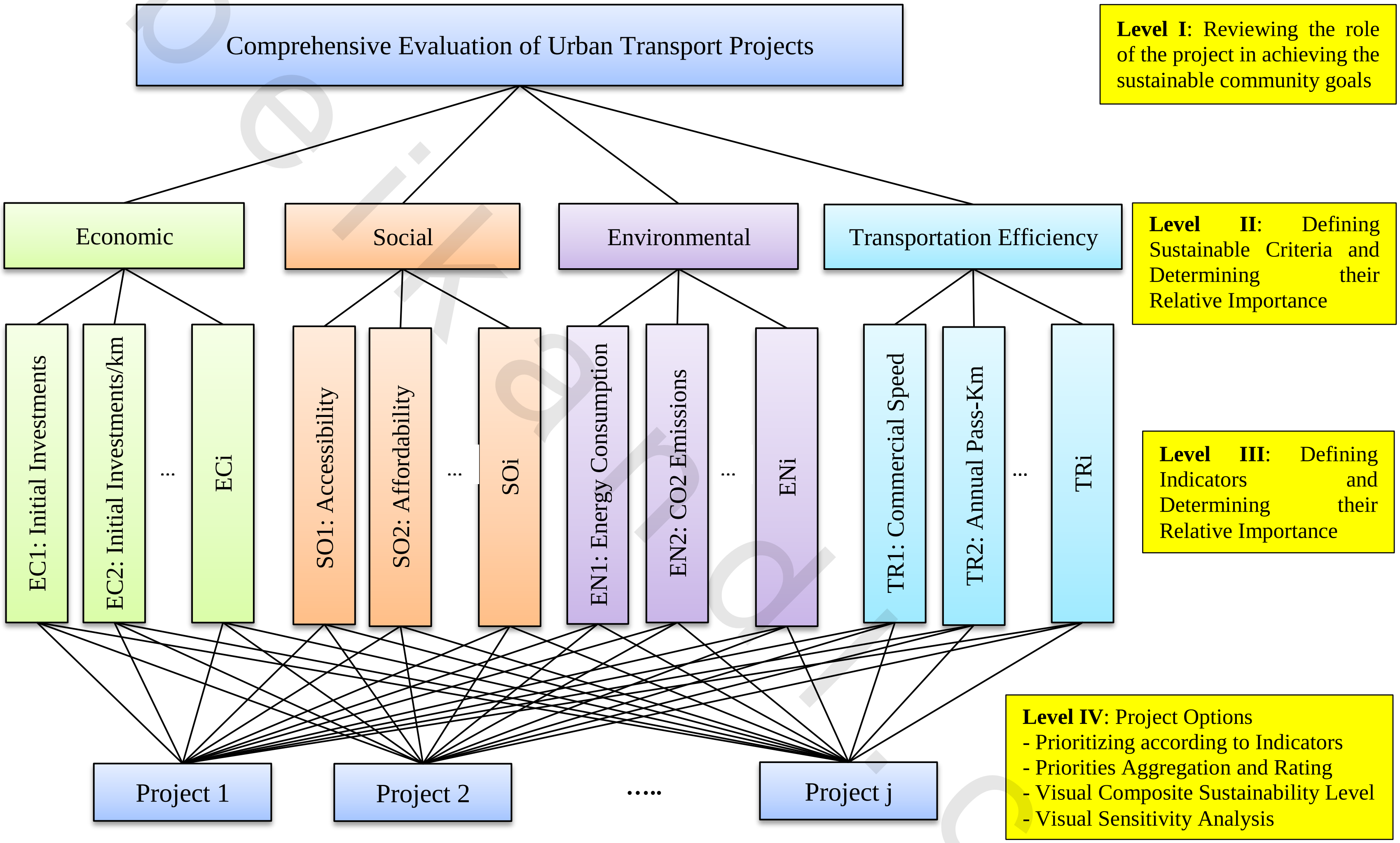


Figure 6: The Hierarchy Structure

If the community lacks a vision or desires a change in the project area, the politicians should collaborate with the public and interdisciplinary team to develop the sustainability concepts. Thus, the objective of level I in the hierarchy structure is to review the role of the project under consideration in achieving the sustainable community goals (Yigitcanlar & Dur, 2010).

The purpose of the second level (Level II) is to determine the relative importance of the four general sustainability criteria (economic, social, environmental, and transportation efficiency). Qualitative knowledge and experience regarding the relative importance of the sustainability criteria are captured from politicians, policy makers, experts, and transport system providers. It is necessary to note, that "the transport efficiency" is added to the three elements which describe the city sustainability, as the goal in this process is to evaluate transportation projects.

In the third level (Level III), the various relevant stakeholders are then identified; e.g. experts, transport system providers, system users and non-users, local residents and businesses, as well as environmental and non-governmental organizations (NGOs). The stakeholders are people who have an interest in the concerns of any decisions taken. They define the sub-criteria (indicators) according to their knowledge and senses, and indicate the relative importance of each indicator.

Finally, system providers and experts comprehensively investigate in the fourth level (Level IV) the relative importance of each candidate project option with respect to positively impacting each indicator, and prioritize options.

In this way, the comprehensive evaluation framework captures the scientific knowledge of the system providers and experts and the local knowledge of the other stakeholders in Level III, and integrates them in Level IV based on the relative weightings of the general sustainability criteria of both groups (Sagaris, 2014). CETP is also adapted to be applied in group decisions with the same rules of AHP, which are described above.

Table 6 presents the step-by-step Data Flow in the CETP-Structure and its Goals

5.2.2 Relative Importance of the four Sustainable Criteria

This phase is based on five steps:

1. Carry out a pairwise comparison between the four sustainable criteria based on the weights of stakeholders. Participants are politicians, experts, and system providers.
2. Constructing a pairwise comparison matrix.
3. Generate a normalized matrix.
4. Calculate the average of each row, which presents the Priority Vector of the criteria.
5. Perform the consistency test to insure that an acceptable consistency between the weights is achieved.

Table 6: The step-by-step Data Flow in the CETP-Structure and its Goals

Data Flow in the CETP-Structure and the Goals	
(A) Criteria	
1. Define Sustainable Criteria 2. Construct pairwise comparison matrix, based on given weights 3. Formulate a normalized matrix 4. Calculate the priority vector of each criterion 5. Perform consistency test for accepting the used weights 6. Determine the relative importance of the criteria	Relative importance of the criteria

(B) Indicators	
1. Define the indicators of each criterion 2. Construct pairwise comparison matrix for indicators, based on given weights 3. Formulate a normalized matrix 4. Calculate the priority vector of each indicator 5. Performing consistency test for accepting the used weights 6. Determining their relative importance of indicators of each criterion	Relative importance of indicators of each criterion

(C) Prioritizing Project Options	
1. Classify the indicators to quantitative and qualitative 2. For Quantitative indicators: ○ Construct a project options/indicator matrix for each criterion, containing quantitative performance values ○ Locate the relative weights of each Indicator for all criteria ○ Formulate a scale matrix and a normalized matrix ○ Calculate the priority weighted vector of each indicator 3. For Qualitative indicators: ○ Construct pairwise comparison matrix based on given weights ○ Formulating a normalized matrix ○ Calculate the priority vector as well as the local priority vector of each specific indicator ○ Calculate the global priorities of the options to combine the local priority vectors across all criteria. The global priorities are used for rating options ○ Calculate the composite sustainability level of each option, which presents the percentage of the achieved sustainability of an option to the maximum achievable sustainability	• Priority of project options for each Indicator • Priority of project options regarding the sustainable criteria • Priorities Aggregation • Final priority of project options • percentage of achieved sustainability of each option

(D) Visualize Interrelationships	
1. Relative importance of the criteria among each other 2. Relative importance of indicators of each criterion 3. Importance of indicators in ration options 4. Final Rating of project options 5. Composite sustainability level of each option	Visual representation of Inter-relationships and Results

(E) Visual Sensitivity Analysis	
Interactive Graphical Interface	Trade-offs between indicators to identify the best appropriate ranking of options from all perspectives

5.2.3 Relative Importance of the Indicators

This phase is based on the following successive steps:

1. For each of the four sustainable criteria, identify the sub-criteria, and relative weights from the viewpoint of the stakeholders.
2. For each sustainable criterion:
    - Constructing a pairwise comparison matrix between the indicators of each sustainable criterion based on the weights of specific stakeholders. Participants are experts, transport system providers.
    - Generate a normalized matrix (sum the elements of each column j and divide each value by its column sum).
    - Calculate the average of each row.
    - Compute the Priority Vector of the indictors by multiplying the average by the specific criteria priority.
    - Perform the consistency test to insure that an acceptable consistency between the weights is reached

5.2.4 Priority of Project Alternatives regarding the Sustainable Criteria

This phase is carried out in two steps; one for quantitative criteria and the other for qualitative criteria.

For Quantitative Criteria, the rating of project alternatives is achieved using the Multi-Criteria Decision Analysis (MCDA), as follows:

1. Construct a matrix that contains the performance values of each criterion for all alternatives, as well as the relative stakeholder weights of the different criterion.
2. Determine the minimum and the maximum performance value of each criterion, and calculate the deference between them.
3. Create a scaling matrix for "more is better" criterion and "less is better" criterion:
    - In case of criteria with more is better, set 0 for the minimum value and 1 for the maximum value for each criterion, and the other values of this criterion in a linear scale between 0 and 1; and
    - In case of criteria with less is better, set 1 for the minimum value and 0 for the maximum value for each criterion, and the other values of this criterion in a linear scale between 0 and 1.

   The scaled matrix contains, then, the relative importance of each criterion for each project option in a scale between 0 and 1, i.e. a_{ij} (i = from 1to m, and j= 1 to n).
4. Calculate the Weighted Sum Score for each project regarding each criterion by multiplying the normalized value by the specific indicator weight.

For Qualitative Criteria, the rating of project alternatives is reached using the Analytical Hierarchy Process (AHP), as follows:

1. Constructing pairwise comparison matrices based on the weights of stakeholders.
2. Sum the elements of each column j

3. Divide each value by its column sum to generate normalized matrices. The sum of each column will be 1
4. Calculate the average of each row, which presents the Priority Vector (P_i) of the row
5. Calculate the Local Priority Vector (LP_i) of each alternative:
   - In case of a “more is better” criterion, the priority vector Pi of alternative i presents the local priority vector (LPi) of a particular criterion
   - In case of a “less is better” criterion, the priority vector Pi of alternative i regarding this criterion should be regulated to calculate the local priority vector LPi
6. Pairwise comparison between each two criterion to determine the weighted vector (W_i) for each criterion.
7. Construct a Matrix that includes Local Priority (LP_{ij}) of all alternatives against all criteria, as well as the weighted vector (W_i) for each criterion.
8. Calculate the Global Priority GP_i of the alternatives to combine the local priorities across all criteria. the Global Priority is the sum of the local priorities LP_{ij} multiplied by weighted vector W_i

5.2.5 Priorities Aggregation and Sustainability Composite Index

After determination of the Global Priority of all alternatives among all sustainable criteria, construct alternative/criteria matrix in the following form, then

1- Calculate the sum of local priority of each option to determine its Composite Index .
2- Prioritize the options according to their indexes.

	Sustainable Criteria				Sustainability Composite Index
Options	Economic	Social	Environmental	Transport Efficiency	SUM
Alternative 1					
Alternative k					

5.2.6 Visual Composite Sustainability Level

Using the four sustainability global priorities for each option, a profile graph can be drawn to capture different dimensional of sustainability (trapezium shape), as shown in Figure 7. This trapezium reflects the relative sustainability global priorities of each option. The maximum achievable levels of sustainability of the options on each axis; define the edges of the trapezium that presents the maximum achievable sustainability level. The relative sustainability level of an option is the percentage of the option trapezium area to the maximum achievable trapezium area. Thus, the sustainability level of any alternative can be calculated from the following equation:

Sustainability Level = Achieved Sustainability ÷ Maximum Achievable Sustainability (In %) (23)

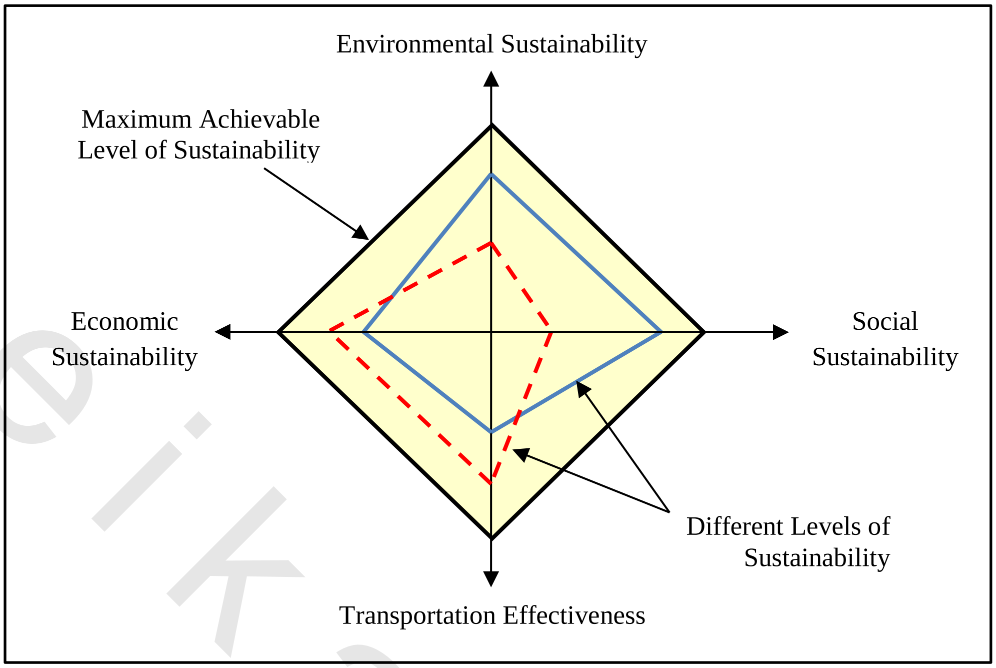


Figure 7: Visual Composite Sustainability Index

5.2.7 Visual Sensitivity Analysis

Weighting of criteria and indicators in group is usually difficult. In this procedure, to bypass this difficulty, it is proposed to allocate the weights by each participant, and the final weights can be postponed after the calculation of the priorities. An aggregation after the calculation of priorities allows the discussion of any further disagreement (Escobar & Moreno-jiménez, 2007). The visualization of the analysis of each participant can facilitate the final decision.

Sensitivity analysis addresses the question, "How sensitive is the overall decision to small changes in the individual weights assigned during the pair-wise comparison process?" This question can be answered by varying slightly the values of the weights, and observing the effects on the decision (Anjali Awasthi & Chauhan, 2011). If the ranking does not change, the results are said to be strong, otherwise it is sensitive (Sipahi & Timor, 2010).

In the proposed procedure, the interactive graphical interface allows a better visualization of the impact of the changes in the allocated weights, as well as enables an explicitly and deeply investigation of the inter-relationships in the evaluation process. Thus, the visualization tool supports decision maker to discover and assess the trade-offs between differences to identify the best appropriate ranking of options from all perspectives.

5.3 Illustrative Example

For a simple numerical example suppose that three candidate project options P 1, P 2, and P 3 are subjected to CETP application for screening and rating. The Table below shows the four sustainable criteria used for the evaluation of project options:

Sustainability Criteria	
Economic Sustainability	A
Social Sustainability	B
Environmental Sustainability	C
Transport System Efficiency	D

The CETP contains six phases:

1. Relative Importance of the Sustainable Criteria.
2. Relative Importance of the Indicators.
3. Prioritizing Project Options for each Indicator.
4. Priorities Aggregation for all Sustainable Criteria.
5. Visual Composite Sustainability Level.
6. Visual Sensitivity Analysis

Phase 1: The Relative Importance of the Sustainable Criteria

The next Table presents the construction of the pairwise comparison matrix for the four sustainable criteria, based on given weights, including the calculation of the Priority Vector of each criterion (Item 5.2.2 above).

Pairwise Comparison		
A	2.0	B
A	0.5	C
A	1.0	D
B	1.0	C
B	0.5	D
C	0.5	D

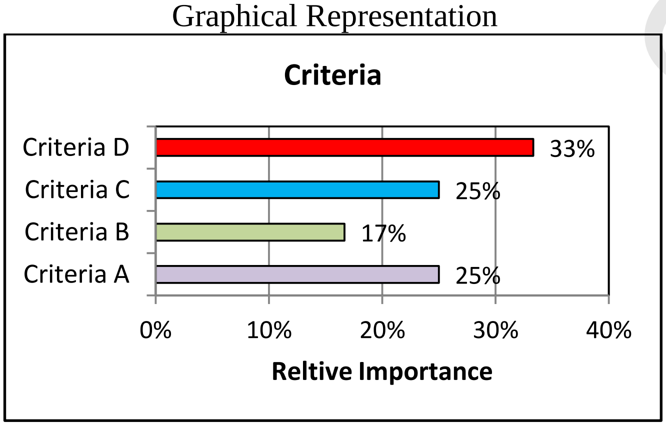
Pairwise Comparison Matrix				
Criteria	A	B	C	D
A	1	2.0	0.5	1.0
B	0.5	1	1.0	0.5
C	2.0	1.0	1	0.5
D	1.0	2.0	2.0	1
SUM	4.5	6.0	4.5	3.0

Consistency Ratio = 0.093 < 0.1

Normalized Matrix			
A	B	C	D
0.2	0.3	0.1	0.3
0.111	0.167	0.222	0.167
0.444	0.167	0.222	0.167
0.222	0.333	0.444	0.333

Priority (Average)
25.00%
16.67%
25.00%
33.33%

Graphical Representation



Phase 2: The Relative Importance of Indicators

The indicators of the four sustainable criteria are defined, and classified to quantitative and qualitative.

Sustainable Criteria and their Indicators

Sustainable Criteria	A	B	C	D
Quantities Indicators	A1		C 1	D 1
	A 2		C 2	
Qualitative Indicators		B1	C 3	D 2
		B 2	C 4	

The next Tables contain the construction of a pairwise comparison matrix for each one of the four sustainable criteria, established on proposed weights. The Tables include the calculation of the Priority Vector of each indicator (Item 5.2.3).

A. Economic Sustainability (Criterion A)

Pairwise Comparison		
A 1	0.5	A 2

Pairwise Comparison Matrix		
Indicators	A 1	A 2
A 1	1	0.5
A 2	2	1
SUM	3.0	1.5

Consistency Ratio < 0.1

Normalized Matrix	
A 1	A 2
0.3	0.3
0.7	0.7
1.0	1.0

AVG
0.33
0.67
1.00

Priority Vector
0.08
0.17
0.25

B. Social Sustainability (Criterion B)

Pairwise Comparison		
B 1	9	B 2

Pairwise Comparison Matrix		
Indicators	B 1	B 2
B 1	1	9
B 2	0.1	1
SUM	1.1	10

Consistency Ratio < 0.1

Normalized Values	
B 1	B 2
0.9	0.9
0.1	0.1
1.0	1.0

AVG
0.9
0.1
1.0

Priority
0.15
0.02
0.167

C. Environmental Sustainability (Criterion C)

Pairwise Comparison		
C 1	1	C 2
C 1	1	C 3
C 1	0.5	C 4
C 2	1	C 3
C 2	0.5	C 4
C 3	0.5	C 4

Pairwise Comparison Matrix				
	C 1	C 2	C3	C 4
C 1	1	1	1	0.5
C 2	1	1	1	0.5
C3	1	1	1	0.5
C 4	2	2	2	1
∑	5.00	5.00	5.00	2.50

Consistency Ratio < 0.1

Normalized Values			
C 1	C 2	C3	C 4
0.20	0.20	0.20	0.20
0.20	0.20	0.20	0.20
0.20	0.20	0.20	0.20
0.40	0.40	0.40	0.40
1.0	1.0	1.0	1.0

AVG
0.20
0.20
0.20
0.40
1.0

Priority
0.05
0.05
0.05
0.10
0.25

D. Transport Efficiency Sustainability (Criterion B)

Pairwise Comparison		
D 1	0.11	D 2

Pairwise Comparison Matrix		
	D 1	D 2
D 1	1	0.11
D 2	9.01	1
Sum	10.01	1.11

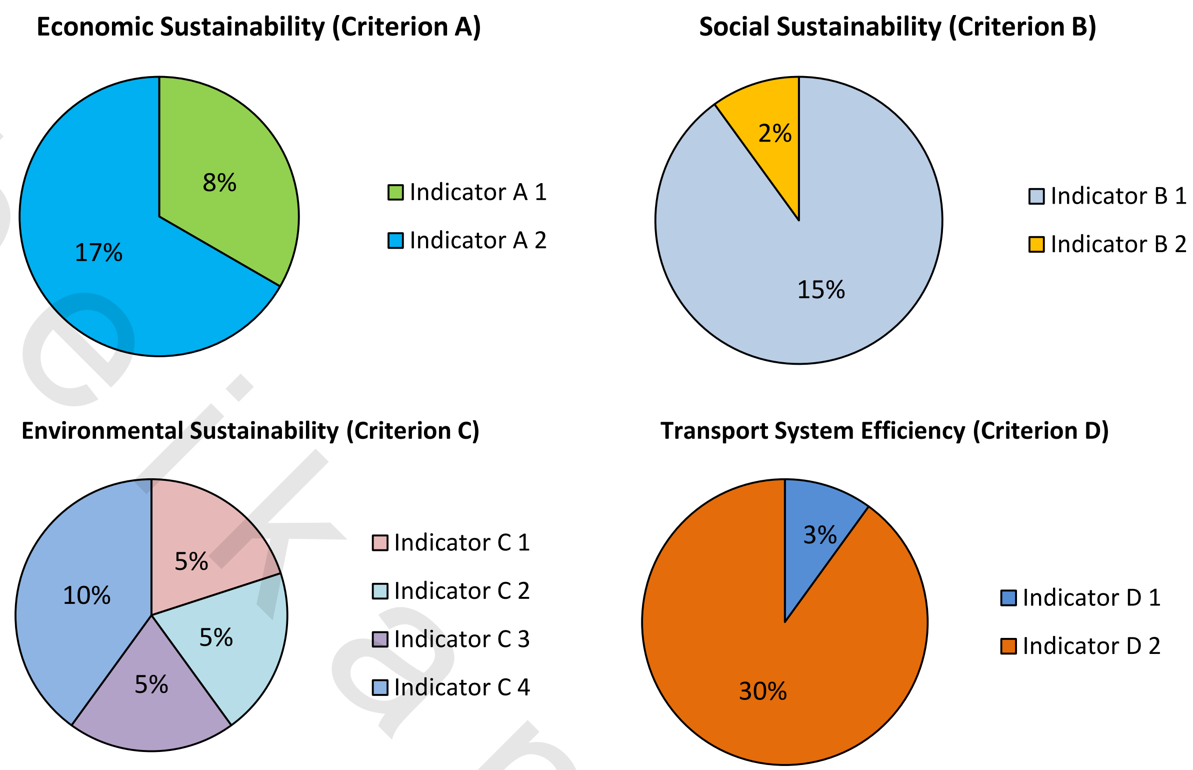
Consistency Ratio < 0.1

Normalized Values	
D 1	D 2
0.10	0.10
0.90	0.90
1.0	1.0

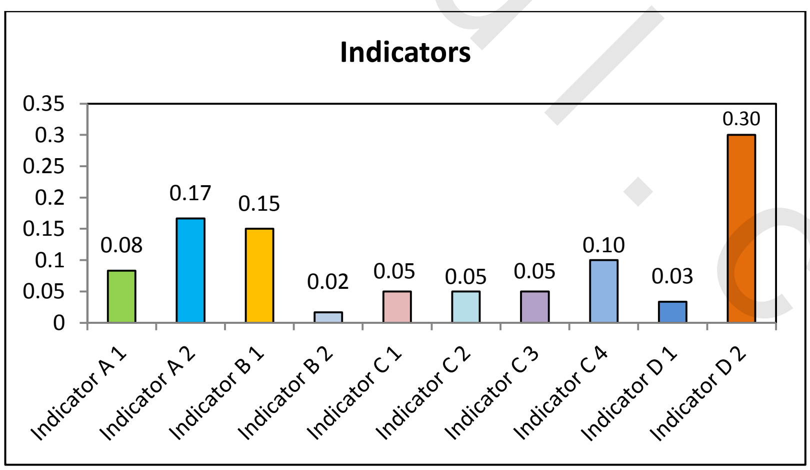
AVG
0.10
0.90
1.0

Priority
0.03
0.30
0.33

Graphical Representation



Relative Importance of each Indicator



Phase 3: Prioritizing Project Options for each Indicator (Item 5.2.4)

For Quantitative indicators, a matrix is constructed containing the performance values of each indicator for all project options, as well as given relative weights of the different indicators. A scaled matrix is then formulated to involve the relative importance of each indicator for each option. The Weighted Sum Score (Priority Weighted Vector) for each option regarding each indicator is calculated by multiplying the normalized value by the specific indicator weight.

For Qualitative indicators, a pairwise comparison matrix is constructed based on assumed weights. After normalizing this matrix, the average of each row (option) is calculated. It presents the Priority Vector as well as the Local Priority Vector of each specific indicator, in case of "more is better" indicators. In the other case "less is better", the Priority Vector of each indicator is regulated to determine the local priority vector (local priority vector =1- priority vector).

A. Economic Sustainability

Quantitative Indicators

Options Matrix				Scaling Matrix			Normalized Values		Priority Weighted Vector	
Options	A 1	A 2		A 1	A 2		A 1	A 2	A 1	A 2
Project P 1	25	20		0.75	0.5		0.43	0.33	0.04	0.06
Project P 2	10	30		0	1		0.00	0.67	0.00	0.10
Project P 3	30	10		1	0		0.57	0.00	0.04	0.01
Δ	20	20	∑	1.75	1.5	Weights	0.08	0.17	0.08	0.17

B. Social Sustainability

Qualitative Indicators

For B 1

Options	Pairwise Comparison Matrix			Normalized Values			AVG	Consistency Test				
	P 1	P 2	P 3	P 1	P 2	P 3		WV	CF	λ	CI	CR
Project P 1	1	5	3	0.65	0.71	0.6	0.66	2.00	3.06	3.03	0.01	0.03
Project P 2	0.2	1	1	0.13	0.14	0.2	0.16	0.48	3.01			
Project P 3	0.33	1	1	0.22	0.14	0.2	0.19	0.56	3.01			
∑	1.53	7	5	1.0	1.0	1.0	1.0					

For B 2

Options	Pairwise Comparison Matrix			Normalized Values			AVG	Consistency Test				
	P 1	P 2	P 3	P 1	P 2	P 3		WV	CF	λ	CI	CR
Project P 1	1	3	5	0.65	0.67	0.63	0.65	1.95	3.01	3.00	0.00	0.00
Project P 2	0.33	1	2	0.22	0.22	0.25	0.23	0.69	3.00			
Project P 3	0.2	0.5	1	0.13	0.11	0.13	0.12	0.37	3.00			
∑	1.53	4.5	8	1.0	1.0	1.0	1.0					

Priority Weighted Vectors

Options	Priority Vectors			Priority Weighted Vectors		
	B 1	**B 2**				
Project P 1	0.655	0.648		0.098	0.011	
Project P 2	0.158	0.230		0.024	0.004	
Project P 3	0.187	0.122		0.028	0.002	
Weights	0.15	0.02	∑	0.15	0.017	0.167

C. Environmental Sustainability

Quantitative Indicators

Options Matrix				Scaling Matrix			Normalized Values		Priority Weighted Vector	
Options	C 1	C 2		C 1	C 2		C 1	C 2	C 1	C 2
Project P 1	20	25		0.75	0.67		0.43	0.44	0.02	0.02
Project P 2	5	30		0.00	1.00		0.00	0.67	0.00	0.03
Project P 3	40	15		1.00	0.00		0.57	0.00	0.03	0.000
Δ	35	15	∑	1.75	1.67	Weights	0.05	0.05	0.05	0.05

Qualitative Indicators
For C 3

Options	Pairwise Comparison Matrix			Normalized Values			AVG	Consistency Test				
	P 1	P 2	P 3	P 1	P 2	P 3		W V	CF	λ	CI	CR
Project P 1	1	0.2	0.25	0.1	0.12	0.08	0.10	0.3	3.01	3.3	0.012	0.02
Project P 2	5	1	2	0.5	0.59	0.62	0.57	1.7	3.04			
Project P 3	4	0.5	1	0.4	0.29	0.31	0.33	1.0	3.03			
∑	10	1.7	3.25	1.0	1.0	1.0	1.0					

For C 4

Options	Pairwise Comparison Matrix			Normalized Values			AVG	Consistency Test				
	P 1	P 2	P 3	P 1	P 2	P 3		WV	CF	λ	CI	CR
Project P 1	1	2	4	0.57	0.12	0.08	0.56	1.7	3.0	3.02	0.01	0.02
P 2	0.5	1	3	0.5	0.59	0.62	0.32	1.0	3.0			
P 3	0.25	0.33	1	0.4	0.29	0.31	0.12	0.4	3.0			
∑	1.75	3.33	8	1.0	1.0	1.0	1.0					

Priority Weighted Vectors

Options	Priority Vectors			Priority Weighted Vectors		
	C 3	**C 4**				
Project P 1	0.098	0.56		0.098	0.06	
Project P 2	0.568	0.32		0.024	0.03	
Project P 3	0.334	0.12		0.028	0.01	
Weights	0.05	0.1	∑	0.05	0.1	0.15

D. Transport Efficiency

Quantitative Indicators

Options Matrix			Scaling Matrix		Normalized Values	Priority Weighted Vector
Options	D 1		D 1		D 1	D 1
Project P 1	15		0.25		0.14	0.0048
Project P 2	10		0		0.00	0.0000
Project P 3	45		1		0.57	0.0190
Δ	35	∑	1.25	Weights	0.03	

Qualitative Indicators
For D2

Options	Pairwise Comparison Matrix			Normalized Values			AVG
	P 1	P 2	P 3	P 1	P 2	P 3	
Project P 1	1	1	0.5	0.25	0.33	0.2	0.26
Project P 2	1	1	1	0.25	0.33	0.4	0.33
Project P 3	2	1	1	0.5	0.33	0.4	0.41
∑	4	3	2.5	1.0	1.0	1.0	1.0

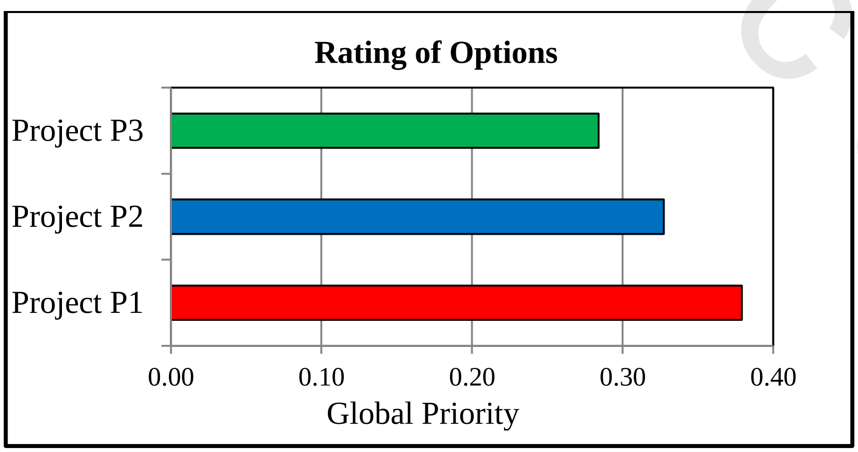
Consistency Test				
WV	CF	λ	CI	CR
0.79	3.04	3.05	0.03	0.05
1.00	3.05			
1.26	3.07			

Options	Priority Vectors D 2		Priority Weighted Vectors	
Project P 1	0.26		0.08	
Project P 2	0.33		0.10	
Project P 3	0.41		0.12	
Weights	0.30	∑	0.30	0.30

Phase 4: Priorities Aggregation for all Sustainable Criteria and Sustainability Composite Index (Item 5.2.5)

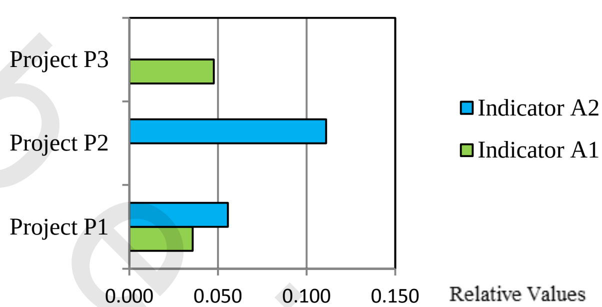
The Global Priorities of the project options are calculated to combine the local priority vectors across all criteria. The Global Priority is the sum of the local priority vectors multiplied by weighted vector of each indicator. The Global Priorities are used for rating the project options.

Criteria	Economic		Social		Environmental				Transport Efficiency		Global Priority
	A1	A2	B 1	B 2	C 1	C 2	C3	C4	D 1	D 2	
Project P1	0.036	0.056	0.098	0.011	0.02	0.02	0.00	0.06	0.00	0.08	0.379
Project P2	0.000	0.111	0.024	0.004	0.00	0.03	0.03	0.03	0.01	0.10	0.327
Project P3	0.048	0.000	0.028	0.002	0.04	0.00	0.02	0.01	0.02	0.12	0.284
∑	0.083	0.167	0.150	0.017	0.05	0.05	0.05	0.10	0.03	0.30	1.000
Weights	0.25		0.167		0.25				0.33		

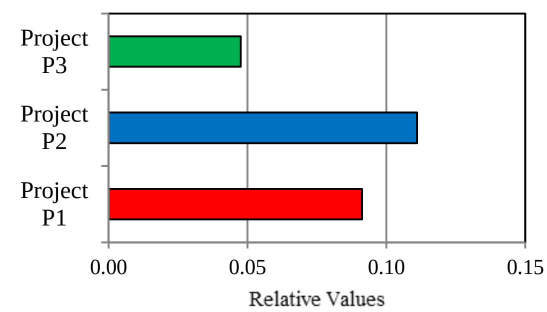


Graphical Representation
Importance of indicators for Rating Project Options

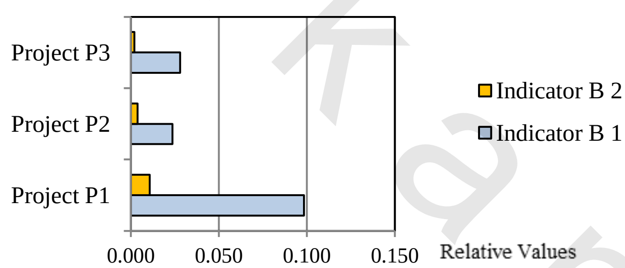
Options and Economic Indicators



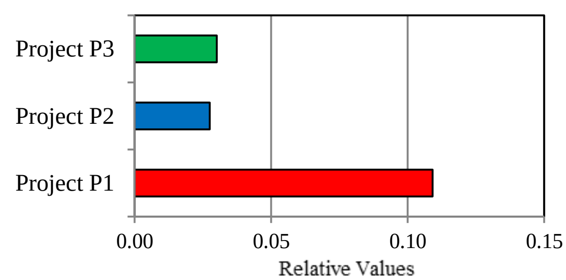
Priorities and Economic Criteria



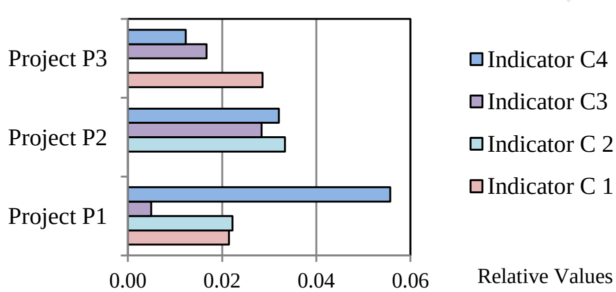
Options and Social Indicators



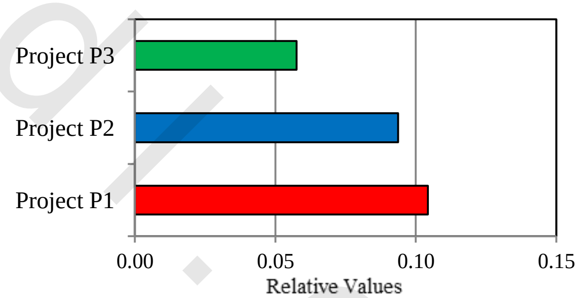
Priorities and Social Criteria



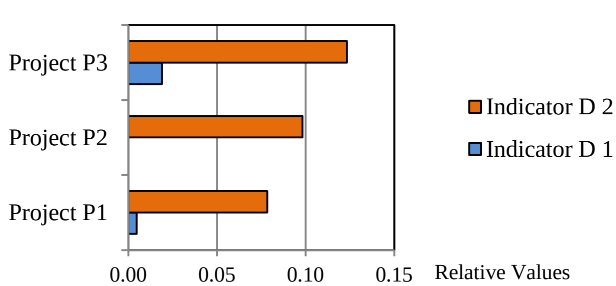
Options and Environmental Indicators



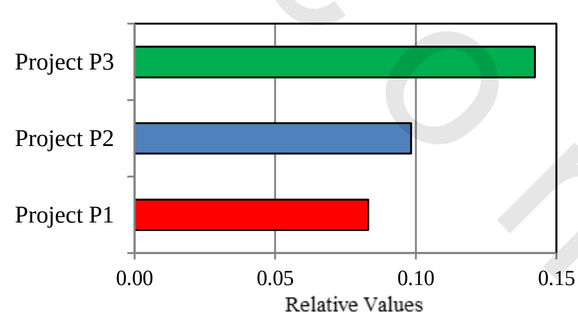
Priorities and Environmental Criteria



Options and Transport Efficiency



Priorities and Transport Efficiency

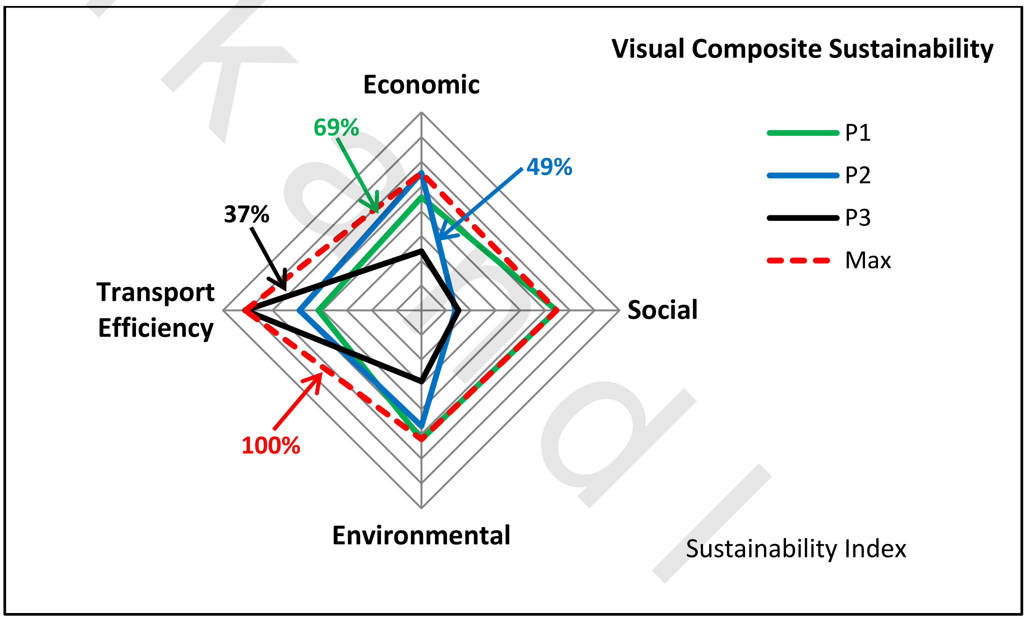


Phase 5: Visual Composite Sustainability Level (Item 5.2.6)

After the determination of the Global Priority of all project options among all sustainable criteria, construct a project option/criteria matrix is constructed to calculate the Composite Sustainability Level of each project option, which presents the percentage of the achieved sustainability of an option to the maximum achievable sustainability.

Sustainable Criteria	A	B	C	D	Area	Index	Rating
Project P 1	0.091	0.109	0.096	0.083	0.018	69%	1
Project P 2	0.111	0.027	0.090	0.098	0.013	49%	2
Project P 3	0.048	0.030	0.064	0.142	0.010	37%	3
Maximum Achievable Sustainability	0.111	0.109	0.096	0.142	0.026	100%	

Graphical Representation



Phase 6: Visual Sensitivity Analysis (Item 5.2.7)

There are variances between the three project options in the overall sustainability levels, and also in the scores of the four different sustainability dimensions. However, Project 1 and Project 2 are still comparable options.

The analysis of these multiple dimensional levels using the visualizing tool enables the decision maker to discover the trade-offs between the differences. This type of trade-offs can be valuable for understanding the impacts of decision making on the urban ability to achieve its current priorities. Understanding the impacts of selecting one option over another requires investigating the trade-offs that are being made from option to option.

Project 1 is the superior option in the overall level, and regarding social and environmental scores. While project 2 is in the second level and has some advantages in the economic dimensions.

If the indicator B1 is eliminated from the evaluation as a social indicator, Project P2 will be the first-class project, followed by Project P1. Otherwise, excluding any other indicator from the evaluation procedure has no effects in the ranking off all projects.

Eliminating any indicator from the evaluation has no effects in the ranking of all projects, except the indicator B1. If it is excluded from the evaluation, Project P2 will be the first-class project, followed by Project P1.

Otherwise, the priorities which are determined from subjective distributed weights are critical, so that in the analysis equal levels of importance are placed on all measures and dimensions. In this case, Project 2 obtains the highest score, then project 2. As a standard, such a ‘‘neutral’’ weighting analysis enables decision makers to readily track the changes in the results by applying different weights. However, the importance of weights for the various criteria should be in a farther study recognized. For instance, if the Global Priority of Project 1 decreases with 6% and at the same time it increases for Project 2 with 8%, the rating of both projects will be changed.