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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

D5.7. Report on the multicriteria methodology, the process and the results of the decision making – Évora, Portugal

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Executive Summary	
This report presents the optimal ranking of available urban energy upgrading alternative actions considered for the municipality of Évora 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 Analysis (MCDA) software Visual PROMETHEE v.1.4.0.0. 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 Analysis (MCDA); PROMETHEE; Ranking of urban energy upgrading actions; Stakeholders' preferences; Decision-making; Hinkle's method; Deliberative MultiCriteria Evaluation (DMCE) methodology

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Acronyms and Definitions

B-Y – Base year of the TIMES_Evora (2013)

FEC - Final Energy Consumption

LED - Light-emitting diode lamp

MCDA – Multi Criteria Decision Analysis

MSW- Municipal Solid Waste

GHG – Greenhouse Gas Emissions

GIS – Geographic Information System

RES – Renewable Energy Sources

SEAP – Sustainable Energy Action Plan

Vkm - vehicle-kilometre representing a measure of traffic flow, determined by multiplying the number of vehicles on a given road or traffic network by the average length of their trips measured in kilometre.

WP – Working Package

LPG – Liquefied Petroleum Gas

TIMES – The Integrated Markal EFOM System model generator of the Energy Technology System Analysis Programme of the International Energy Agency

1 Introduction

1.1 Overview of InSMART

The InSMART concept brings together cities, scientific and industrial organizations in order to establish and implement a comprehensive methodology for enhancing sustainable planning addressing the current and future city energy needs through an integrative and multidisciplinary planning approach.

InSMART project intends to identify the optimum mix of short, medium and long term measures for a sustainable energy future, addressing the efficiency of energy flows across various city districts, namely buildings, transport and mobility. Urban spaces, water/sewage system, waste chain and decentralized energy supply.

Each city's energy system is analysed, covering all relevant sectors and a comprehensive GIS platform including energy database was developed. Apart from being a valuable planning tool, the GIS database informs and is linked to the TIMES energy planning model. This model was used to analyse the cost-optimal mix of measures required to meet sustainable energy targets taking into account exogenous parameters (*e.g.*, environmental targets, city expansion). These measures were further assessed with respect to non-technical criteria using a multi-criteria decision making software aid (PROMETHEE) that addressed economic, environmental, as well as social issues.

A detailed economic analysis of the mid-term measures identified through this two stage optimisation procedure will be undertaken, identifying all relevant investment indicators in WP6. Finally, a detailed, realistic and applicable mid-term implementation plan will be developed to describe the necessary steps, required resources and monitoring procedures for each city.

1.2 Objectives of this Report

This report refers to WP5 (Task 5.3) and it focuses the analysis of the TIMES model results for the city of Évora (TIMES_Evora) within this same WP5 in tasks 5.1 and 5.2.

The goal of WP5 was to: 1) Develop city specific energy system models, 2) Define and analyse sustainability scenarios in order to identify the economical optimum mix of measures and 3) Implement multi-criteria decision analysis (MCDA) support process in order to identify the city optimum sustainability path. The first two goals are covered in a different report whereas this report focus on the third goal regarding the MCDA.

1.3 Outline of the Report

The report is organized in three chapters. Chapter 2 presents a brief description of the MCDA approach model for Évora and Chapter 3 presents the results of the MCDA for Évora.

2 The MCDA approach used for Évora

2.1 Background on MCDA applications for energy planning

Multi-Criteria Decision Analysis (MCDA) is a generic approach or framework used to inform and support complex decision-making situations with multiple and often conflicting objectives "that stakeholders groups and/or decision-makers value differently" (Saarikoski *et al*, 2016).

MCDA is an "umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter" (Belton and Stewart, 2002). MCDA has its origins in operational research and is suitable for addressing complex problems, as sustainable energy planning, "featuring high uncertainty, conflicting objectives, different forms of data and information, multi interests and perspectives, and the accounting for complex and evolving biophysical and socio-economic systems" (Wang *et al*, 2009)

Both energy and environment policies involve large numbers of stakeholders with differing views and preferences. Because many of the attributes of these policy alternatives are non-market valued (e.g. preservation of biodiversity), the multiple views of the stakeholders cannot always be determined in advance or with certainty (Greening and Bernow, 2007). Therefore, the use of MCDA allows a better alternative to cost/benefit or cost-effectiveness based methods (Wang et al, 2009, Greening and Bernow, 2007).

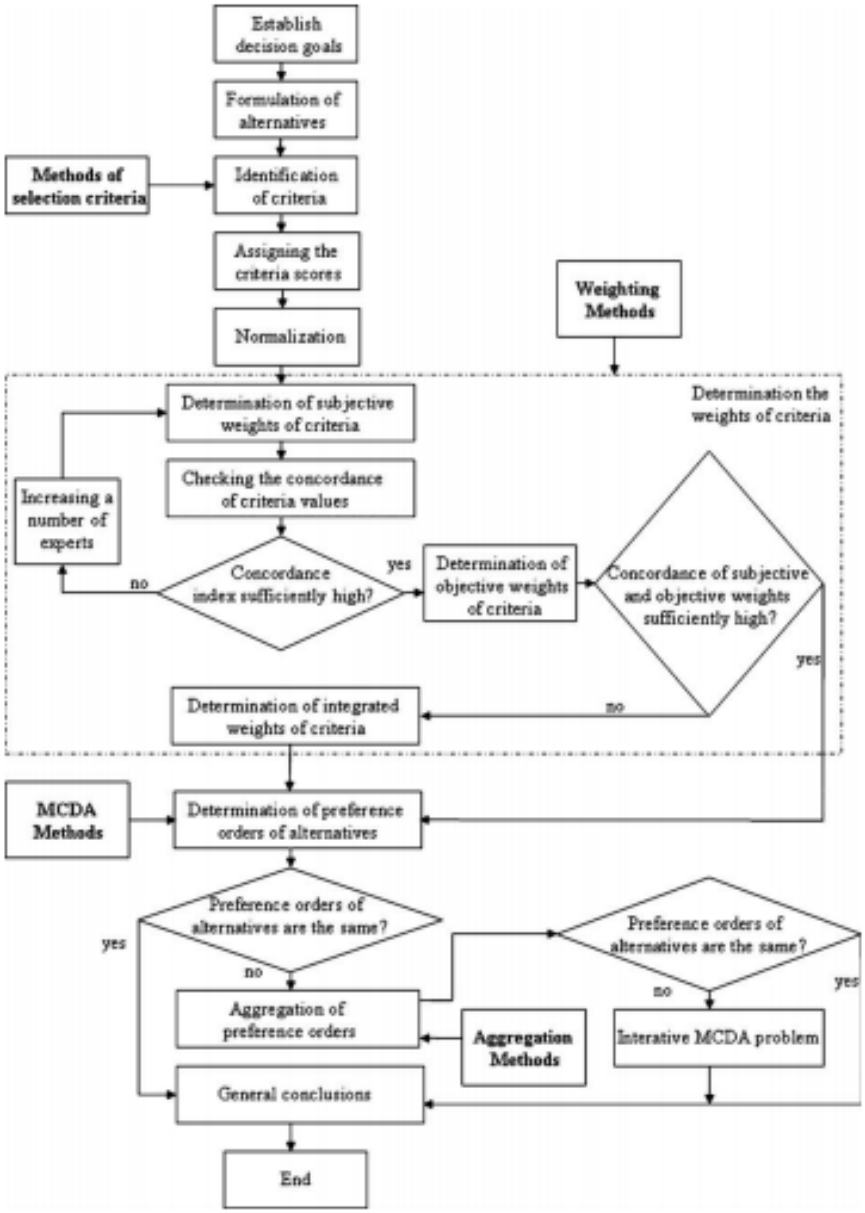
An example of a decision-making situation assisted by MCDA methods is the selection of the optimal energy supply scenario for a certain energy system, for example introduction of natural gas (as done by Dinca *et al*.(2007)), which has a variety of economic, environment and social consequences regarded as desirable by some stakeholders (e.g. regulators concerned with energy diversification) and undesirable by others (e.g. environmental organizations).

MCDA methods have been widely employed to sustainable energy decision-making considering multi-criteria. In a typical MCDA process applied to energy planning, as depicted in Figure 1, there are usually includes four main stages (Wang *et al.*, 2009):

1. alternatives' formulation and criteria selection,
2. criteria weighting,
3. evaluation,
4. final treatment and aggregation.

The first stage in MCDA is to formulate the alternatives for the sustainable energy problem from a set of selected criteria and, if needed, to normalize the original data of criteria. In the second stage the weights of each criterion are determined to show the relative importance of criteria in MCDA. In the third stage the acceptable alternatives are ranked using one or varied MCDA methods considering the previously selected

criteria weights. Finally, the alternatives' ranking is ordered in the fourth stage (Wang *et al*, 2009).



Source: (Wang *et al.*, 2009)

Figure 1 - . MCDA process in sustainable energy decision-making

There are several possible methods to select criteria (e.g. Delphi, Least Mean Square, Minmax deviation), to weigh them (e.g. equal methods, rank-order weights) and to evaluate them (i.e. to determine the preference orders of alternative to get the ranking order). Some of the MCDA evaluation methods are a simple weighted sum or a weighted product methods, or the more elaborate methods of "unique synthesizing criteria" as AHP or TOPSIS. Yet another group of MCDA evaluation methods is the "outranking method" that includes "Elimination et choice translating reality" (ELECTRE) method and "Preference ranking organization method for enrichment

evaluation" (PROMETHEE). The latter was used in the INSMART project and is thus more detailed here.

The PROMETHEE method was developed by Brans (Brans, 1984) and has been used in energy planning and applications. The method uses the outranking principle to rank the alternatives, combined with the ease of use and decreased complexity. It is well adapted to problems where a finite number of alternatives require ranking considering several, sometimes-conflicting criteria (Wang *et al*, 2009, Terrados, 2009).

This method is applied for the city of Évora and provided a ranking of smart-city energy planning actions from the best to the worst (in the context of compromising the mix of evaluation criteria) possible intervention suggestions.

2.2 The MCDA approach used in Évora

The approach was commonly used across the INSMART partner cities and is based on a Deliberative MultiCriteria Evaluation (DMCE) approach with the following main steps:

STEP 1: Defining criteria together with stakeholders': The main stakeholders/decision-makers related to the sustainable energy urban planning problem were grouped in four categories: (a) Local authorities, which includes the Municipality, (b) Regional authorities, (c) Private sector, and (d) Civil society. These groups are described in more detail in Table 2. A set of six criteria was defined (see the next section) and discussed in detail with stakeholders during one initial dedicated workshop to better refine these and to allocate weights on the different criteria following the different stakeholder groups' preferences. The criteria weights were used in the decision-making in the following steps.

STEP 2: Decision-making scheme definition: Based on the aforementioned result the full decision-making problem was defined regarding the objective function, criteria, sub-criteria and weights' assignment.

STEP 3: MultiCriteria Decision Analysis (MCDA) approach: The available databases of pairs of "action-vector of criteria", meaning the impacts (values of criteria) as provided by the TIMES_Evora model for each modelled scenario for the municipality of Évora, were further processed so as to solve the decision-making scheme for each stakeholder grouped as mentioned in STEP 1, using the specialized MCDA software Visual PROMETHEE v.1.4.0.0 (Academic edition). As a result, a ranking of alternative scenarios was produced which prioritizes the actions from the one with the best to the one with the worst compromise among the evaluation criteria. This ranking was discussed with the stakeholders during a second workshop looking in particular for necessity in changing the criteria weights. 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 municipality of Évora.

Each of these steps is explained in more detail in the following sections and were used to apply the MCDA to the measures in Table 1.

Table 1 – Sustainable Energy measures tested for Évora for the two visions REF and Smart

Name	Description	Code	Current status
Public lighting			
Changing luminaires with more efficient lamps	Change 80% public lighting to LEDs by 2020	PL1	0.4% of public lighting has LED in 2014
	Change all public lighting to LEDs by 2030	PL2	
Residential Buildings			
Solar Thermal	Install solar thermal hot water panels in 10% of dwellings by 2020	RSD1	0.2% of dwellings in 2014
	Install solar thermal hot water panels in 40% of dwellings in 2030	RSD2	
Solar PV	Solar PV installed corresponding to 10% of maximum feasible potential by 2020	RSD3	4% of maximum feasible in 2014
	Solar PV installed corresponding to 30% of maximum feasible by 2030	RSD4	
Insulation windows	Double glazing in 80% of dwellings by 2030	RSD6	39% of dwellings in 2014
Insulation infiltration	Small scale insulation solutions in 50% of dwellings by 2030	RSD7	10% of dwellings in 2014
Insulation walls and roofs	Wall & Roof insulation combined in 60% of dwellings by 2030	RSD8	20% of dwellings in 2014
Waste, water and waste water			
Increase recycling	Increase by 35% the share of recycled MSW after 2020	R1	7% MSW were recycled in 2014, planned 8% by 2020 (i.e. increase of 24%)
Decrease MSW production	Decrease MSW production per capita in 20% from 2013 values	R2	502 kg MSW per capita in 2013 and 6% reduction from 2009 till 2014
Energy efficiency in water system	Improve energy efficiency in water treatment plants in 50% by 2030 compared to 2009	R3	from 2009 till 2014 energy consumption in water treatment decreased 12%

Name	Description	Code	Current status
Energy efficiency in waste water treatment	Improve energy efficiency in waste water treatment plant in 30% compared to 2009 by 2030	R4	from 2009 till 2014 energy consumption in wastewater treatment decreased 12%
Transport			
Promotion of cycling	Extension of the existent 7 km cycling lanes combined with making city bikes available from 2020 onwards	TRA1	8.3 km of cycling lanes in 2014 and no city bikes
City Centre Traffic Restrictions	Duplicate parking fees in historic center from 2020 onwards	TRA2	0.7eur/hr. up to 11eur/day in 2014
	Interdiction for all type of vehicles and concerning all purposes to the Évora Acropolis from 2020 onwards	TRA3	n.a.
Speed Reductions	Speed limitation to 30km/h, for all vehicles in diverse zones from 2020 onwards	TRA4	n.a.
Electric vehicles	15% of passenger cars are electric by 2030	TRAelc	3 electric cars in 2014
Biofuel buses	All busses use biofuels by 2030	TRAbus	No biofuel buses in 2014
Increase historic center parking – concentrated	Construction of 3 parking lots with a total of 500 parking spaces for non-residents in the historic center from 2020 onwards	TRA7	215 parking spaces for non-residents in historic center in 2014
Increase historic center parking – disperse	300 new disperse parking spaces for residents in the historic center from 2020 onwards	TRA8	2019 total disperse parking spaces in historic center in 2014 of which 748 were for residents
Increase public transportation	Shift of 15% from private cars mobility to public transportation from 2020 onwards	TRA9	1029 pkm travelled by passenger car in 2014

Note that the CAP scenario modelled in TIMES_Evora was not used in the MCDA since its purpose was to inform the assessment of the other measures. The CAP in itself is not an action that will lead to more sustainable energy as a stand-alone.

2.2.1 The criteria defined for Évora

With the involvement of the stakeholders listed in Table 2, it was agreed upon the following set of criteria to evaluate the measures:

A. Reduction of energy consumption
B. GHG emission reduction
C. Financial effort associated with implementation (represents the total investment costs associated with implementation, as well as the annual operation & maintenance costs if applicable)

D. Contribution for local development (translates the job creation for both public and private institutions within the municipality, including the activation of new businesses and reduction of energy consumption costs)
E. Contribution for improving comfort and quality of life of residents (reflects improvements of the indoor thermal comfort in buildings, improved lighting, ease of access to parking places or lower traffic congestion)
F. Feasibility of implementation (refers to the time needed for implementation, complexity of the required permitting process (if applicable), as well as the number of persons or institutions promoting the implementation of the measure)

The first three are qualitative objective criteria, whereas the other three are qualitative and subjective.

Table 2 - List of stakeholders involved in developing the scenarios analysed and defining the criteria and respective weights used in the MCDA

#	Organisation	Sector
1	ADRAL - Agência de Desenvolvimento Regional do Alentejo	Regional Public Authorities
2	ACDE - ASSOCIAÇÃO COMERCIAL DO DISTRITO DE ÉVORA	Business
3	GESAMB - Gestão Ambiental e de Resíduos, EIM	Regional Public Authorities
4	DianaGas	Business
5	GARE Associação para a Promoção de uma Cultura de Segurança Rodoviária	Civil Society
6	EDP	Business
7	Cycloid – Produção de Energias Renováveis Lda	Business
8	Cycloid – Produção de Energias Renováveis Lda	Business
9	ArenaTejo	Regional Public Authorities
10	NERE - Núcleo Empresarial da Região de Évora	Business
11	CIMAC - Comunidade Intermunicipal do Alentejo Central	Regional Public Authorities
12	CCDRA - Comissão de Coordenação e Desenvolvimento Regional do Alentejo	Regional Public Authorities
13	Instituto da Conservação da Natureza e das Florestas / Departamento de Conservação da Natureza e Florestas do Alentejo	Regional Public Authorities
14	EDIA, S.A. - Empresa de Desevolvimento e Infraestruturas do Alqueva	Business
15	DECO - Associação Portuguesa para a Defesa do Consumidor / Delegação Regional de Évora	Civil Society
16	Fundação Alentejo / EPRAL - Escola Profissional da Região Alentejo	Civil Society
17	Colégio Fundação Alentejo	Civil Society
18	Universidade de Évora - Centro de Geofísica de Évora Escola de Ciências e Tecnologia	Civil Society
19	Universidade de Évora - Departamento de Paisagem, Ambiente e Ordenamento	Civil Society
20	União de Freguesias do Bacelo e da Senhora da Saúde	Local authorities
21	União de Freguesias de Malagueira e de Horta de Figueiras	Local authorities
22	Câmara Municipal de Évora / Divisão de Ordenamento e Reabilitação Urbana	Local authorities

#	Organisation	Sector
23	Câmara Municipal de Évora / Gabinete de Apoio à Presidência e Vereação - Grupo de Avaliação Permanente do Espaço Público	Local authorities
24	Câmara Municipal de Évora / Gabinete de Apoio à Presidência e Vereação - Grupo de Avaliação Permanente do Espaço Público	Local authorities
25	Câmara Municipal de Évora / Divisão de Obras Municipais	Local authorities

The performance of each measure against the selected criteria was defined as in Table 3.

Table 3 – Performance of each criterion

Criterion	Indicator(s) to assess performance	Source of the indicator value
A. Reduction of energy consumption	PJ of saved final and primary energy	From TIMES compared with Baseline scenario
B. Reduction of GHG emission	t CO_2 of avoided emissions	From TIMES compared with Baseline scenario
C. Financial effort	€ of total investment cost + € of annual operation and maintenance cost	From TIMES and municipality experts and compared with Baseline
D. Contribution for local development	***High*** - new jobs creation, foreseen involvement of local companies providing services/products in the implementation, no potential for the creation of new businesses ***Medium*** - no jobs are created, foreseen involvement of local companies providing services/products in the implementation, no potential for the creation of new businesses ***Low*** – no jobs are created, no foreseen involvement of local companies providing services/products in the implementation, no potential for the creation of new businesses	Expert guess of the InSmart Portugal team based on literature data and bilateral consultation with Évora stakeholders
E. Contribution for improving comfort and quality of life	***High*** - significant improvements in indoor thermal comfort, mobility services (including congestion and parking), public lighting ***Medium*** - moderate improvements in indoor thermal comfort, mobility services (including congestion and parking), public lighting ***Low*** – no foreseen improvements in indoor thermal comfort, mobility services (including congestion and parking), public lighting	Expert guess of the InSmart Portugal team based on literature data and bilateral consultation with Évora stakeholders
F. Feasibility of implementation	***High*** – Directly involves less than 100 end-targets as implementers, permitting process entails approval of a maximum of 2 different institutions, estimated implementation time is lower than 1 year, will not create social opposition ***Medium*** – Directly involves more than 1000 end-targets as implementers, permitting process entails approval of a	Expert guess of the InSmart Portugal team based on literature data and bilateral consultation with Évora stakeholders

Criterion	Indicator(s) to assess performance	Source of the indicator value
	maximum of 4 different institutions, estimated implementation time is longer than 1 year, most probably will not create social opposition ***Low*** – Directly involves more than 5000 end-targets as implementers, permitting process entails approval of at least 4 different institutions, estimated implementation time is longer than 2 years, potentially will create social opposition	

2.2.2 Weighting the criteria

Each criterion was weighted with the stakeholders in a workshop in Évora. A value from 1 to 5 was allocated for each criterion, where 1 stands for "*Very Low Relevance Criterion*" and 5 for "*Highly Relevant Criterion*".

During the workshop in Évora the stakeholders were divided in 4 groups: i) Local Authorities; ii) Civil society representatives; iii) Public services and regional authorities and iv) Private sector.

Each group discussed and made the allocation of weights to each criterion. The stakeholders were firstly asked to discuss the criteria in order to achieve a fist common basis of understanding on their meaning and then to allocate the weights in an individual basis. This was then followed by another discussion period in order to try to achieve consensus on the weights, which was only possible for two of the stakeholder groups. The results in the weighing are presented in **Error! Reference source not found.**.

Table 4 - Results of the criteria weight allocation made during the stakeholder workshop

Group	Allocated weight (1 to 5)					
	A. Reduction of energy consumption	**B. Reduction of CO_2 emission**	**C. Financial effort**	**D. Contribution for local development**	**E. Contribution for improving comfort and quality of life**	**F. Feasibility of implementation**
Average						
Local Authorities	5	3	4	4	4	3
Civil society	5	4	3	4	4	3
Public services and regional authorities	5	5	3	5	3	2
Private sector	3	4	4	3	4	3
Median						
Local Authorities	5	3	3	3	4	4

Group	Allocated weight (1 to 5)					
	A. Reduction of energy consumption	B. Reduction of CO_2 emission	C. Financial effort	D. Contribution for local development	E. Contribution for improving comfort and quality of life	F. Feasibility of implementation
Civil society	5	4	3	4	4	3
Public services and regional authorities	5	5	3	5	4	2
Private sector	3	4	3	4	4	3
Consensus						
Local Authorities	No consensus was obtained, median was used					
Civil society	No consensus was obtained, median was used					
Public services and regional authorities	5	5	3	5	3	2
Private sector	3	5	4	1	4	2

2.2.3 Performance of the measures according to the criteria

The sustainable energy measures studied using the TIMES_Evora model were classified according to their performance in each of the six selected criteria as summarised in Table 5 and Table 6 for the REF and Smart visions.

Table 5 – Performance of the measures in each criterion. Indicated as difference to the Baseline for the quantitative criteria for 2030 - REF

Code	Reduction of energy consumption (GJ)	Reduction of CO_2 emission (t)	Financial effort (1000 euros 2015)		Local development	Quality of life	Feasibility
			Investment	O&M			
PL1	525.08	56,163.31	624.51	920.33	low	medium	high
PL2	525.08	56,163.31	624.51	920.33	medium	medium	high
RSD1	-58.01	-5,621.20	16.68	1.44	medium	medium	low
RSD2	11,128.42	1,981,304.08	41.23	3.42	high	high	low
RSD3	-112.53	2,984,843.21	3,869.48	357.70	high	high	low
RSD4	-148.95	8,962,242.45	12,696.72	1,173.71	high	high	low
RSD6	46,646.43	1,108,710.65	480.38	-0.37	high	high	low
RSD7	50,111.90	1,112,240.23	2,625.65	-0.41	high	high	low
RSD8	50,111.90	1,112,240.23	4,590.43	-0.38	high	high	low

Code	Reduction of energy consumption (GJ)	Reduction of CO_2 emission (t)	Financial effort (1000 euros 2015)		Local development	Quality of life	Feasibility
			Investment	O&M			
R1	692.29	64,615.98	200.00	n.a.	medium	low	low
R2	950.87	89,661.35	300.00	n.a.	low	low	low
R3	-54.52	-	1,000.00	n.a.	low	low	medium
R4	0.00	-	3,000.00	n.a.	low	low	medium
TRA1	2,958.89	197,633.11	1,190.00	n.a.	medium	medium	high
TRA2	3,695.38	261,206.75	0.00	n.a.	low	medium	low
TRA3	1,617.27	109,703.48	15.00	n.a.	low	medium	low
TRA4	18,340.87	1,303,332.86	20.00	n.a.	low	medium	medium
TRAelc	14,346.84	1,299,388.09	2,309.89	213.53	medium	low	low
TRAbus	-37,399.19	2,272,947.66	4,122,984.85	762,276.98	low	low	medium
TRA7	901.77	58,467.00	7,000.00	n.a.	high	high	medium
TRA8	952.66	62,173.32	13.50	n.a.	medium	high	medium
TRA9	9,217.64	657,772.23	10.00	n.a.	low	low	medium

n.a. – not available

Table 6 - Performance of the measures in each criterion. Indicated as difference to the Baseline for the quantitative criteria - Smart

Code	Reduction of energy consumption (GJ)	Reduction of CO_2 emission (t)	Financial effort (1000 euros 2015)		Local development	Quality of life	Feasibility
			Investment	O&M			
PL1	641.80	62,190.38	624.51	920.33	low	medium	high
PL2	675.67	65,472.02	624.51	920.33	medium	medium	high
RSD1	20.62	405.86	16.68	1.44	medium	medium	low
RSD2	12,513.62	4,050,561.55	83.50	5.89	high	high	low
RSD3	4.30	2,990,880.66	3,869.48	357.70	high	high	low
RSD4	-80.32	9,014,011.76	12,696.72	1,173.71	high	high	low
RSD6	70,290.88	3,868,833.71	667.65	-1.95	high	high	low
RSD7	108,039.21	4,906,616.30	3,439.34	-2.14	high	high	low
RSD8	115,720.18	115,720.18	5,510.43	-2.16	high	high	low
R1	485.64	92,902.40	200.00	n.a.	medium	low	low

Code	Reduction of energy consumption (GJ)	Reduction of CO_2 emission (t)	Financial effort (1000 euros 2015)		Local development	Quality of life	Feasibility
			Investment	O&M			
R2	-134.47	35,779.49	300.00	n.a.	low	low	low
R3	-0.00	-	1,000.00	n.a.	low	low	medium
R4	-0.11	-10.37	3,000.00	n.a.	low	low	medium
TRA1	2,897.02	243,003.72	1,190.00	n.a.	medium	medium	high
TRA2	3,946.62	327,340.65	0.00	n.a.	low	medium	low
TRA3	1,602.37	157,687.73	15.00	n.a.	low	medium	low
TRA4	19,959.54	1,462,605.45	20.00	n.a.	low	medium	medium
TRAelc	16,252.21	1,448,668.11	2,546.49	235.40	medium	low	low
TRAbus	-37,399.29	2,272,937.29	4,122,984.85	762,276.98	low	low	medium
TRA7	720.54	94,260.25	7,000.00	n.a.	high	high	medium
TRA8	791.89	99,470.21	13.50	n.a.	medium	high	medium
TRA9	9,950.55	757,052.36	10.00	n.a.	low	low	medium

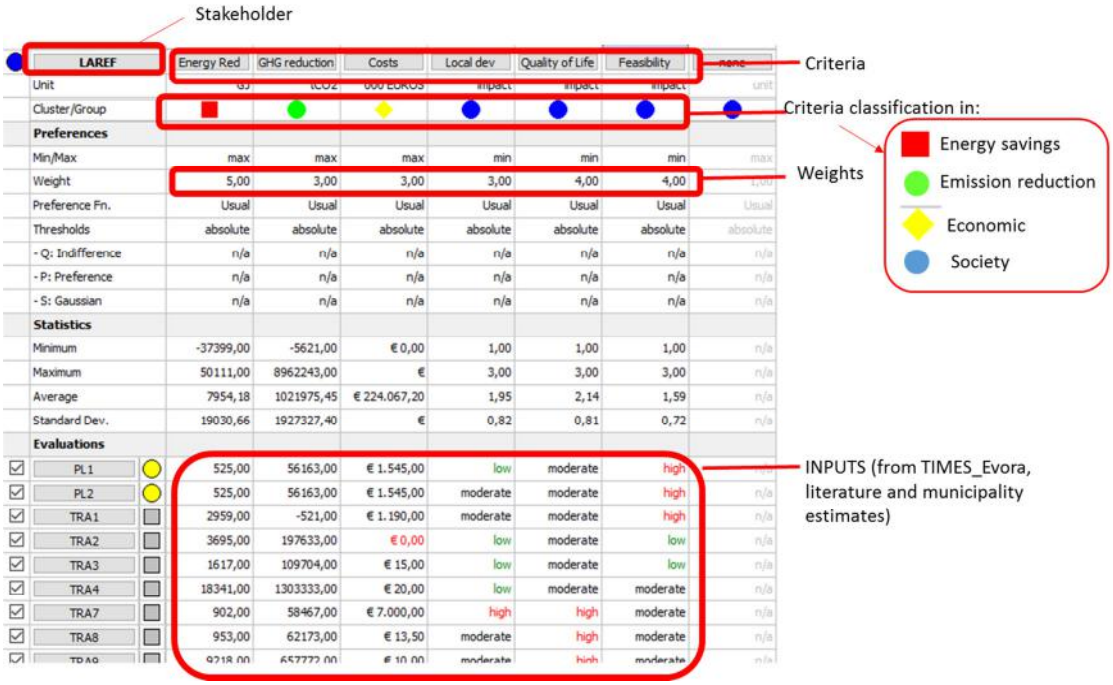
2.2.4 Implementation of the MCDA using the PROMETHEE method

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

1) Set-up a 'problem' sheet for each stakeholder group; in this case, 4 different sheets for the Local Authorities, Regional authorities, Private Sector and Civil Society.
2) Specification and grouping of the criteria, i.e.: Economical criteria (Investment costs, O&M costs); Savings (Energy savings); Bureaucracy as an implementation barrier (Feasibility of implementation); and, Social criteria (Quality of life, and Feasibility).
3) Specification of scenarios (as in Table 1), classification and inputs. For each scenario, each indicator' value is imposed in the INPUTS matrix. The inputs were produced by the TIMES_Evora model analysis (described in deliverable D5.3), by literature analysis for the case of waste and waste water, and by the municipality for the case of transport measures.
4) For each Stakeholder group (problem sheet), the weights agreed upon and presented in Table 4 are inserted, which weighs each criterion according to the preference of the Stakeholder.

For the case of Évora the problem was not further constrained using the Preference function accompanied with P and Q thresholds and the preference function was the Usual default one.

The above steps of the problem set-up process are illustrated in Figure 2, using the Local Authorities stakeholder group as an example. Similar sheets were developed for the other Stakeholders as well, utilizing the corresponding weights.



LAREF	Energy Red	GHG reduction	Costs	Local dev	Quality of Life	Feasibility	none
Unit	GJ	tCO2	000 EUROS	impact	impact	impact	unit
Cluster/Group	■	●	◆	●	●	●	●
Preferences							
Min/Max	max	max	max	min	min	min	max
Weight	5,00	3,00	3,00	3,00	4,00	4,00	1,00
Preference Fn.	Usual	Usual	Usual	Usual	Usual	Usual	Usual
Thresholds	absolute	absolute	absolute	absolute	absolute	absolute	absolute
- Q: Indifference	n/a	n/a	n/a	n/a	n/a	n/a	n/a
- P: Preference	n/a	n/a	n/a	n/a	n/a	n/a	n/a
- S: Gaussian	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Statistics							
Minimum	-37399,00	-5621,00	€ 0,00	1,00	1,00	1,00	n/a
Maximum	50111,00	8962243,00	€	3,00	3,00	3,00	n/a
Average	7954,18	1021975,45	€ 224.067,20	1,95	2,14	1,59	n/a
Standard Dev.	19030,66	1927327,40	€	0,82	0,81	0,72	n/a
Evaluations							
PL1	525,00	56163,00	€ 1.545,00	low	moderate	high	n/a
PL2	525,00	56163,00	€ 1.545,00	moderate	moderate	high	n/a
TRA1	2959,00	-521,00	€ 1.190,00	moderate	moderate	high	n/a
TRA2	3695,00	197633,00	€ 0,00	low	moderate	low	n/a
TRA3	1617,00	109704,00	€ 15,00	low	moderate	low	n/a
TRA4	18341,00	1303333,00	€ 20,00	low	moderate	moderate	n/a
TRA7	902,00	58467,00	€ 7.000,00	high	high	moderate	n/a
TRA8	953,00	62173,00	€ 13,50	moderate	high	moderate	n/a
TRA9	9218,00	657772,00	€ 10,00	moderate	high	moderate	n/a

Figure 2 – MCDA implementation for Évora – Indicative sheet for the Local Authorities

3 Results

The MCDA results are presented separately for each stakeholder group through 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. A 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 Évora municipality are presented in the following subsections.

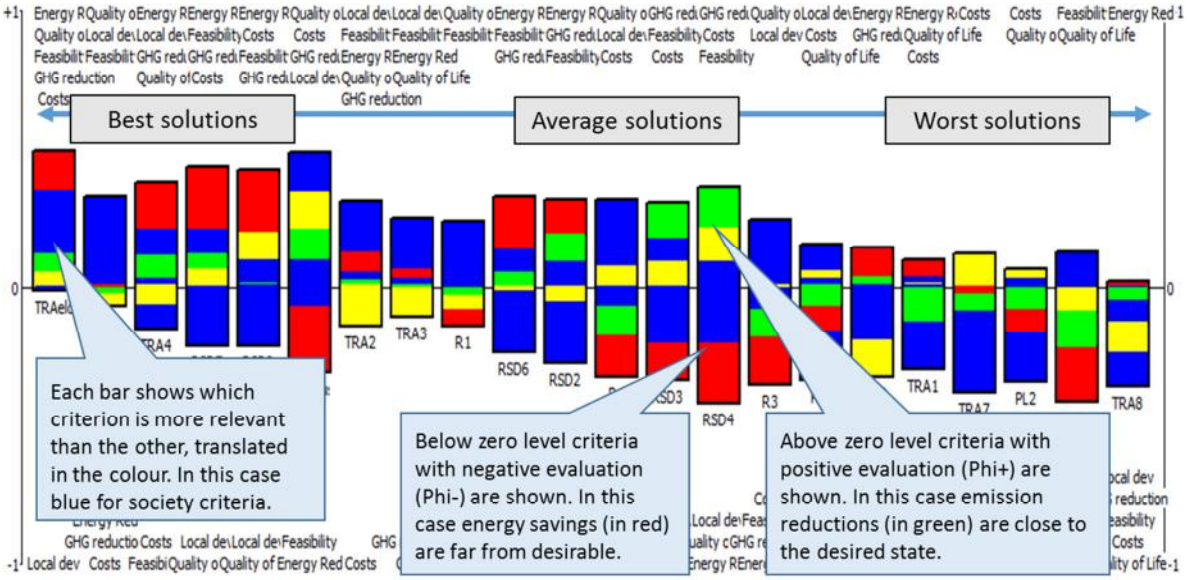
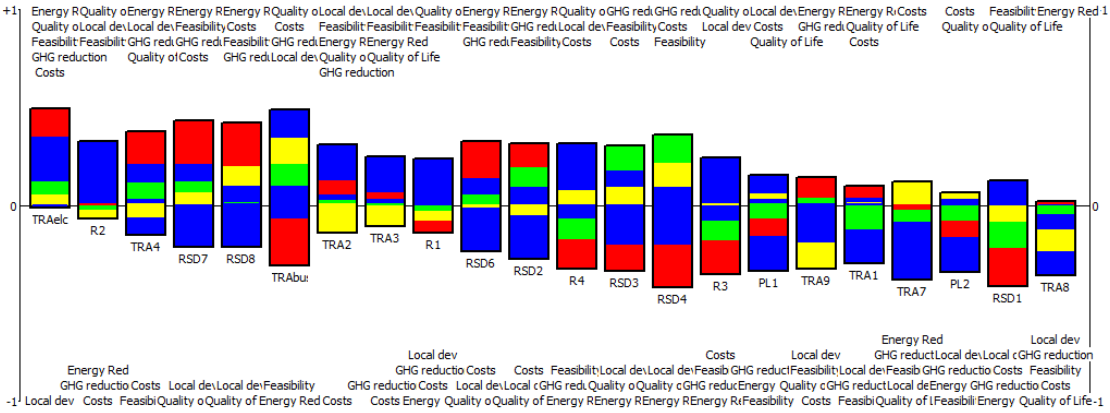


Figure 3 – Assessing MCDA results using a rainbow chart

3.1 MCDA result for the Local Authorities

The hierarchy of actions for the Local Authorities stakeholder group is presented in Figure 4. It is observed that the best solutions include actions with the best impacts on energy savings and on society, i.e. red-colour (energy savings) and blue-coloured (society) 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 action have little energy savings, which is not considered acceptable by the Local Authorities, despite having other positive aspects.



Rank	action	Phi	Phi+	Phi-
1	TRAelc	0,4762	0,6494	0,1732
2	R2	0,2532	0,5346	0,2814
3	TRA4	0,2143	0,5325	0,3182
4	RSD7	0,2100	0,4978	0,2879
5	RSD8	0,1970	0,4913	0,2944
6	TRAbus	0,1710	0,5152	0,3442
7	TRA2	0,1623	0,4848	0,3225
8	TRA3	0,1320	0,4697	0,3377
9	R1	0,0866	0,4545	0,3680
10	RSD6	0,0866	0,4416	0,3550
11	RSD2	0,0346	0,4156	0,3810
12	R4	-0,0216	0,4156	0,4372
13	RSD3	-0,0346	0,3810	0,4156
14	RSD4	-0,0693	0,3636	0,4329
15	R3	-0,1212	0,3658	0,4870
16	PL1	-0,1861	0,3377	0,5238
17	TRA9	-0,1905	0,3247	0,5152
18	TRA1	-0,2078	0,3420	0,5498
19	TRA7	-0,2684	0,2857	0,5541
20	PL2	-0,2835	0,2922	0,5758
21	RSD1	-0,2987	0,2576	0,5563
22	TRA8	-0,3420	0,2489	0,5909

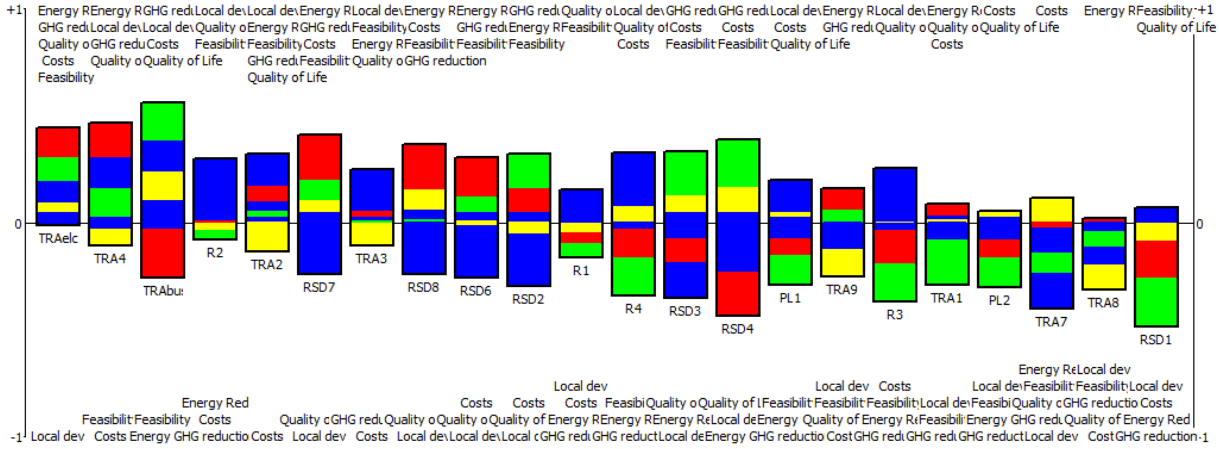
Figure 4 – "Rainbow" and Phi result for the Local Authorities- REF

Based on the obtained Phi values, the acceptable solutions are (Phi>0): TRAelc - deployment of electric cars to satisfy 5% of the mobility demand; R2 - decrease MSW per capita production; implement city centre traffic restrictions; RSD7- implement light insulation measures (reducing cold air infiltrations); RSD8 - refurbishing residential buildings with insulation options (wall and roof); TRAbus – have all buses circulation with biodiesel; TRA2 - increase parking fees; TRA3 – promote city centre traffic restrictions; R2 – increase share of recycled MSW; RSD6 – install double-glazed windows, and RSD2 - install solar thermal water panels.

The remaining actions are considered not acceptable (Phi<0) by the Local Authorities, the worst one being TRA8- increase disperse parking in the historic centre; PL1 – install LED in public lighting and TRA7 – build parking lots in the centre.

3.2 MCDA results-Regional authorities

The hierarchy of actions for the Regional authorities' stakeholder group is presented in Figure 5.



Rank	action	Phi	Phi+	Phi-
1	TRAelc	0,4224	0,6418	0,2195
2	TRA4	0,3478	0,6066	0,2588
3	TRAbus	0,2961	0,5839	0,2878
4	R2	0,2133	0,5321	0,3188
5	TRA2	0,1781	0,5114	0,3333
6	RSD7	0,1615	0,4969	0,3354
7	TRA3	0,1325	0,4886	0,3561
8	RSD8	0,1159	0,4741	0,3582
9	RSD6	0,0352	0,4389	0,4037
10	RSD2	0,0186	0,4306	0,4120
11	R1	-0,0166	0,4224	0,4389
12	R4	-0,0248	0,4182	0,4431
13	RSD3	-0,0311	0,4058	0,4369
14	RSD4	-0,0559	0,3934	0,4493
15	PL1	-0,0973	0,3789	0,4762
16	TRA9	-0,1014	0,3810	0,4824
17	R3	-0,1201	0,3706	0,4907
18	TRA1	-0,2091	0,3416	0,5507
19	PL2	-0,2526	0,3064	0,5590
20	TRA7	-0,2919	0,2857	0,5776
21	TRA8	-0,2961	0,2836	0,5797
22	RSD1	-0,4244	0,2153	0,6398

Figure 5- "Rainbow" and Phi results for the Regional authorities

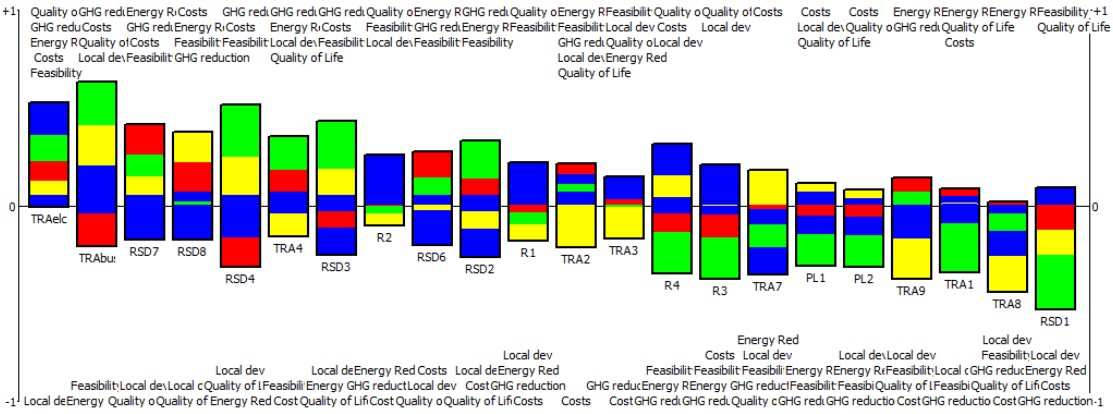
Contrary to the Local Authorities stakeholder, the Regional Authorities are more interested in environmental performance than the initial investment cost or than the societal aspects, i.e. CO_2 emission reduction is more important than quality of life and

local development (as in the allocated weights). In any case the deployment of electric vehicles is still the most desirable solution fulfilling emission reductions. More specifically, the acceptable solutions (Phi>0) are: TRAelc; TRA4; TRAbus; R2; TRA2; RSD7; TRA3; RSD8; RSD6 and RSD2.

The remaining actions are considered not acceptable (Phi<0) by the Regional Authorities, the worst ones being: RSD1 and TRA8.

3.3 MCDA results-Private Sector

The ranking of actions for the Private Sector is presented in Figure 6.



Rank	action	Phi	Phi+	Phi-
1	TRAelc	0,5138	0,6967	0,1830
2	TRAbus	0,4160	0,6591	0,2431
3	RSD7	0,2356	0,5388	0,3033
4	RSD8	0,1955	0,5188	0,3233
5	RSD4	0,1930	0,5213	0,3283
6	TRA4	0,1855	0,5388	0,3534
7	RSD3	0,1679	0,5088	0,3409
8	R2	0,1504	0,5138	0,3634
9	RSD6	0,0677	0,4586	0,3910
10	RSD2	0,0627	0,4561	0,3935
11	R1	0,0376	0,4586	0,4211
12	TRA2	-0,0050	0,4311	0,4361
13	TRA3	-0,0251	0,4211	0,4461
14	R4	-0,0376	0,4261	0,4637
15	R3	-0,1729	0,3584	0,5313
16	TRA7	-0,1779	0,3484	0,5263
17	PL1	-0,2005	0,3409	0,5414
18	PL2	-0,2381	0,3233	0,5614
18	TRA9	-0,2381	0,3183	0,5564
20	TRA1	-0,2581	0,3283	0,5865
21	TRA8	-0,4286	0,2231	0,6516
22	RSD1	-0,4436	0,2130	0,6566

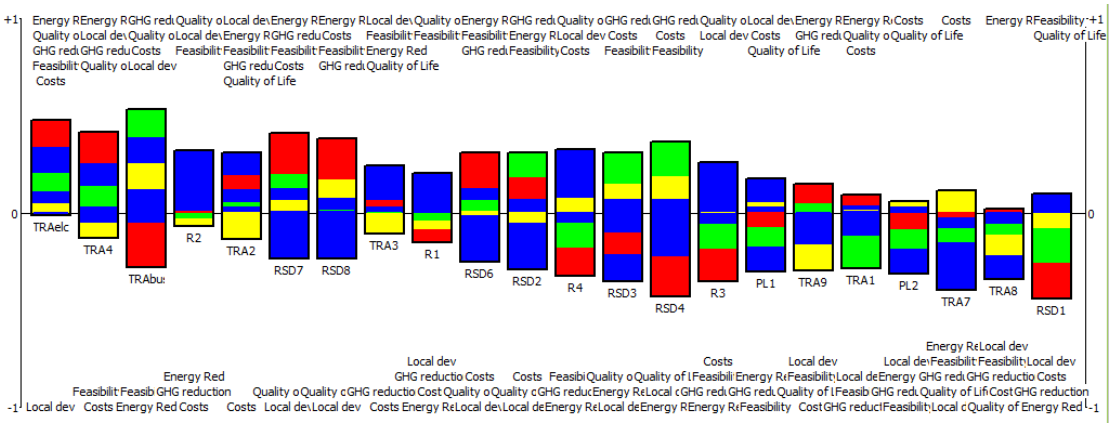
Figure 6 – "Rainbow" and Phi results for the Private Sector - REF

Based on the obtained Phi values, the acceptable solutions are (Phi>0): TRAelc; RSD7; RSD8; RSD4; TRA4; RSD3; R2; RSD6; RSD2 and R1.

The remaining actions are considered not acceptable (Phi<0) by the Private Sector, the worst ones being: RSD1 (solar thermal in 2020), TRA1 (cycling lane) and TRA8 (disperse parking in the centre). The most evident difference from the other two stakeholders is the poor performance of the TRA1 measure which is seen as an average measure by local and regional authorities' stakeholders.

3.4 MCDA results for the Civil Society

The raking of actions for the Civil Society stakeholder group are presented in Figure 7.



Rank	action		Phi	Phi+	Phi-
1	TRAelc	▭	0,4555	0,6480	0,1925
2	TRA4	▭	0,2795	0,5673	0,2878
3	TRAbus	▭	0,2464	0,5549	0,3085
4	R2	◆	0,2443	0,5383	0,2940
5	TRA2	▭	0,1698	0,4969	0,3271
6	RSD7	■	0,1677	0,4865	0,3188
7	RSD8	■	0,1387	0,4720	0,3333
8	TRA3	▭	0,1325	0,4783	0,3458
9	R1	◆	0,0497	0,4451	0,3954
10	RSD6	■	0,0455	0,4306	0,3851
11	RSD2	■	0,0124	0,4141	0,4017
12	R4	◆	-0,0062	0,4244	0,4306
13	RSD3	■	-0,0455	0,3851	0,4306
14	RSD4	■	-0,0745	0,3706	0,4451
15	R3	◆	-0,1014	0,3768	0,4783
16	PL1	●	-0,1346	0,3602	0,4948
17	TRA9	▭	-0,1553	0,3458	0,5010
18	TRA1	▭	-0,2008	0,3437	0,5445
19	PL2	●	-0,2588	0,3023	0,5611
20	TRA7	▭	-0,2878	0,2795	0,5673
21	TRA8	▭	-0,3251	0,2609	0,5859
22	RSD1	■	-0,3520	0,2402	0,5921

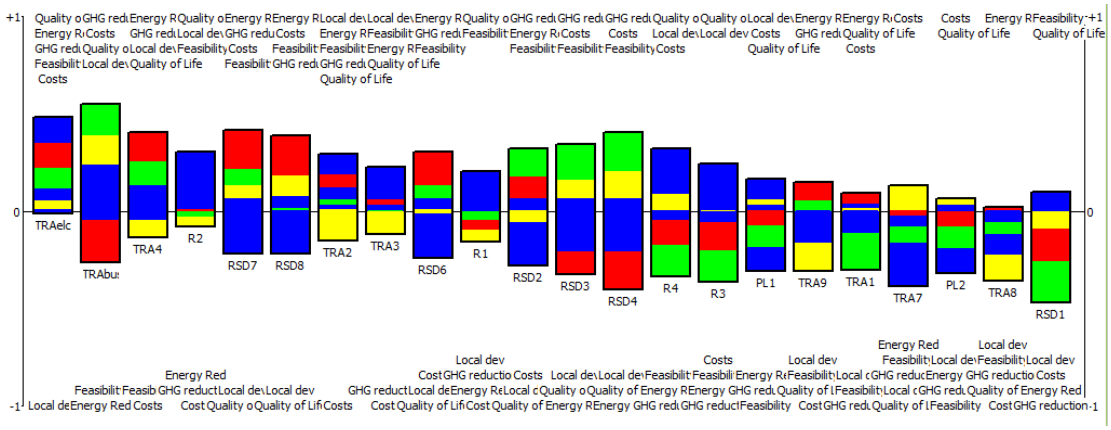
Figure 7 – "Rainbow" and Phi results for the Civil Society stakeholders

Based on the obtained Phi values, the acceptable solutions are (Phi>0): TRAelc; TRAbus; R2; TRA2; RSD7; RSD8; TRA3; R1; RSD6, and RSD2. It is clear that the civil society stakeholders are less concerned with feasibility and the financial effort criteria and this is way an expensive measures as the biodiesels buses is so high in the ranking.

The remaining actions are considered not acceptable by the Civil Society stakeholders, the worst ones (Phi<0) being: RSD1, TRA8 and TRA7, similarly to the regional authorities.

3.5 MCDA results-Compromise solution

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



Rank	action	Phi	Phi+	Phi-
1	TRAelc	0,4670	0,6590	0,1920
2	TRAbus	0,2824	0,5783	0,2959
3	TRA4	0,2568	0,5613	0,3045
4	R2	0,2153	0,5297	0,3144
5	RSD7	0,1937	0,5050	0,3113
6	RSD8	0,1618	0,4891	0,3273
7	TRA2	0,1263	0,4811	0,3548
8	TRA3	0,0930	0,4644	0,3714
9	RSD6	0,0587	0,4424	0,3837
10	R1	0,0393	0,4452	0,4058
11	RSD2	0,0321	0,4291	0,3970
12	RSD3	0,0142	0,4202	0,4060
13	RSD4	-0,0017	0,4122	0,4139
14	R4	-0,0226	0,4211	0,4436
15	R3	-0,1289	0,3679	0,4968
16	PL1	-0,1546	0,3544	0,5090
17	TRA9	-0,1713	0,3424	0,5137
18	TRA1	-0,2190	0,3389	0,5579
19	TRA7	-0,2565	0,2998	0,5563
20	PL2	-0,2583	0,3061	0,5643
21	TRA8	-0,3479	0,2541	0,6020
22	RSD1	-0,3797	0,2315	0,6112

Figure 8 – "Rainbow" and Phi results for the compromise solution among the four groups of stakeholders

3.6 Summary of the MCDA for the municipality of Évora

In conclusion, Table 7 presents the classification the acceptable (Phi>0) and the three worst (lowest negative Phi) actions for each stakeholder group together with the ones obtained by the compromise problem.

Table 7 – Summary of the alternatives per stakeholder group ranked per Phi value and only listing the three worst performing solutions

	Local authorities	Regional Authorities	Private	Civil society
#	**Best-performing solutions**			
1	Electric cars (TRAelc)	Electric cars (TRAelc)	Electric cars (TRAelc)	Electric cars (TRAelc)
2	Decrease MSW production (R2)	Speed reductions (TRA4)	Biofuel buses (TRAbus)	Speed reductions (TRA4)
3	Speed reductions (TRA4)	Biofuel buses (TRAbus)	Light insulation (RSD7)	Biofuel buses (TRAbus)
4	Light insulation (RSD7)	Decrease MSW production (R2)	Wall & Roof insulation (RSD8)	Decrease MSW production (R2)
5	Wall & Roof insulation (RSD8)	Increase parking fees (TRA2)	Solar PV roof up to 30% potential (RSD4)	Increase parking fees (TRA2)
6	Biofuel buses (TRAbus)	Light insulation (RSD7)	Speed reductions (TRA4)	Light insulation (RSD7)
7	Increase parking fees (TRA2)	City centre traffic restrictions (TRA3)	Solar PV up to 10% maximum feasible (RSD2)	Wall & Roof insulation (RSD8)
8	City centre traffic	Wall & Roof insulation	Decrease MSW production	City centre traffic

	restrictions (TRA3)	(RSD8)	(R2)	restrictions (TRA3)
9	Increase recycling (R1)	Double glazing windows (RSD6)	Double glazing windows (RSD6)	Increase recycling (R1)
10	Double glazing windows (RSD6)	Solar thermal (RSD2)	Solar thermal (RSD2)	Double glazing windows (RSD6)
11	Solar thermal (RSD2)	Increase recycling (R1)	Increase recycling (R1)	Solar thermal (RSD2)
	Three worst solutions			
	PL2	TRA7	TRA1	TRA7
	RSD1	TRA8	TRA8	TRA8
	TRA8	RSD1	RSD1	RSD1

Green coloured actions represent solutions acceptable by all stakeholder groups, also appearing in the compromise solution; Blue coloured actions represent solutions acceptable by at least 2 stakeholder groups also appearing in the compromise solution; Red coloured actions represent actions among the three worst ones for all stakeholder groups and for the compromise solution; Orange coloured actions represent actions reflecting at least two stakeholder groups' preferences but also appearing in the compromised solution.

With this analysis it is concluded that the MCDA analysis provided the following results (reflecting a compromise among all stakeholder groups' preferences):

A) Acceptable measures:

TRAelc – Shift of 15% from private cars mobility to public transportation from 2020 onwards;

TRAbus – All buses use biofuels in 2030;

R2 – Decrease MSW production per capita in 20% from 2013 values;

TRA4 – Speed limitation to 30km/h, for all vehicles in diverse zones from 2020 onwards;

RSD7 – Small scale insulation solutions in 50% of dwellings by 2030;

RSD8 – Wall & Roof insulation combined in 60% of dwellings by 2030;

RSD6 – Double glazing in 80% of dwellings by 2030;

RSD2 – Install solar thermal hot water panels in 40% of dwellings in 2030;

TRA2 – Duplicate parking fees in historic centre from 2020 onwards;

TRA3 – Interdiction for all type of vehicles and concerning all purposes to the Évora Acropolis from 2020 onwards.

B) Worst measures:

TRA8 – Increase historic centre parking disperse with 300 new disperse parking spaces for residents in the historic centre from 2020 onwards;

RSD1 – Install solar thermal hot water panels in 10% of dwellings by 2020;

PL2 – Change all public lighting to LEDs by 2030.

These measures here analysed for the REF visions are not substantially different from the ones in the Smart vision as can be seen in Figure 9.

Local

Rank	action	Phi
1	TRAelc	0,4502
2	RSD7	0,2771
3	RSD8	0,2208
4	TRA4	0,1883
5	TRA2	0,1494
6	RSD6	0,1385
7	TRAbus	0,1320
8	TRA3	0,1190
9	RSD2	0,0476
10	RSD4	0,0390
10	R1	0,0390
12	R2	-0,0195
13	TRA1	-0,0909
14	RSD3	-0,0952
15	R4	-0,0996
16	R3	-0,1515
17	PL1	-0,1602
18	TRA9	-0,1905
19	RSD1	-0,2078
20	PL2	-0,2229
21	TRA7	-0,2338
22	TRA8	-0,3290

Regional

Rank	action	Phi
1	TRAelc	0,3810
2	TRA4	0,3064
3	RSD7	0,2671
4	TRAbus	0,2340
5	TRA2	0,1573
6	RSD8	0,1470
7	RSD6	0,1180
8	TRA3	0,1118
9	RSD4	0,0476
10	RSD2	0,0393
11	TRA1	-0,0228
12	PL1	-0,0766
13	R1	-0,0787
14	R2	-0,0973
15	TRA9	-0,1014
16	RSD3	-0,1139
17	R4	-0,1201
18	R3	-0,1615
19	PL2	-0,1905
20	TRA7	-0,2505
21	TRA8	-0,2754
22	RSD1	-0,3209

Private

Rank	action	Phi
1	TRAelc	0,4637
2	RSD7	0,3734
3	TRAbus	0,3409
4	RSD4	0,2682
5	RSD8	0,2281
6	RSD6	0,1679
7	TRA4	0,1353
8	RSD2	0,0877
9	RSD3	0,0777
10	R1	-0,0276
11	TRA2	-0,0301
12	TRA1	-0,0326
13	TRA3	-0,0501
14	R2	-0,1353
15	TRA7	-0,1378
16	R4	-0,1429
17	PL2	-0,1880
18	PL1	-0,1905
19	R3	-0,2180
20	TRA9	-0,2381
21	RSD1	-0,3484
22	TRA8	-0,4035

Civil

Rank	action	Phi	Phi+	Phi-
1	TRAelc	0,4224	0,6315	0,2091
2	RSD7	0,2526	0,5342	0,2816
3	TRA4	0,2464	0,5507	0,3043
4	TRAbus	0,1967	0,5300	0,3333
5	RSD8	0,1656	0,4907	0,3251
6	TRA2	0,1532	0,4886	0,3354
7	TRA3	0,1159	0,4700	0,3540
8	RSD6	0,1118	0,4638	0,3520
9	RSD2	0,0290	0,4224	0,3934
10	RSD4	0,0290	0,4224	0,3934
11	R1	-0,0041	0,4182	0,4224
12	R2	-0,0414	0,3954	0,4369
13	TRA1	-0,0518	0,4182	0,4700
14	R4	-0,0911	0,3810	0,4720
15	PL1	-0,1118	0,3810	0,4928
16	RSD3	-0,1159	0,3499	0,4658
17	R3	-0,1366	0,3582	0,4948
18	TRA9	-0,1553	0,3458	0,5010
19	PL2	-0,1988	0,3416	0,5404
20	TRA7	-0,2505	0,2981	0,5487
21	RSD1	-0,2567	0,2878	0,5445
22	TRA8	-0,3085	0,2692	0,5776

Figure 9 – Overview of ranked measures in the Smart vision

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