Coordination and support action (Coordinating Action)

FP7-ENERGY-SMARTCITIES-2012

WP5 – Integrated planning tool for the development of Strategic Sustainable Energy Plans

Task 5.3 – Multicriteria Analysis

D5.6. Report on the multicriteria methodology, the process and the results of the decision making – Trikala, Greece

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Editors		
	Name (Organisation)	e-mail
Leading participant	G.M. Stavrakakis (CRES) C. Nychtis (CRES) G. Giannakidis (CRES)	gstavr@cres.gr cnychtis@cres.gr ggian@cres.gr
Contributing participants		
WP Leader (WPL)	E4SMA	
Project Coordinator	CRES	

Executive summary	
This report presents the optimal ranking of available urban energy upgrading alternative actions considered for the City of Trikala in the framework of task 5.3. The various impacts (criteria values) of different renovation actions (resulted by TIMES models) are assessed using the MultiCriteria Decision Aid (MCDA) software Visual PROMETHEE v.1.4.0.0 combined with a systematic methodology (Hinkel's method) to determine the weights of the objective function. The MCDA problem is solved using the PROMETHEE software by means of a hierarchical optimization set-up for processing the databases of available pairs of actions and criteria towards the ranking of actions which satisfy and/or compromise preferences and constraints extracted by multiple stakeholders.	
Keywords	MultiCriteria Decision Aid (MCDA); PROMETHEE; Ranking of urban energy upgrading actions; Stakeholders' preferences; Decision-making; Hinkle's method; Deliberative MultiCriteria Evaluation (DMCE) methodology

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1 Introduction

This report presents the optimal ranking of alternative urban energy upgrading scenarios for the city of Trikala in the framework of task 5.3 of the InSMART project. The methodology applied is based on a Deliberative MultiCriteria Evaluation (DMCE) approach comprising the following main steps:

- Manipulation of stakeholders' feedbacks: The main stakeholders/decision-makers related to the urban planning problem are: (a) Municipality, (b) Commercial Association, (c) Trikala Chamber, and (d) Trikala Technical Chamber. To extract stakeholders' preferences, targeted questionnaires were developed including the specific criteria requesting from stakeholders to point out the importance of each criterion over the others. Feedbacks were then manipulated based on the Hinkle's "resistance to change" method[1] towards the conclusion of representative preferences that were used as weights in the decision-making scheme afterwards.
- Decision-making scheme definition: Based on the aforementioned result the full decision-making problem is defined regarding the objective function, criteria, sub-criteria, weights' assignment, and possible constraints for each criterion.
- MultiCriteria Decision Aid (MCDA) approach: The available databases of pairs of "action-vector of criteria", meaning the impacts (values of criteria) as provided by the TIMES model for each urban planning scenario for the City of Trikala, were further processed so as to solve the decision-making scheme for each stakeholder stated in the above step. For that purpose, the specialized MCDA software Visual PROMETHEE v.1.4.0.0 (Academic edition)[2] was used. As a result, a ranking of alternative planning scenarios is produced which prioritizes the actions from the one with the best to the one with the worst compromise among the evaluation criteria. Having considering feedbacks from most important stakeholders involved in the decision making problem, the 1st in ranking options provides the most appropriate and applicable solution for the City of Trikala.

2 Background of the adopted MCDA method

As mentioned above the following methods were used to systematise the decision-making approach:

- Resistance to change grid method
- PROMETHEE method

2.1 "Resistance to change" grid method

In multi-criteria assessment weights of criteria are used to specify the relative importance of each specific criterion. The "resistance to change" method[1] is based on the principle that when comparing a criterion A to a criterion B, the decision maker is most reluctant to change the most important criterion from the desirable state to the undesirable one.

For example, we have a waste management problem to evaluate competing solid waste management systems. We have 8 criteria as follows:

g(1) cost of waste treated;

g(2) technical reliability;

g(3) global warming effects;

g(4) releases with health effects;

g(5) acidificative releases;

g(6) surface water dispersed releases;

g(7) number of employees;

g(8) waste recovery rate.

The weighting method is based on the pairwise comparison of the criteria. For example, we compare criterion g(1) with criterion g(2) and we ask the decision maker if it was to change one of the two criteria from the desirable state to the undesirable state, then which would be the criterion that the decision maker would be reluctant to change. Let's assume that in this case the decision maker is most reluctant to change criterion g(2) from the desirable state, which is "technically reliable", to the undesirable state, which is "technically unreliable". Then criterion g(2) should be considered more important than criterion g(1), because it is more resistant to change.

When we say the desirable state and the undesirable state, the decision maker can build and have in mind the desirable and the undesirable states of the criteria in order to facilitate the comparison. For example, in the 8 criteria above, the pairs of the desirable and undesirable states can be specified as follows:

(C1) economical waste treatment/costly waste treatment;

(C2) technically reliable/technically unreliable;

(C3) negligible global effects/significant global effects;

(C4) negligible releases with health effects/significant releases with health effects;

(C5) negligible acidificative releases/ significant acidificative releases;

(C6) negligible surface water dispersed releases/significant S.W. dispersed releases;

(C7) high employment levels/low employment levels;

(C8) high waste recovery rate/low waste recovery rate.

The pairwise comparison between the criteria states above can be organized in the form of the grid in Table 1.

Table 1: Pairwise criteria-comparison grid

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	Score
C1									7
C2									6
C3				x		x	x	x	1
C4						I		x	3
C5						x		x	1
C6								x	3
C7									2
C8									4

In the grid, an ‘x’ indicates that the criterion in the column is resistant to the change of the one in the row it is compared to. A blank indicates that the criterion in the row resists to the change of the one in the column it is compared to. There are two other cases, where it may prove impossible for the decision maker to make a choice. Firstly, where the two changes appear equally undesirable to the decision maker (denoted in the grid as ‘I’), and, secondly, where the change in one criterion implies the change in the other (denoted in the grid as ‘e’).

In order to derive the scores of each criterion, all the blanks along the rows above the diagonal are added to all the corresponding ‘x’s in the columns to give the final score. Thus, for example see in grid that for criterion 1, there are 7 blank rows, so the score for resistance is 7; for criterion 2, there are 6 blank rows and no ‘x’s, so the score is 6; criterion 4 has 2 blanks and 1 ‘x’, so the score is 3 and so on. Finally the resistance scores for each criterion can be normalised to give the final weights for each criterion, i.e. by dividing the score of each criterion with the sum of scores of all criteria.

2.2 PROMETHEE method

The PROMETHEE method is a multicriteria decision-making method developed by Brans[3]. It is a ranking method quite simple in conception and application compared to other methods for multi-criteria analysis. It is well adapted to problems where a finite number of alternative actions are to be ranked considering several, sometimes conflicting, criteria. Specifically, the PROMETHEE method is appropriate to treat the multicriteria problem of the following type:

$$\max\{f_1(a),...,f_n(a) \mid a \setminus A\} \quad (1)$$

Where A is a finite set of possible alternatives, and f_j are n criteria to be maximized. For each alternative, $f_j(a)$ is an evaluation of this alternative. When two alternatives a, b\A are compared, the result of the comparison has to be expressed in terms of preference. Therefore, a preference function is considered:

$$P(a,b) = F(d) = F[f(a) - f(b)],\ 0 \leq P(a,b) \leq 1 \quad (2)$$

Where $F(d)$ is a monotonically increasing function of the observed deviation (d) between f(a) and f(b). In order to facilitate the selection of specific preference function, six basic types of this preference function are proposed to the decision maker, in each case no more than two parameters (thresholds q, p or s) have to be fixed[4, 5].

Indifference threshold q is the largest deviation to consider as negligible on that criterion. It is small value with respect to the scale of measurement. Preference threshold p is the smallest deviation to consider as decisive in the preference of one alternative over another. It is a large value with respect to the scale of measurement. Gaussian threshold s is only used with the Gaussian preference function. It is usually fixed as an intermediate value between the indifference and the preference threshold.

PROMETHEE permits the computation of the following quantities for alternatives a and b:

a and b are alternatives from the first set of alternatives A. Then is:

$$\pi(a,b) = \sum_{j=1}^{k} P_j(a,b)w_j \quad (3)$$

$$\pi(b,a) = \sum_{j=1}^{k} P_j(b,a)w_j \quad (4)$$

Positive course of preferential (output course):

$$\Phi^+(a) = \frac{1}{n-1}\sum_{x \in A} \pi(a,x) \quad (5)$$

Negative course of preferential (input course):

$$\Phi^-(a) = \frac{1}{n-1}\sum_{x \in A} \pi(x,a) \quad (6)$$

Where w_j are the weights associated with criteria.

For each alternative a belonging to the set A of alternatives, $\pi(a,b)$ is an overall preference index of a over b. The leaving flow $\Phi^+(a)$ is the measure of the outranking character of a (how a dominates all the other alternatives of A). Symmetrically, the entering flow $\Phi^-(a)$ gives the outranked character of a (how a is dominated by all the other alternatives of A). $\Phi(a)$ represents a value function, whereby a higher value reflects a higher attractiveness of alternative a. $\Phi(a)$ is called net flow of alternative a[6]. The concept of preferential flow functions is presented in Figure 1. All the alternatives can be completely ranked by net flow. The geometrical analysis for interactive aid (Gaia) plane displays graphically the relative position of the alternatives in terms of contributions to the various criteria[7].

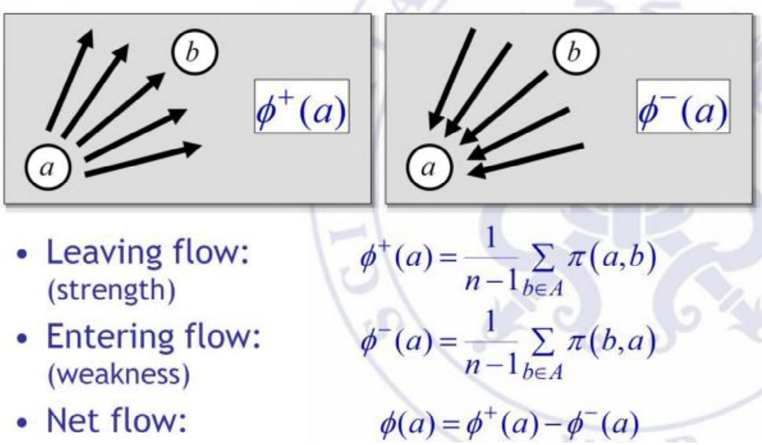


Figure 1: Concept of preferential course function.

2.3 MCDA applications for urban energy planning (short overview)

Energy planning can be defined as a roadmap for meeting the energy needs of a specific area (local, regional, national) and is accomplished by considering multiple factors such as technology, economy, environment, and the society that impact the energy issues. Long-term energy planning is a strategic approach to study how structural changes of a nation would affect the energy demand and supply. This is normally done through scenario analysis which would also cater for uncertainty in planning. Good energy plan would ensure sustainable development which acts as a guiding factor for an energy scheme. Energy planning processes must appreciate the energy demand situation in the area of interest and aim for the satisfaction of future needs, according to many constraints and factors. A MultiCriteria decision-making process is usually adopted in order to face complex economic, environmental and development problems[8].

Mourmouris and Potolias (2013)[9] adopted the MCDA REGIME method, which is a concordance method similar to ELECTRE and PROMETHEE, for the analysis and development of a multilevel decision-making structure, utilizing multiple criteria for energy planning and specifically for the exploitation of Renewable Energy Sources (RES) at regional level. The proposed evaluation framework focused on the use of multi-criteria approach as a tool for supporting energy planning for the area of concern (Thassos island, Greece) based on a pool of qualitative and quantitative evaluation criteria. The latter included economic, environmental, social and technological criteria and the method revealed that the combination of wind-biomass is the most efficient RES followed by the biomass-wind-PV and wind-PV alternatives. Terrados et al. (2009)[10] introduced a hybrid approach for MCDA combining PROMETHEE with the participatory “Delphi” method (experts’ feedbacks) to determine the weights and preferential thresholds of the decision-making problem. The application of the proposed methodology for the case study of Jaen Province revealed that the objective regarding electricity production from renewable resources, on year 2010, is fixed above 1630 GWh,which represents a 43% of the total foreseeable electricity consumption.

Regional or local energy planning refers to energy planning for a city or town or an energy system of a city or town. Examples of local energy planning include urban transportation, district heating, regional development, or plans dealing with environmental problems such as deforestation (fuel wood), urban air quality and waste management[11]. Advanced local energy planning (ALEP) is based on a sustainable approach and it is much more than traditional local energy planning. According to International Energy Agency[12] ALEP makes the use of comprehensive models of systems analysis that are capable of simulating and optimizing the whole system, rather than considering its components. ALEP provides a long-term strategic energy plan that satisfies different sustainability goals (such as reduction of GHG, responsible use of natural resources, social equity, and ecological and economic development). In addition, it involves all affected groups and decision makers to maximize the chance of realization, employs principles of modern project management and is a continuous process rather than a project with a defined end. One review presents 14 state indicators and 4 policy indicators for local energy planning[13]. The authors stipulate that indicators need to be comprehensive, limited and open-ended so that future changes can be made to these energy sustainability indicators. Another review interrogates on the application of different models for decentralized energy planning or local energy planning[14]. After reviewing 6 energy models for integrated community energy systems (ICES) planning (HOMER, DERCAM, EAM, MARKAL/TIMES, RETScreen, H2RES) Mendes et al. (2011)[15] conclude that the Distributed Energy Resources Customer Adoption Model (DERCAM) and the Economic Evaluation of Microgrid (EAM)–which have several successful applications – can be considered preferable tools for the purpose of ICES design modeling. They further concluded that system thinking is a highly valuable approach for designing energy futures. The central theme of decentralized energy planning, suggest preparing an area-based plan to meet the needs and development of alternative energy sources at least cost to the economy and the environment[12]. Deshmukh and Deshmukh (2009)[16] reported that centralized (national) energy planning does not cater for the needs of rural areas due to urban areas given priority for energy supply, social and environmental benefits. Regional or local energy planning would encourage development of economically productive activities.

The present report addresses previous findings regarding territorial energy planning through the use of a hybrid Hinkle-PROMETHEE method taking into account the most important evaluation criteria in accordance to other similar studies. Specifically, the decision-making problem includes energy, environmental, economic, societal and technological considerations in the mix of evaluation criteria, while preference thresholds and weights are taken by a systematic application of the Hinkle's method involving the key stakeholders/decision-makers. The method is applied for the city of Trikala and provided a ranking of smart-city planning actions from the best to the worst (in the context of compromising the mix of evaluation criteria) possible intervention suggestions.

3 MCDA for Smart-City planning of Trikala

The MCDA approach described above is adapted for decision making concerning the identification of the optimum alternative actions (mix of urban planning interventions) that ensure urban sustainability (energy, environment, quality of life) in the context of a future Smart City in Trikala. The decision making problem comprises the following aspects:

- Evaluation criteria for holistic smart-city planning
- Alternative upgrading actions in terms of mixes of planning interventions
- Stakeholders' preferences over the recognized criteria

The evaluation criteria adopted in InSMART are the following (aggregated implications from all urban features, i.e. buildings, transport and mobility, waste and utilities):

- Implementation/investment cost (€)
- Implementation cost efficiency (saved kWh/€ investment spent)
- Energy savings (MWh)
- Operation and maintenance cost (€)
- Revenue production (€)
- Ease of implementation
- City's quality of life improvement (thermal comfort, lighting comfort, traffic conditions, etc.)
- City's economic development improvement

- Level of societal acceptance

Table 2: Alternative smart-city planning actions for Trikala

Action	Short description
Scen1: Buildings all	Refurbishment of all municipal buildings. The refurbishments focus on the reduction of thermal and cooling loads and the improvement of lighting installations.
Scen2: Buildings 80	80% of the buildings within the geographical limits of the municipality, are connected to the natural gas network by 2030. This includes both residential and non-residential buildings.
Scen3: Buildings 1950	Complete renovation of residential buildings that were built before 1950. The complete renovation includes all four options identified in WP2 as appropriate for the building stock in Trikala, namely replacement of windows, insulation of roofs and walls.
Scen4: Buildings exikonomo	Partial renovation of all the residential building typologies following a "Saving at Home" Programme of the Ministry of Energy and Environment, the so-called "Exikonomisi katoikon". This means that the option of windows replacement, roof insulation, walls insulation, all related combination are available, and the preferred mix is calculated by the model using the relative cost and benefits of each intervention in order to minimise the total system cost.
Scen5: Street lighting 6000	Replacement of the 6000 existing sodium street light bulbs with high efficiency LED lamps is implemented.
Scen6: RES 10%	10% of the electricity demand in the municipality will be covered by renewable energy projects, funded by the municipality by 2030 (the share in 2020 will reach 5%).
Scen7: Green spaces	"Green Spaces" options are implemented in all the city squares and open spaces, in order to reduce the cooling demand of buildings in the city.
Scen8R: Mobility ring road	Construction of the ring road around the city which leads to a reduction of the transport load through the city centre.
Scen8C: Cycling routes	Construction of cycling routes with a length of 2.8km in the next 2-3 years and an extra 10km in the next 10 years.
Scen9: Vehicles	Replacement of ten existing municipal small vehicles by electric cars.

Action	Short description
replacement	Furthermore, all the municipal heavy duty vehicles (trucks, refuse collection trucks etc.) will be replaced by Euro 6 vehicles in the next 15 years.
Scen10: Hybrid/electric cars incentives	Incentives for the promotion of hybrid or electric cars in the city center.
Scen11: Landfill 950kW	Installation of 950kWe of a biogas fired power plant in the landfill by 2020, assuming that the generated electricity covers directly the demand in the city.
Scen12: Sewage treatment 20%	Decreased consumption in the sewage treatment plant by 25% with the use of special bacteria.
Scen13: Dam construction	The energy consumption is planned to be reduced through the construction of the small dam which will provide water to the municipality (without the need of pumping due to the geography) and the installation of the small hydro power plant (200kW) at this site, by 2022.

The aforementioned evaluation criteria/indicators were calculated using the TIMES model which elaborated results from suitable impact assessment models, e.g. the Designbuilder software for the building sector[17]. Criteria calculations took place for various alternative feasible actions which are described in Table 2.

3.1 Weighing the evaluation criteria

As mentioned earlier the Hinkle's method is applied to weigh as realistically as possible the net flow function of the decision-making problem in the framework of the PROMETHEE method. Initially, the evaluation criteria were organized into a stakeholder-oriented matrix to better engage and facilitate decision-makers to provide reliable preferences. The matrix is presented in Table 3 and it essentially describes the evaluation criteria considered and their respective desirable and non-desirable states. Thereinafter, the evaluation criteria were oriented in the grid-form of Table 1 requesting from the identified stakeholders to score the criteria according to the instructions provided in section 2.1. The results obtained from each stakeholder scoring and corresponding normalized values (used as weights for each criterion in the PROMETHEE method afterwards) are presented in

Table 4, Table 5,

Table 6 and Table 7.

Table 3: Stakeholder-oriented matrix

Criteria	Code	Brief Description of the Criteria	Desirable state	Non-desirable state
1. Implementation Cost	C1	What is the implementation cost in € of the Investment over the period 2013-2030 in comparison to the implementation cost of the Business as Usual (BAU) case?	Low Cost	High Cost
2. Implementation Cost Efficiency	C2	How efficient in terms of energy is the Investment? How much energy in kWh is saved for every Euro € of Investment spent over the period 2013-2030?	High efficiency	Low Efficiency
3. Energy savings	C3	What is the total Energy that is being saved over the whole period until 2030 from the implementation of the measure in MWh?	High Energy Savings	Low Energy Savings
4. Operation and Maintenance Cost	C4	What is the total Operation and Maintenance cost of the measure over the whole period until 2030 in €?	Low Cost	High Cost
5. Revenue Production	C5	What is the annual Revenue Production of the measure for the period 2015-2030 in €?	High Revenue	Low Revenue
6. Ease of Implementation	C6	Are there technological risks on implementation? Does the scenario comply with, or fail to comply with, existing laws, environmental regulations, etc? Is administrative approval for numerous authorities required? Is the licensing procedure complex and of long time duration?	The implement-tation is simple and easy to complete	The implement-tation is complex and difficult to complete

7. City's Quality of Life Improvement	C7	Does the measure improves the: Thermal Comfort, Lighting Comfort, Traffic Conditions, Improvement of Living Conditions, etc.?	Improvement of City's Quality of Life	No Improvement of City's Quality of Life
8. City's Economic Development Improvement	C8	Does the measure improves the: Labour increase, economic sector increase (construction, tertiary – services , agricultural), etc.?	Improvement of City's Economic Development	No Improvement of City's Economic Development
9. Societal Acceptance	C9	Is the measure accepted by the local society?	High Societal Acceptance	Low Societal Acceptance

Table 4: Evaluation criteria scores and corresponding weights-Municipality

	C1	C2	C3	C4	C5	C6	C7	C8	C9	SCORE	normalize
C1				I					X	6	19.4
C2			e		I					5	16.1
C3					I					5	16.1
C4					I					4	12.9
C5						X	X		X	1	3.2
C6							X	X	X	1	3.2
C7									X	3	9.7
C8									X	1	3.2
C9										5	16.1

Table 5: Evaluation criteria scores and corresponding weights - Technical Chamber

	C1	C2	C3	C4	C5	C6	C7	C8	C9	SCORE	normalize
C1		X	X	I	I	X	X	X	X	0	0.0
C2			X	I		X	X	X	X	2	7.1
C3					I		I		I	5	17.9
C4					I	X	X	X	X	0	0.0
C5							X	X		2	7.1
C6							X	X	X	3	10.7
C7								X	e	5	17.9
C8										7	25.0

	C1	C2	C3	C4	C5	C6	C7	C8	C9	SCORE	normalize
C9										4	14.3

Table 6: Evaluation criteria scores and corresponding weights – Commercial Association

	C1	C2	C3	C4	C5	C6	C7	C8	C9	SCORE	normalize
C1										8	23.5
C2			e	X	X			X		3	8.8
C3				X	X					4	11.8
C4					X					6	17.6
C5										7	20.6
C6								X		2	5.9
C7								X		1	2.9
C8										3	8.8
C9										0	0.0

Table 7: Evaluation criteria scores and corresponding weights – Trikala Chamber

	C1	C2	C3	C4	C5	C6	C7	C8	C9	SCORE	normalize
C1				I	X					6	18.8
C2			e	X	X					4	12.5
C3				e	X					4	12.5
C4					I					5	15.6
C5										7	21.9
C6							X	X	X	0	0.0
C7								X		2	6.3
C8										3	9.4
C9										1	3.1

3.2 MCDA problem implementation in PROMETHEE

The multi-criteria decision problem is implemented in the PROMETHEE tool as follows:

- Set-up a ‘problem’ sheet for each Stakeholder-Decision maker; in this case, 4 different sheets for the Municipality, the Technical Chamber, the Commercial Association and the Trikala Chamber.
- Specification and grouping of the criteria, i.e.: Economical criteria (Cost/Investment, Cost efficiency, OM cost and Revenues); Savings (Energy savings); Bureaucracy as an implementation barrier (Ease of implementation); and, Social criteria (Quality of life, Economic development and general societal acceptance).
- Specification of scenarios/actions (refer to Table 2), classification and inputs. For each action, each indicator’ value is imposed in the INPUTS matrix. The inputs are produced by the TIMES-MARKAL model analysis (found in ref. 18). Similarly to the criteria considered, the interventions are also classified into: Buildings (Scen1-4), Street lighting (Scen5), RES (Scen6), Green spaces (Scen7), Mobility (Scen8-11), Waste (Scen12-13), and Water (Scen14).
- For each Stakeholder (problem sheet), the weights tabulated in Tables 4-7 are imposed, which essentially weigh each criteria according to the preference of the Stakeholder.
- The problem is further constrained using the so-called Preference function accompanied with P and Q thresholds, which strengthen the preference of each Stakeholder and, therefore, leading to a solution/decision more biased to the Stakeholder preference.

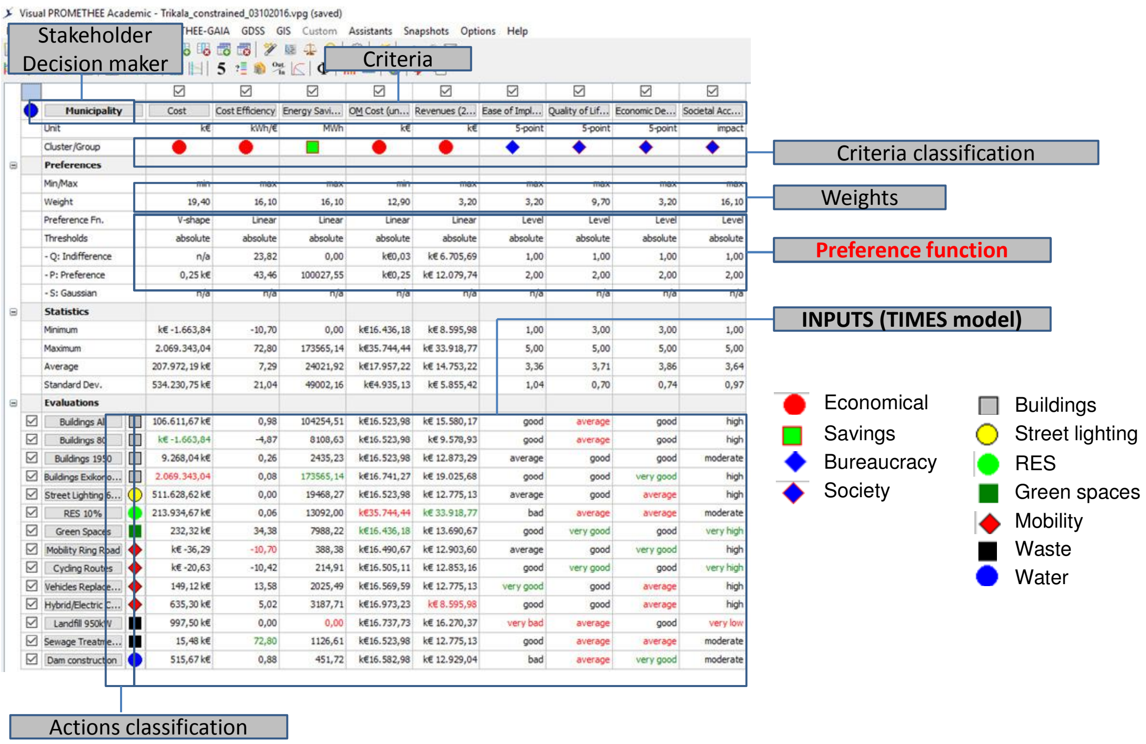
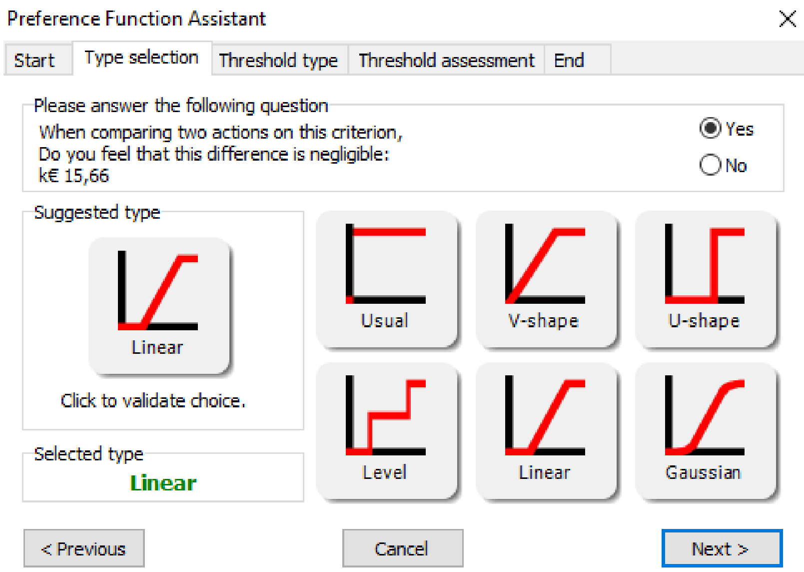


Figure 2: MCDA implementation for Trikala- Indicative sheet for the Municipality.

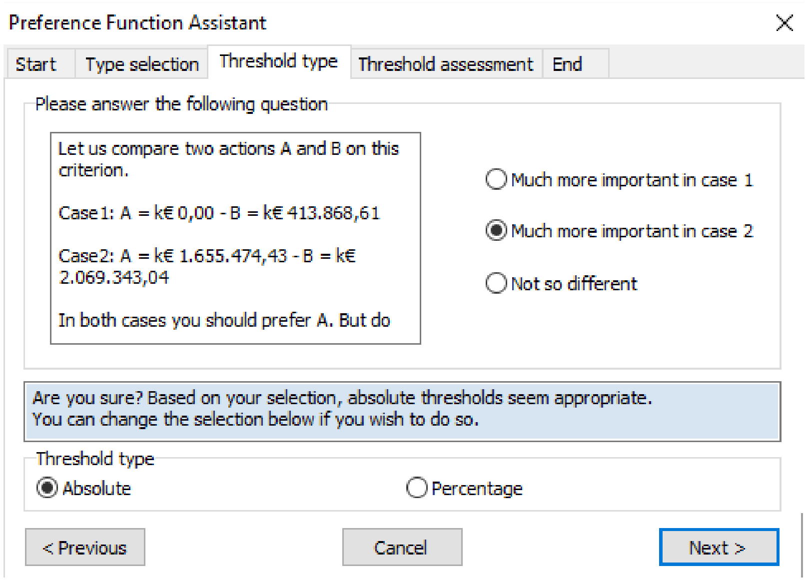
The above steps of the problem set-up process are illustrated in Figure 2, indicatively for the Municipality. Similar sheets are developed for the other Stakeholders as well, utilizing the corresponding weights.

Preference functions

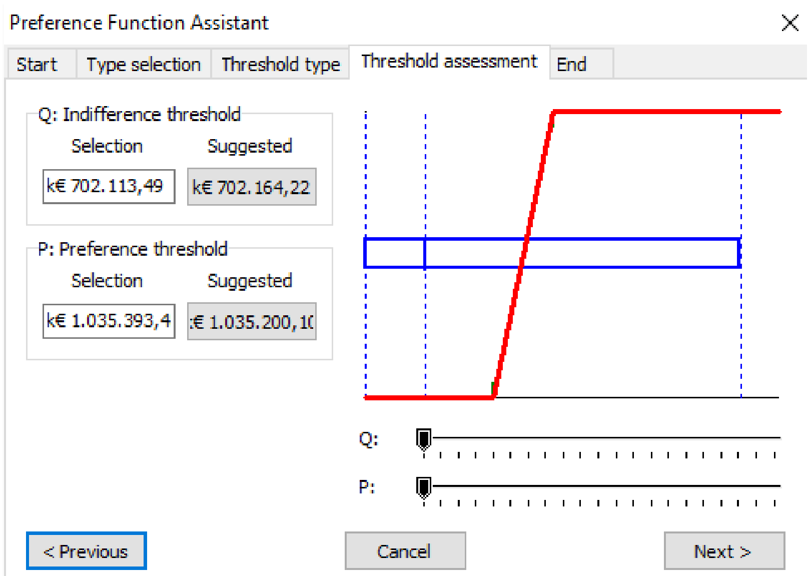
The preference functions are defined following a special Wizard of the software, which according to the criteria-values domain and to a series of rational questions it defines the preference function, the preference P and indifference Q (essentially Q declares the maximum acceptable difference from the ideal (max or min) value for the criterion). For example, in case of the Municipality and regarding the investment (Cost criterion) of the adopted action the following questions appear in the Wizard:



Indeed, an amount of 15,660.00€ is a reasonable divergence from an optimal (minimum) cost value in energy renovation projects at city scale, so the answer to the question is that such a difference is negligible. However, it is very important to retain high investments as low as possible as specified in the answer of the next Wizard's question below:



The above could not be true for a different Stakeholder/Decision-maker. For example, the Technical Chamber does not give priority to minimum costs (the respective weight is Zero), which in the same question means an answer of "Not so different", which allows much more flexibility in selecting an action/scenario. The main result of answering the questions includes a linear preference function with the following P and Q thresholds:



The Wizard exercising took place for all criteria and for each Stakeholder and the P and Q values obtained are shown in Table 8.

Table 8: Prefence functions and thresholds for Preference (P) and Indifference (Q).

Stakeholder	Preference parameter	Criteria				
		Cost (k€)	Cost	Energy	OM Cost	Revenues

			efficiency (kWh/€)	Savings (MWh)	(until 2030) (k€)	(2015-30) (k€)
Municipality	Pref. Function	Linear	Linear	Linear	Linear	Linear
	P value	1,035,393.48	0.25	100027.55	9,514.89	12,079.74
	Q value	702,113.49	0.03	59,208.49	6,653.69	6,705.69
Technical Chamber	Pref. Function	Linear	V-shape	V-shape	Linear	Linear
	P value	1,035,393.48	0.25	100027.55	9,514.89	12,079.74
	Q value	702,113.49	-	0	6,653.69	6,705.69
Commercial Association	Pref. Function	V-shape	Linear	Linear	V-shape	Linear
	P value	1,035,393.48	0.25	100027.55	9,514.89	12,079.74
	Q value	-	0.03	59,208.49	-	6,705.69
Trikala Chamber	Pref. Function	Linear	Linear	Linear	Linear	Linear
	P value	1,035,393.48	0.25	100027.55	9,514.89	12,079.74
	Q value	702,113.49	0.03	59,208.49	6,653.69	6,705.69

5-point (Level) criteria

The last 4 criteria, i.e. Ease of implementation, Quality of life, Economic development and Societal acceptance, are handled as 5-point scale criteria being assigned with a “level” pref. function and graded as follows:

2-very bad or very low

1-bad or low

0-average or moderate

1-good or high

2-very good or very high

According to previous experience on large-scale energy-upgrading projects as well as to the feedbacks obtained by the continuous discussions, consultations and 1-1 meetings with stakeholders’ representatives in Trikala Workshops, the grades presented in Table 9 are concluded.

Table 9: 5-point scaled criteria and corresponding grades for each intervention.

Intervention/ Action	Ease of implementation	Quality of life	Economic development	Societal acceptance
Scen1: Buildings all	Good	Average	Good	High
Scen2: Buildings 80	Good	Average	Good	High
Scen3: Buildings 1950	Average	Good	Good	Moderate
Scen4: Buildings exikonomo	Good	Good	Very good	High
Scen5: Street lighting 6000	Average	Very Good	Average	High
Scen6: RES 10%	Bad	Average	Average	Moderate
Scen7: Green spaces	Good	Very good	Good	Very high
Scen8: Mobility ring road	Average	Good	Very good	High
Scen9: Cycling routes	Good	Very good	Good	Very high
Scen10: Vehicles replacement	Very good	Good	Average	High
Scen11: Hybrid/electric cars incentives	Good	Good	Average	High
Scen12: Landfill 950kW	Very bad	Average	Good	Very low
Scen13: Sewage	Good	Average	Average	Moderate

treatment 20%				
Scen14: Dam construction	Bad	Average	Very good	Moderate

4 Results

MCDA results are presented separately for each Stakeholder by means of the total cost-function value (Phi value) obtained for each action and are further assessed in the so-called “rainbow” fashion. The considerations adopted to assess “rainbow” results are presented in Figure 3. Rainbow diagram prioritizes the actions/interventions from the highest to the lowest Phi value in its scaled form in the range from -1 (worst solutions) to +1 (best solutions), meaning that actions with positive Phi could be considered acceptable. Criteria with positive and negative contributions/flows (Phi+ and Phi-) for each action are illustrated in the rainbow’s bars by means of their colour pre-set for criteria’ categories; therefore, providing a clear view of the level of achievement of optimal values of criteria in relation to the preference (weight, P and Q) defined for each stakeholder. Results for the specific problem of the city of Trikala are presented in the following subsections.

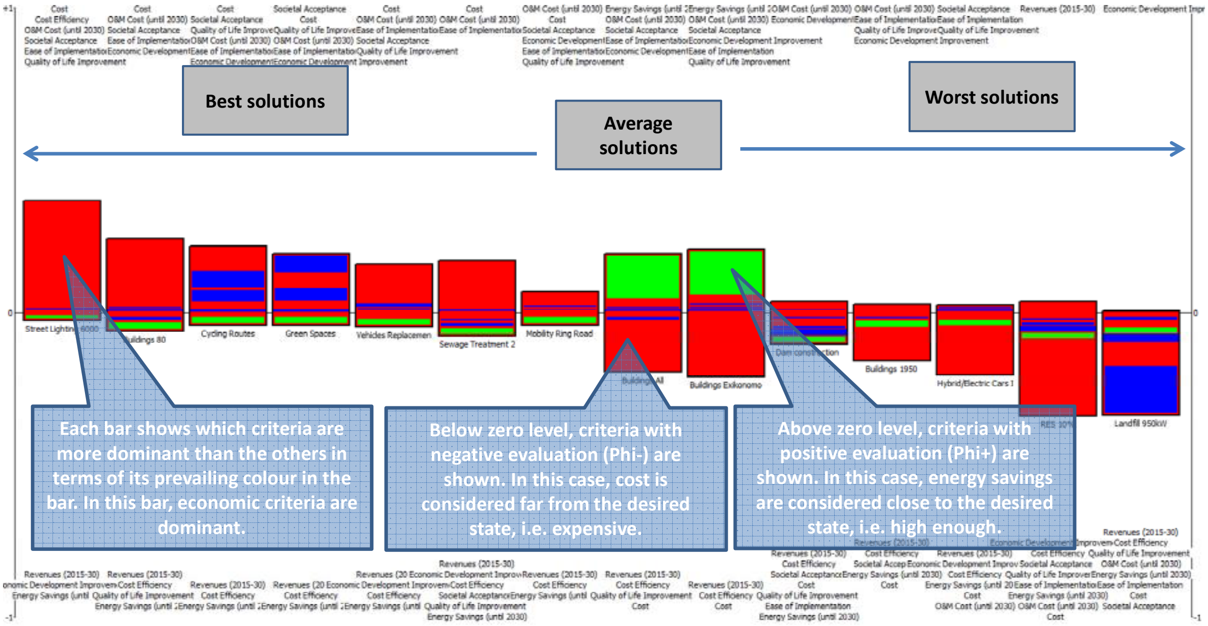
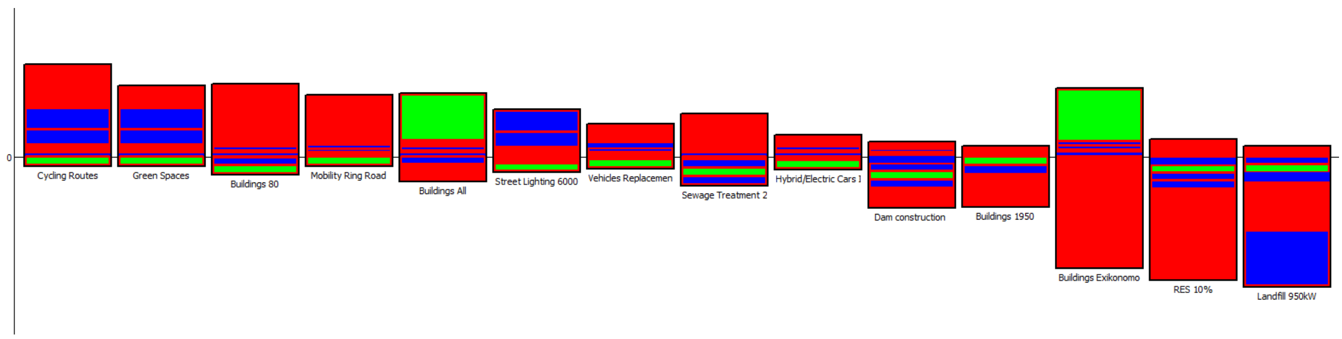


Figure 3: Considerations for assessing MCDA results in a "rainbow fashion".

4.1 MCDA results-Municipality

The hierarchy of actions for the Municipality is presented in Figure 4. It is observed that the best solutions include actions with the best economic criteria, i.e. red-colour contributions appeared in the positive side of the diagram. On the contrary, the worst solutions have the red-coloured in the negative side meaning a "disagreement" with the preferred trend, e.g. the "Buildings-Exikonomo" action is a very high investment, which despite its high energy-savings and high grading of 5-point criteria is not considered acceptable by the Municipality.



Φ Preference Flows

	Phi+	Phi-	Phi
Buildings All	0,2374	0,1271	0,1103
Buildings 80	0,2058	0,0497	0,1561
Buildings 1950	0,0702	0,1909	-0,1207
Buildings	0,1997	0,3291	-0,1294
Street Lighting	0,2085	0,1193	0,0893
RES 10%	0,0611	0,3715	-0,3104
Green Spaces	0,2506	0,0757	0,1749
Mobility Ring Road	0,1884	0,0421	0,1463
Cycling Routes	0,2754	0,0397	0,2358
Vehicles	0,1512	0,0966	0,0546
Hybrid/Electric Cars	0,1314	0,1113	0,0201
Landfill 950kW	0,0253	0,3788	-0,3535
Sewage Treatment	0,1686	0,1314	0,0372
Dam construction	0,0992	0,2097	-0,1105

Figure 4: "Rainbow" and Phi results for the Municipality.

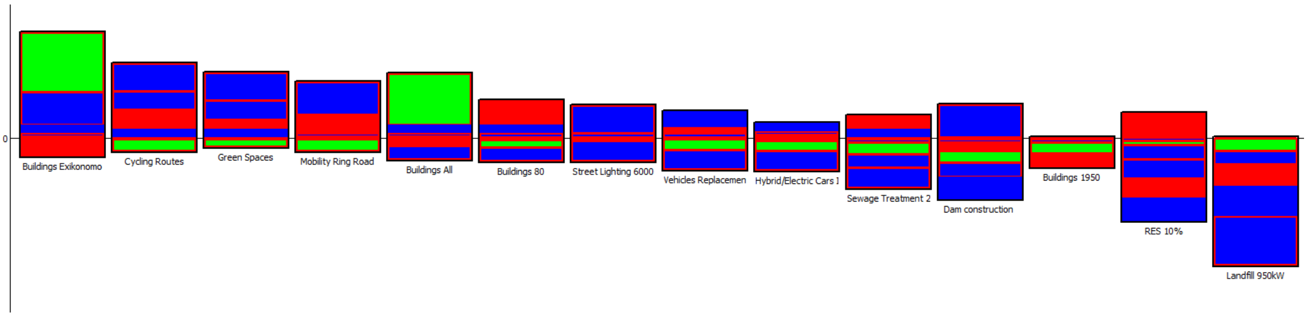
Based on the obtained Phi values, the acceptable solutions are (Phi>0):

- Cycling routes
- Green spaces
- Buildings 80
- Mobility ring road
- Buildings All
- Street lighting
- Vehicles replacement
- Sewage treatment
- Hybrid/electric cars

The rest part of actions is considered not acceptable (Phi<0) by the Municipality, the worst ones being: Buildings Exikonomo; RES 10%; and, Landfill 950kW.

4.2 MCDA results-Technical Chamber

The hierarchy of actions for the Technical Chamber is presented in Figure 5.



Φ Preference Flows

	Phi+	Phi-	Phi
Buildings All	0,2209	0,1000	0,1209
Buildings 80	0,1143	0,0788	0,0355
Buildings 1950	0,0344	0,1233	-0,0889
Buildings	0,3154	0,0640	0,2514
Street Lighting	0,1587	0,1351	0,0237
RES 10%	0,0978	0,2735	-0,1757
Green Spaces	0,2189	0,0566	0,1623
Mobility Ring Road	0,1755	0,0542	0,1214
Cycling Routes	0,2224	0,0462	0,1762
Vehicles	0,1052	0,1238	-0,0186
Hybrid/Electric Cars	0,0761	0,1335	-0,0574
Landfill 950kW	0,0010	0,3790	-0,3780
Sewage Treatment	0,0908	0,1770	-0,0863
Dam construction	0,1291	0,2154	-0,0863

Figure 5: "Rainbow" and Phi results for the Technical Chamber.

Contrary to the Municipality Stakeholder, the Technical Chamber is much more interested in tangible benefits from the energy-upgrading other than the initial investment cost, i.e. energy savings, quality of life (environmental benefits) and economic development (refer to the weights). This is clearly reflected in the results above, promoting the Buildings-Exikonomo solutions as the best one fulfilling high savings and high social acceptability. More specifically, the acceptable solutions (Phi>0) are:

- Buildings-Exikonomo

- Cycling routes

- Green spaces

- Mobility ring road

- Buildings All

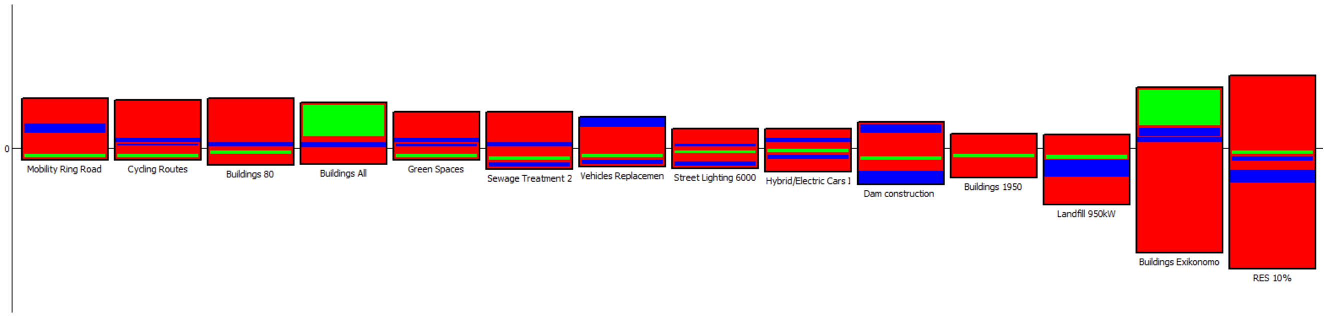
- Buildings 80

- Street lighting

The rest part of actions is considered not acceptable by the Technical Chamber (Phi<0), the worst ones being: Buildings 1950; RES 10%; and, Landfill 950kW.

4.3 MCDA results-Commercial Association

The hierarchy of actions for the Commercial Association is presented in Figure 6.



Φ Preference Flows

	Phi+	Phi-	Phi
Buildings All	0,1807	0,0994	0,0813
Buildings 80	0,1407	0,0482	0,0925
Buildings 1950	0,0596	0,1080	-0,0484
Buildings	0,1934	0,3267	-0,1333
Street Lighting	0,0971	0,1039	-0,0068
RES 10%	0,2254	0,3715	-0,1461
Green Spaces	0,1283	0,0603	0,0680
Mobility Ring Road	0,1524	0,0454	0,1070
Cycling Routes	0,1408	0,0409	0,0999
Vehicles	0,1201	0,0890	0,0311
Hybrid/Electric Cars	0,0985	0,1169	-0,0183
Landfill 950kW	0,0406	0,1712	-0,1305
Sewage Treatment	0,1203	0,0816	0,0387
Dam construction	0,0995	0,1345	-0,0350

Figure 6: “Rainbow” and Phi results for the Commercial Association.

Based on the obtained Phi values, the acceptable solutions are (Phi>0):

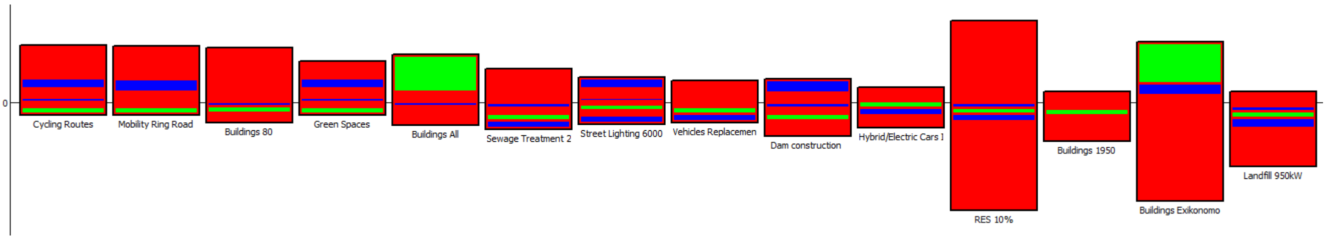
- Mobility ring road
- Cycling routes
- Buildings 80
- Buildings All
- Green spaces
- Sewage treatment

- Vehicles replacement

The rest part of actions is considered not acceptable by the Commercial Association (Phi<0), the worst ones (Phi<0) being (similarly to the Municipality): Buildings Exikonomo; RES 10%; and, Landfill 950kW.

4.4 MCDA results-Trikala Chamber

The hierarchy of actions for the Trikala Chamber are presented in Figure 7.



Φ Preference Flows

	Phi+	Phi-	Phi
Buildings All	0,1790	0,1106	0,0684
Buildings 80	0,1537	0,0582	0,0955
Buildings 1950	0,0524	0,1392	-0,0869
Buildings	0,1906	0,3072	-0,1167
Street Lighting	0,1250	0,1214	0,0037
RES 10%	0,2369	0,3198	-0,0829
Green Spaces	0,1538	0,0736	0,0803
Mobility Ring Road	0,1706	0,0456	0,1250
Cycling Routes	0,1731	0,0456	0,1274
Vehicles	0,1057	0,1057	-0,0001
Hybrid/Electric Cars	0,0961	0,1309	-0,0349
Landfill 950kW	0,0295	0,1907	-0,1612
Sewage Treatment	0,1249	0,1082	0,0167
Dam construction	0,1034	0,1376	-0,0343

Figure 7: "Rainbow" and Phi results for the Trikala Chamber.

Based on the obtained Phi values, the acceptable solutions are (Phi>0):

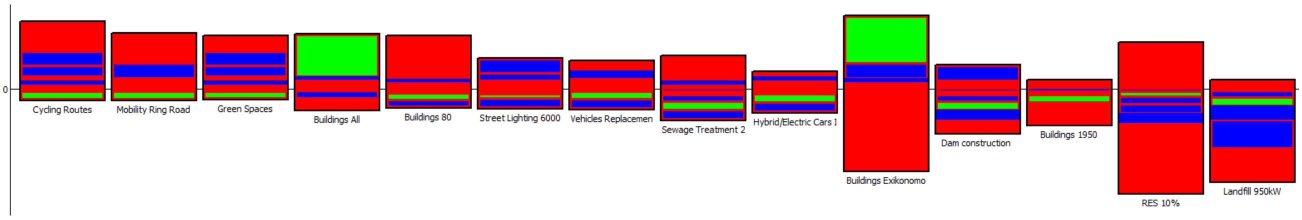
- Cycling routes
- Mobility ring road
- Buildings 80
- Green spaces
- Buildings All

- Sewage treatment
- Street lighting

The rest part of actions is considered not acceptable by the Trikala Chamber, the worst ones (Phi<0) being: Buildings 1950; Buildings Exikonomo; and, Landfill 950kW.

4.5 MCDA results-Compromised solution

This section summarizes all acceptable solutions for the different stakeholders and presents a compromised solution based on a special PROMETHEE algorithm which balances the results of each separate scenario/stakeholder and provides a total solution. The compromised solution among all stakeholders is presented in Figure 8.



Φ Preference Flows

	Phi+	Phi-	Phi
Buildings All	0,2045	0,1093	0,0952
Buildings 80	0,1536	0,0587	0,0949
Buildings 1950	0,0541	0,1404	-0,0862
Buildings	0,2248	0,2568	-0,0320
Street Lighting	0,1474	0,1199	0,0275
RES 10%	0,1553	0,3341	-0,1788
Green Spaces	0,1879	0,0666	0,1214
Mobility Ring Road	0,1717	0,0468	0,1249
Cycling Routes	0,2029	0,0431	0,1598
Vehicles	0,1205	0,1038	0,0167
Hybrid/Electric Cars	0,1005	0,1231	-0,0226
Landfill 950kW	0,0241	0,2799	-0,2558
Sewage Treatment	0,1262	0,1246	0,0016
Dam construction	0,1078	0,1743	-0,0665

Figure 8: "Rainbow" and Phi results for the compromised solution among Stakeholders.

Table 10: Stakeholders' decision matrix.

Stakeholders' Decisions Matrix	Municipality	Technical Chamber	Commercial Association	Trikala Chamber	Compromised

Acceptable solutions in descending order of Phi (Phi>0)	Cycling routes	Cycling routes	Mobility ring road	Cycling routes	Cycling routes
	Green spaces	Green spaces	Cycling routes	Mobility ring road	Mobility ring road
	Buildings 80	Mobility ring road	Buildings 80	Buildings 80	Green spaces
	Mobility ring road	Buildings All	Buildings All	Green spaces	Buildings All
	Buildings All	Buildings 80	Green spaces	Buildings All	Buildings 80
	Street lighting	Street lighting	Sewage treatment	Sewage treatment	Street lighting
	Vehicles replacement		Vehicles replacement	Street lighting	Vehicles replacement
	Sewage treatment				Sewage treatment
	Hybrid/electric cars				
Worst solutions (lowest negative Phi's)	Buildings Exikonomo	Buildings 1950	Buildings Exikonomo	Buildings 1950	Buildings 1950
	RES 10%	RES 10%	RES 10%	Buildings Exikonomo	RES 10%
	Landfill 950kW	Landfill 950kW	Landfill 950kW	Landfill 950kW	Landfill 950kW

The acceptable (Phi>0) and the three worst (lowest negative Phi) actions for each Stakeholder together with the ones obtained by the compromised problem are presented in Table 10 in Phi's descending order. InTable 10: Green coloured actions represent solutions acceptable by all stakeholders, also appearing in the compromised solution; Blue coloured actions represent solutions acceptable by at least 2 stakeholders also appearing in the compromised solution; Red coloured actions represent actions among the three worst ones for all stakeholders and for the compromised solution; Orange coloured actions represent actions reflecting at least two stakeholders, also appearing in the compromised solution.

In conclusion, the MCDA analysis provided the following results (compromised among all stakeholders):

Acceptable actions:

- *Cycling routes:* construction of cycling routes with a length of 2.8km in the next 2-3 years and an extra 10km in the next 10 years.

- *Mobility ring road:* construction of the ring road around the city which leads to a reduction of the transport load through the city centre. The primary ring-road has been completed and the secondary has been completed by 50% and the remainder is estimated to be completed by 2025.

- *Green spaces:* implemented in all the city squares and open spaces, in order to reduce the cooling demand of buildings in the city. According to relevant studies[19] it is expected that the cooling energy demand in buildings will be reduced by 5% by 2030 once Green open spaces techniques are applied in the whole of the city.

- *Buildings All:* refurbishment of all the Municipal Buildings following the example of the upgrades of the 16 buildings included in the Baseline scenario. The refurbishments focus on the reduction of thermal and cooling loads and the improvement of lighting installations.

- *Buildings 80:* 80% of the buildings within the geographical limits of the municipality, are connected to the natural gas network by 2030. This includes both residential and non-residential buildings.

- *Street lighting:* replacement of existing sodium street light bulbs with high efficiency LED lamps is implemented.

- *Vehicles replacement:* replacement of ten existing municipal small vehicles by electric cars. Furthermore, all the municipal heavy duty vehicles (trucks, refuse collection trucks etc.) will be replaced by Euro 6 vehicles in the next 15 years.

- *Sewage treatment:* The sewage treatment plant is a considerable consumer in the energy system of the city (WP4 data). Based on studies that were already done the energy consumption can be reduced by at least 25% with the use of special bacteria with limited extra cost. This action can be implanted by 2019.

Worst actions:

- *Buildings 1950:* Complete renovation of residential buildings that were built before 1950. The complete renovation includes all four options identified in WP2 as appropriate for the building stock in Trikala, namely replacement of windows, insulation of roofs and walls.

- *RES 10%:* 10% of the electricity demand in the municipality will be covered by renewable energy projects, funded by the municipality by 2030 (the share in 2020 will reach 5%).

- *Landfill 950 kW:* The landfill of Trikala can be used as an energy source according to recent studies. In this scenario the installation by 2020 of a 950kWe biogas fired power plant in the landfill is included. It is assumed that the generated electricity covers directly the demand in the city.

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