Coordination and support action (Coordinating Action)

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INSMART

Integrative Smart City Planning

Report on the multicriteria methodology, the process and the results of the decision making – Cesena

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Executive Summary	
Multi-criteria analysis and ranking of the alternative planning hypotheses.	

Keywords	Alternatives, criteria, stakeholders, preferences, ranking.

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Acronyms and Definitions

CHP – Combined Heat and Power

ESM – Energy City Model

GIS – Geographic information system

MCDA – Multi Criteria Decisions Analysis

O&M – Operation and maintenance

PROMETHEE – Preference Ranking Organization METHod for Enrichment of Evaluations

PV – Photovoltaic

RES – Renewable energy sources

SG – Stakeholder Group

TIMES – The Integrated MARKAL-EFOM System

1. Introduction

An application of the innovative city planning method, developed within the EU FP7 project InSMART, is applied to the municipality of Cesena (Italy). A multi-model approach is used to explore and rank alternative plans (combinations of actions and measures) towards the sustainable development of the municipality, with a particular focus on the residential and transport sectors.

A technology-explicit model of the city is designed to be used as a test bed for exploring the evolution of energy-environmental variables in the urban area. A reference projection of the local system is calculated and then modified through six combinations of actions and measures aiming at representing six alternative sustainable-oriented planning hypotheses. Making use of the dynamic responses of the urban system model (results per each alternative), a multi-criteria method is used to determine the ranking of the alternative options, evaluated against a set of elements (technological, social, environmental, economic), and on the basis of local stakeholders' preferences.

Key stakeholders of the municipality of Cesena have been engaged to participate in the design of alternative planning hypotheses, in the definition and evaluation of the criteria, and of the responses of the tool (results of multi-criteria analysis). This report presents the main components of the multi criteria decision analysis – MCDA - (alternatives, criteria, weights) and the results.

The main goal of this activity is to get insights from the modelling exercises about the planning hypotheses, and to shortlist one (or few) options which can be deeper explored and analysed in the framework of the preparation of the strategic energy action plan (WP6).

2. Problem structuring - Scenarios identification

2.1. Problem structuring

Due to the complexity of the decision planning process for the city, the wide diversity of impacts of the projects, and the multiple stakeholders involved or impacted by the projects, a participatory multi-criteria approach is used. Local stakeholders have been engaged in all the key stages of the development of the analysis: in the design of the planning options (stakeholders have been asked to imagine and suggest actions and measures to simulate in a time horizon of around 20 years), in the definition of the criteria against which the alternative are evaluated, and in the selection of the preferences (weights) on those criteria.

The first step to involve stakeholders in the scenario definitions and in the MCDA method, was the formal establishment of an interdisciplinary working municipal group of Cesena composed of technicians from the following departments:

Environmental, Mobility, Urban planning, Public and private buildings and GIS, and a representative of "Energie per la città Ltd". The group has actively participated in the data collection and in the definition of the first draft of scenarios.
The second step was the enlargement of the stakeholder group to involve in process others local actors directly related to the theme of the project, in particular:

- University (Architecture, Engineering)
- CEAS (Municipal environmental sustainability education center composed by different associations involved in urban sustainability projects)
- Professional orders (Order of architects, Order of engineers)
- Professional associations (CNA Confesercenti, Confartigianato, Confcommercio)
- Consumers associations (Federconsumatori, Adoc Adiconsum)

This group was involved in the evaluation of the first list of the scenarios and in the evaluation of the KPI indicators through the following steps, organized within the Municipality of Cesena with the collaboration of E4SMA:

- March, 14 2016 - I workshop
  Presentation of the MCDA method and first draft of the scenarios
- June 2016 - On-line survey for the evaluation of the KPI indicators
- July, 5 2016 - II workshop
  Presentation of the second draft of the scenarios

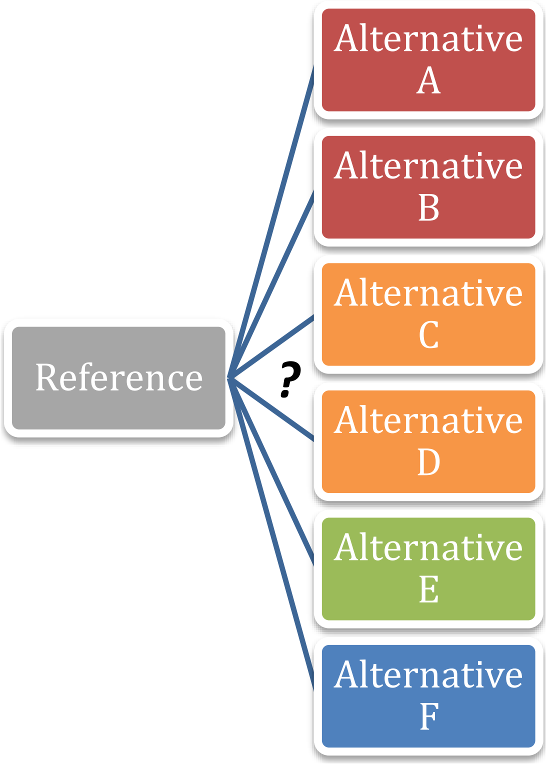
The III workshop to present the final elaboration of the scenarios and the results of the ranking analysis, is scheduled for November 29, 2016.

In parallel three meetings with the political parties of the municipality of Cesena were organized:

- January, 28 2016 - Presentation of the first draft of the scenarios to the Councillor of Urban Planning, Councillor of Sustainable Development and Europe, Councillor of Mobility;
- 13 March, 13 2016 – Special workshop dedicated to the City Council to present the presentation of the MCDA method and a first draft of the scenarios;
- 10 May, 10 2016 - Presentation of the scenarios Council Committee Environment and Energy.

2.2. Presentation of the alternatives

On the basis of the possible space of decisions of the municipality of Cesena, "alternative" planning hypotheses have been prepared and tested making use of the city model and scenario analysis. These are built around different themes (urban regeneration, urban development - new constructions, transport measures, behaviour and organisation, renewables) with the aim of exploring the potential benefits (or drawbacks) of the combination of specific "competitive" projects, actions, standards, targets. A short description of the different alternatives is reported in the figure and table below.



Alternative **A** - More oriented on **urban regeneration** Existing building stock: 10% from class E to class A and 30% from class E to class C; Simple measures on transport; Strong info campaigns.
Alternative **B** - More oriented on **urban regeneration** Buildings: 40% from E to B; Important measures on transport. Moderate info campaigns.
Alternative **C** - More oriented on **"new" constructions** Standard building efficiency for new construction; Simple measures on transport; Strong info campaigns.
Alternative **D** - More oriented on **"new" constructions** High building efficiency for new construction; Different organization of transport; Low info campaigns.
Alternative **E** - More oriented on **transport** New transport infrastructures; Moderate regeneration of existing building stock; Moderate info campaigns.
Alternative **F** - More oriented on **renewables** New renewables; Moderate regeneration of existing building stock; Strong info campaigns.

Fig. 1. Six competitive strategies - Tab. 1. Description of the alternatives

A pure "what-if" analysis is at the basis of six alternative planning hypotheses (combination of actions of different areas) for the decision makers. The key outcome of such an explorative analysis of alternative planning hypotheses (which makes use of a city energy system model) is the identification of an optimum mix of applicable measures and technologies that will pave the way towards the achievement of the sustainable targets of the municipality of Cesena.

Alternatives are all built by combining actions and measures of different sectors in "comprehensive" plans, some are more focused on the existing building stock, some on the analysis of the impact of new districts, some more oriented to the transport, and others to the renewables. A more detailed description of the storylines and the corresponding results are reported in the *Report on optimum sustainability pathways – Cesena. Deliverable D5.4*.

3. Criteria Identification and Evaluation

3.1. Criteria

The expectation of any decision-maker is to identify a strategy that is the best (optimal) on all the criteria at the same time. This is usually impossible as the relevant criteria, against which decisions are taken, are sometimes conflicting each with other. The objective of MCDA is thus to identify the best "compromise" decisions for the integrated urban-energy planning of the municipality of Cesena.

In order to explore the planning problem of the city, nine criteria have been selected in agreement with the local stakeholders, aiming at "measuring" the pros and cons of each alternative configuration of the future urban-energy system. Some of the criteria are "quantitative" and can be directly derived by the outputs of the ESM model (and from the transport analysis), while some others are "qualitative" (measured with a 5-points Likert scale on the basis of the impact assessments of past experiences at the municipality level, and on the opinion of "third-party" local experts). The inclusion of qualitative criteria gives additional space for a more "comprehensive" evaluation of the alternatives.

The criteria against which the alternative planning hypotheses are evaluated (emerged during the problem structuring and discussion with the stakeholders) are: the energy consumption in the building sector in 2030 (C1), the total CO_2 emissions in 2030 (C2), the total particulate emissions in 2030 (C3), the investments costs (C4) over the period of analysis, the onsite renewable production of energy in 2030 (C5), the private vehicles dependency in 2030 (C6), and some qualitative criteria like the aesthetic integration of technologies and infrastructures (C7), the easiness of implementation of the strategy (C8), and the local development (C9).

Table below summarizes the criteria, the unit of measure chosen, the direction of the preference of each criterion, and the cluster.

Quantitative

C1: Energy consumption in the building sector in 2030. (TJ). MIN. Energy.

C2: Total CO_2 emissions in 2030. (t). MIN. Environment.

C3: Total particulate emissions in 2030 (kg). MIN. Environment.

C4: Investments (and maintenance) costs (until 2030). (kEuro). MIN. Economy.

C5: Onsite renewable production of energy in 2030. (TJ). MAX. Energy.

C6: Indicator of private vehicles (cars, moto) dependency in 2030. (Mpass-km). MIN. Social.

Qualitative

C7: Aesthetics/architectonic integration of technologies and infrastructures. (5-points scale). MAX. Environment.

C8: Easiness of implementation of the strategy. (5-points scale). MAX. Social.

C9: Local development. (5-points scale). MAX. Social.

Tab. 2. List of criteria

The criteria are formulated as to follow some basic characteristics: “understandability” (decision makers well-know the actual meaning of the indicators); “measurability” (both quantitative and qualitative criteria are determined making use of analytic approach); “non-redundancy” (criteria should not be virtually over-weighted by presenting the same issue with more than one item); “independence” (there must be at least one variable of the alternative for which two criteria compete); and “completeness” (number and types of criteria should be evaluated and selected in order to cover all the key aspects and complexities of the specific decision problem).
If (or when) the above mentioned set of criteria is modified (by adding or removing criteria of the problem), the final ranking of alternatives may differ.

3.2. Weights

According to the selected “outranking” method[1], local stakeholders have been called to specify priorities and perceptions between criteria, and deviation of alternatives within each criterion. This is actually their space of freedom, where the subjective views can be captured and included in the decision making process.
Weights have been collected in two stages, following two meetings with the stakeholders held in Cesena. After the first round, 19 participants have expressed their preferences among criteria, while after the second round a smaller group of stakeholders (4) has participated.
The Hinkle’s method (“resistance to change grid”) for estimating criterion importance ranking has been employed. The rationale of the method is in the definition of two terms per each criterion, one expressing its most desirable outcome and the other expressing the least desirable outcome (“bipolar form”). The decision makers are then asked to explore the “bipolar” expression in a pairwise manner by filling a resistance-to-change grid like to one shown below (see Tab.3, and Tab.4).
Method was presented during the first meeting in Cesena to all the participants, and a short guideline (with an example) was shared with them to facilitate their work.

Cx	**Cy**	**C***		**Cx**	**Cy**	**C***
C1	C2	**C2**		C4	C5	**C4**
C1	C3	**C3**		C4	C6	**C6**
C1	C4	**C4**		C4	C7	**C7**
C1	C5	**C1**		C4	C8	**C8**
C1	C6	**C1**		C4	C9	**C9**
C1	C7	**C1**				
C1	C8	**C8**		C5	C6	=
C1	C9	=		C5	C7	**C7**
				C5	C8	**C8**
C2	C3	=		C5	C9	=

[1] A short description of the method is reported in Appendix I.

C2	C4	**C4**				
C2	C5	**C2**		C6	C7	**C7**
C2	C6	**C2**		C6	C8	**C8**
C2	C7	**C2**		C6	C9	**C9**
C2	C8	**C8**				
C2	C9	**=**		C7	C8	**C7**
				C7	C9	**C7**
C3	C4	**C4**				
C3	C5	**C3**		C8	C9	**=**
C3	C6	**C3**				
C3	C7	**C3**				
C3	C8	**C8**				
C3	C9	**=**				

Tab. 3. Example of pairwise comparison (in bold the options which resist to change)

	c1	c2	c3	c4	c5	c6	c7	c8	c9
c1	-	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.5
c2	1.0	-	0.5	0.0	1.0	1.0	1.0	0.0	0.5
c3	1.0	0.5	-	0.0	1.0	1.0	1.0	0.0	0.5
c4	1.0	1.0	1.0	-	1.0	0.0	0.0	0.0	0.0
c5	0.0	0.0	0.0	0.0	-	0.5	0.0	0.0	0.5
c6	0.0	0.0	0.0	1.0	0.5	-	0.0	0.0	0.0
c7	0.0	0.0	0.0	1.0	1.0	1.0	-	1.0	1.0
c8	1.0	1.0	1.0	1.0	1.0	1.0	0.0	-	0.5
c9	0.5	0.5	0.5	1.0	0.5	1.0	0.0	0.5	-

Tab. 4. Hinkle's grid: preferences (1) and indifferences (0.5) among criteria

Figures below show the final results of the elaboration of the two different stakeholders groups. Individual preferences are compared to the "average" (nineteen stakeholders in the left case and four stakeholders in the right case). Both the charts show the different shapes of the preferences across the criteria. For example, on the left chart, stakeholder "P2" assigns a high weight to criterion 3 and a much minor relevance to criterion 8, which is very important for stakeholder P1 though.

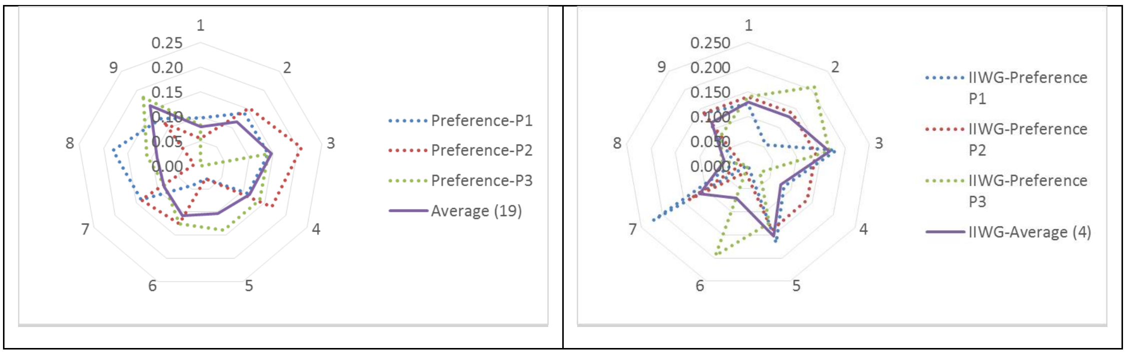


Fig. 2. Individual preferences, and working groups (average) preferences, across the nine criteria

There is another powerful way to analyse the results of the weights elaborations (Hinkle's method), as reported in the four following charts. As the method is based on a pairwise comparison, two example are presented to illustrate some interesting findings obtained from the stakeholder group 1 and the stakeholder group 2.

On the left side, the "strength" of criterion 1 (C1) against all the remaining criteria is shown. The blue section of the bar is (almost) always shorter than the red section, so that the C1 (Energy consumption in the building sector) is almost dominated by the other criteria in a "1 to 1" competition. On the right side, C9 (qualitative criterion) dominates all the remaining criteria (the blue section is longer), so that local development is considered the dominant one in the decision process, according to the stakeholder-group-1 based dataset.

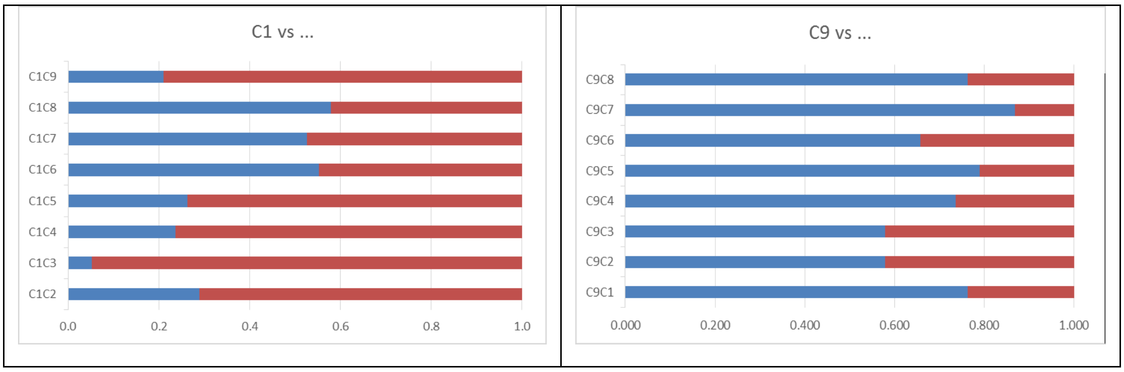


Fig. 3. Examples of pair-wise comparison - SG1

The following figures report the same examples with the stakeholder-group-2 based dataset, and show a more balanced distribution of strengths and weaknesses in the pairwise comparisons of C1 and C9.

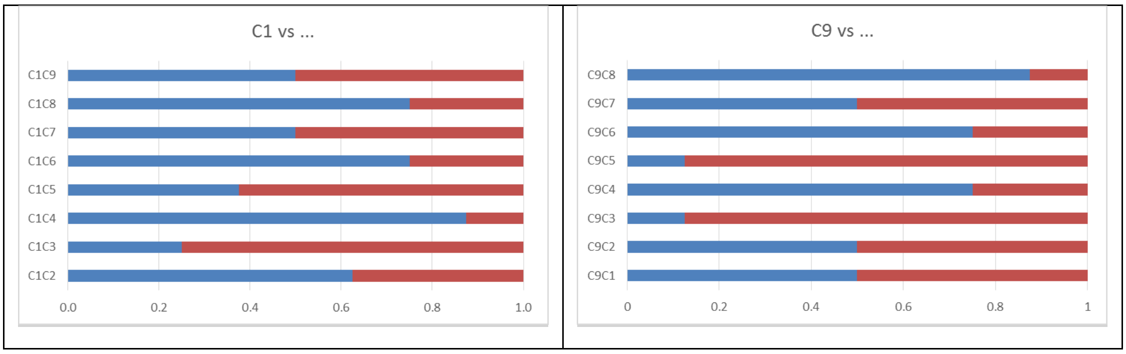


Fig. 4. Examples of pair-wise comparison - SG2

The final weights calculated making use to the two stakeholders groups average preferences (data can be also read from the radar charts) are then inputted to MCDA tool, as shown below, to create two different variants of the same multi-criteria problem.

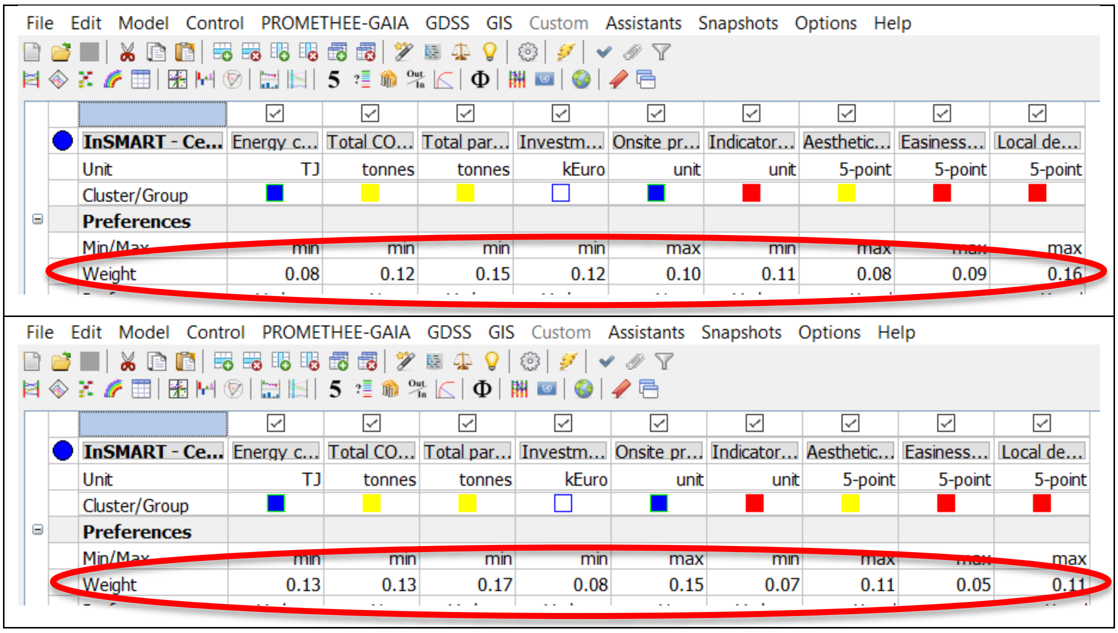


Fig. 5. Weights from the first and second stakeholder WGs

Preferences of the second working group (weights) have been selected as "default" values for the analysis. Although the number of participants was much lower, respondents proved to be well-aware of the method and more familiar with the actual meanings assigned to the criteria. Based on these data, the overall weight of the qualitative components is 1/4 of the total (3/4 for quantitative).

Data coming from the first SG have been used for sensitivity analysis.

4. MCDA Model Implementation

4.1. Evaluation matrix

Making use of the dynamic responses of the city ESM (set of results per each alternative) and of the transport model, the multi-criteria tool is used to determine the ranking of the alternative options. Table below shows the "quantitative outputs" of the two models which are used as "quantitative inputs" for the multi-criteria analysis ran in cascade.

C1	C2	C3	C4	C5	C6
Unit: TJ	Unit: t	Unit: kg	Unit: kEuro	Unit: TJ	Unit: Mpass-km
1,965	310,639	11,296	2,353,204	1,358	1.168
1,809	289,242	10,924	2,471,972	1,358	1.123
1,828	307,194	12,324	2,787,580	1,358	1.165
1,877	289,895	9,542	2,228,977	1,361	1.151
1,874	349,334	13,055	2,846,468	1,358	1.198
1,886	263,509	6,901	2,118,472	1,358	1.076
1,838	282,351	9,624	2,381,794	1,673	1.168

Evaluations									
Reference	1965.388	310638.85	11295.645	2353203.7	1358.242	1.168	average	very good	very bad
Alternative A	1808.800	289242.50	10924.210	2471971.7	1358.241	1.123	good	average	good
Alternative B	1828.331	307194.41	12324.380	2787580.4	1358.241	1.165	good	average	good
Alternative C	1893.260	289895.19	9542.250	2228976.8	1360.863	1.151	bad	good	average
Alternative D	1873.923	349333.88	13054.965	2846468.2	1358.241	1.198	bad	average	very good
Alternative E	1886.026	263509.37	6901.294	2118471.5	1358.241	1.076	very bad	very bad	bad
Alternative F	1838.496	282350.53	9623.840	2381793.7	1672.695	1.168	average	average	good
Alternative G	0.000	0.000	0.000	0.000	0.000	0.000	average	average	average

Fig. 6. Evaluation table

The evaluation table of the tool is reported above. It allows to visually compare the alternative (rows) by criterion (column) and to immediately see the best performing (green) and the worst performing options (red) per each column. Although this is a mono-dimensional and simplified comparison (no weights are used), it makes clear the complex nature of the decision problem, as some alternatives perform very well on few criteria but are weak on other criteria. It also makes evident that there is no alternative which dominates the others[2], as well as there is no alternative which is fully dominated, so that none of the options can be discharged "a priori". For instance, Alternative E (more renewable oriented) is the best options in four (over nine) criteria but it is also the worst in two cases. Solving the complexity of this problem for the municipality of Cesena is the goal of such a multi-criteria modelling task.

The performances of qualitative criteria have been determined via a different approach instead. Each alternative has been evaluated on a 5-points Likert scale basis by a restricted group of technical partners and municipality technicians. The results of these estimations are shown in the table above (red box). The quantification of these performances have been evaluated and discusses in group, as result of a general agreement among the group.

A summary of the element which underpinned the scores is presented below:

- C7: Alternatives A and B have similar (positive) impacts to the aesthetic of the city, as a number of houses will be refurbished. However, Alt. B provides slightly better performance as more houses will be retrofitted and measures on transport organization will impact positively on the landscape. Urban development scenarios (Alt. C and D) will perform badly according to this criteria, as new houses will translate in higher land consumption and will the construction of new roads, services, etc. Alt. E will perform very badly, given the impacts on the construction of the tramway. Alt. F has a neutral

[2] When an option dominates the others (is better of the other alternatives against all the criteria), the decision problem does not exist or is probably not well structured.

performance on this criteria, as is assumed that new renewables will be fully integrated to building roofs and structures.

- C8: Alternatives C, D have a good performance on this criteria, as the decision of developing new construction areas is determined and regulated at central level (municipality council). Between these D has been slightly penalized (score: average) given the higher complexity on developing houses with *Passive House* energy standards. Alternatives A, B and F require the deep involvement of citizens, which are the key actors on the decision on new investments, even some subsidies or supporting mechanism may be added (not applied here). Alternative E performs very badly as will involve the construction of completely new infrastructures and new financing options.
- C9: Alternative D performs very good as it provides the realization of high efficiency houses (*Passive Houses*) using and creating skill within the municipality. Alternative F also performs well as as skilled expertise on designing and installing renewables will be required. Alt. E performs badly as to build new tram lines will involve expertise and support from companies which are external to the municipal territory, hence no real impact is foresee on the local development. Alternatives A and B perform good as local skills will be employed and specialized in refurbishment activities. Alternatives C will have an average performance on this criterion as, even if it will impact positively on the local development (i.e. jobs in building sector), these will not imply the formation of high skilled professional people.

4.2. Preference functions

The shape of the preference functions have been selected following the wizard of the software: “Linear” and “V-shape” options have been used for the quantitative criteria in order to account even for small deviations of performances over the space of the variables, while the “Usual” (step-wise) shape option has been chosen for the qualitative criteria[3].

5. Results

It is expected that the multi-criteria decision analysis will identify a combination of measures (planning hypothesis) that are ranked high in the preferences of the stakeholders in the city. These specific interventions will form the basis of a deeper explorations under the framework of WP6, and will feed the technical part of Sustainable Energy Action Plan for the city of Cesena.

[3] As suggested by the software/methodology: “the Usual preference function, is a good choice for qualitative criteria including a small number of evaluation levels (like the often used 5-point scale ranging from very bad to very good)”.

The following charts show a graphical representation of the "uni-criterion[4]" net flow scores for the selected alternatives. Figures provide a disaggregated view of the "strengths and weaknesses" of each competitive option across the single criteria, and easy-to-read information for the analysis.

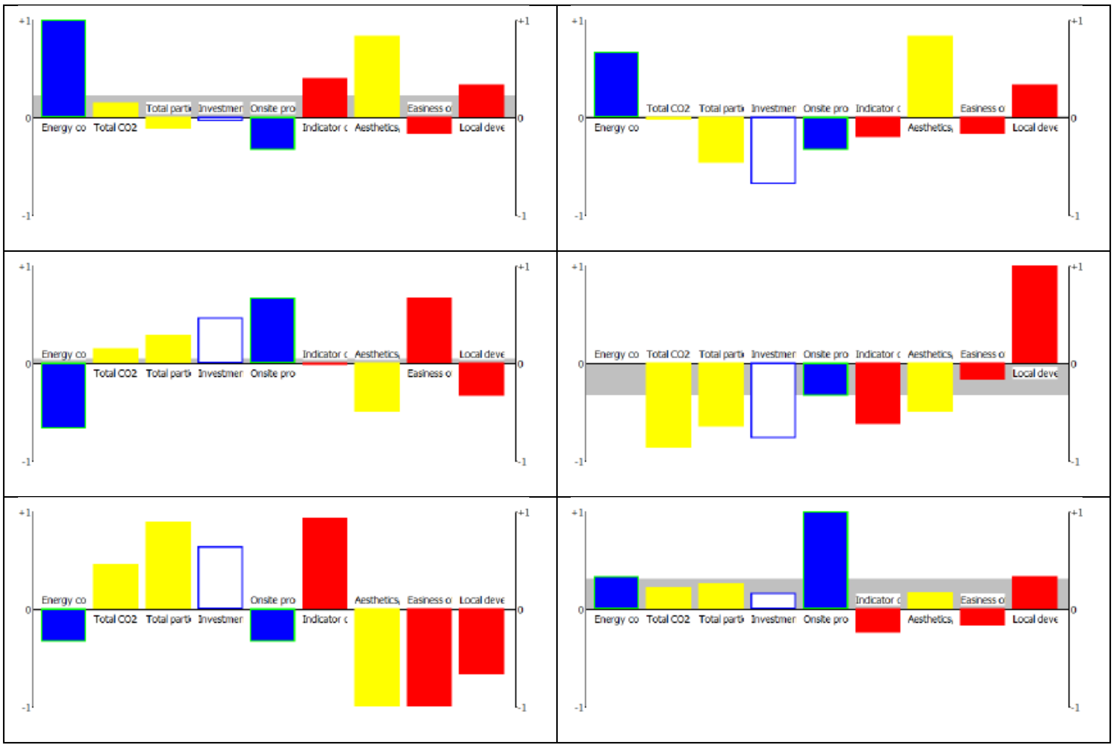


Fig. 7. Alternative profile windows (Top: A, B), (Center: C, D), (Bottom: D, E)

It's easy to see, for example, that Alternative D has only one important element of "strength" (C9), while is generally very weak on the other criteria. Alternative E is generally preferred on the basis of quantitative criteria (see vertical bars C2, C3, C4, C6) but shows weaknesses on the qualitative side, while Alternative F reports almost all positive elements (elements of strengths).

Table below shows the final ranking of the alternatives based on the "net preference flows" (Phi) and its positive and negative components (Phi+, Phi-); the key findings can be summarised as follows:

- alternative F is the best one according to the net preference flows (complete ranking);
- alternatives F and A have positive net preference flows (for all the others a negative Phi is calculated);
- alternative F is reported to be "stronger" (with respect to the positive outranking power) than alternative A, but also "weaker" than alternative A (with respect to the negative outranking power).
- alternative D is the last option in terms of net Phi, but also in terms of positive component (Phi+) as well as in terms of negative components (Phi-). That

[4] See Appendix I for the mathematical description and more details.

means, this is the option with the lowest “strength” and the highest “weakness” (low outranking power) at the same time.
- Alternative C has a slightly negative net preference flow value, although its positive outranking power (Phi+) is very close to the one of Alternative A.

Rank	Alternative	Phi	Phi+	Phi-
1	Alternative F	0.2863	0.4769	0.1906
2	Alternative A	0.2039	0.3844	0.1806
3	Alternative C	-0.0038	0.3627	0.3665
4	Alternative B	-0.0246	0.2805	0.3051
5	Alternative E	-0.1066	0.3351	0.4417
6	Alternative D	-0.3553	0.1986	0.5539

Tab. 5. Ranking of the alternatives

A network-like representation of the relative strengths and weaknesses is shown below. Alternatives are represented by nodes, and arrows are drawn to indicate preferences. Chart should be read from the top to the bottom (Alternative F is better than B and C, and all perform better than E and D).
Non-dominance of the alternatives or “incomparabilities” are very easy to detect (for example there is no arrow linking Alternative F and A, or C and B), and proximity between alternatives (distance of the nodes) gives the degrees of comparability in the partial ranking.

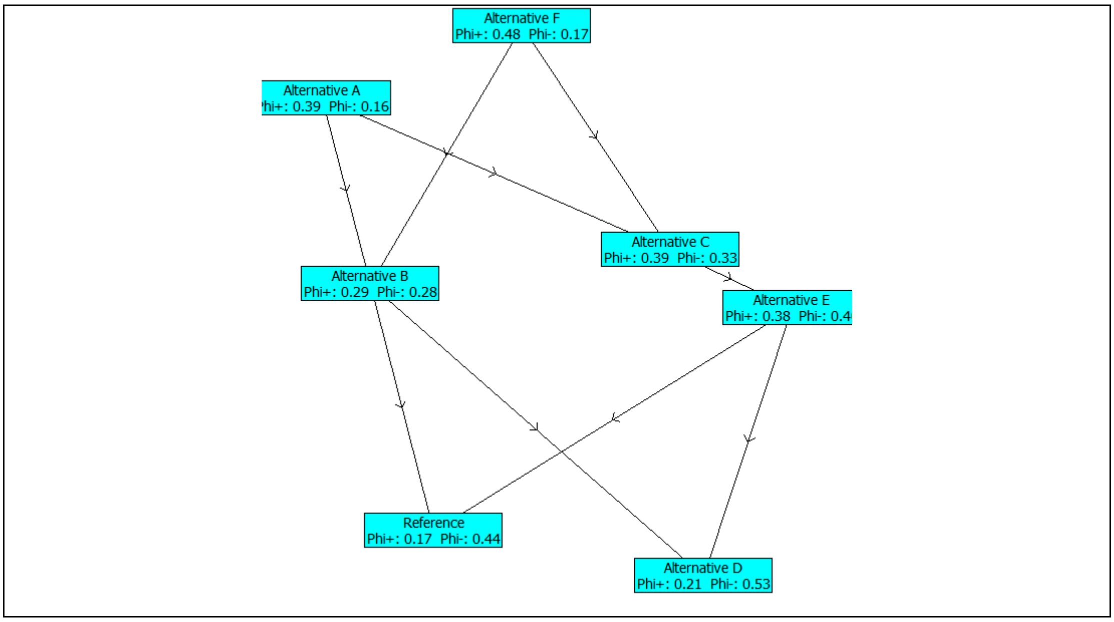


Fig. 8. Promethee network

Taking “final and definitive” decisions on the basis of the findings reported above might be risky and too simplistic. All can be suggested at this stage, is that some combinations of measures (alternative planning hypotheses) deserve to be further examined and considered for the final preparation of the strategic energy action plan, while others look (much) less interesting and can be excluded from deeper investigations. Table below summarizes the findings of this analysis.

Rank	Alternative	Findings
1	Alternative F	Shortlisted
2	Alternative A	Shortlisted
3	Alternative C	Right below the threshold
4	Alternative B	Likely not of interest
5	Alternative E	Likely not of interest
6	Alternative D	Discarded

Tab. 6. Findings about the alternatives in the default model

6. Sensitivity analysis

Once the complete ranking of the model (ran in default mode) is generated, robustness of results can be tested through sensitivity analysis in order to check the responsiveness of the solutions (and of the corresponding first findings) to some elements of uncertainty and subjectivity. Some extra scenarios are explored making use of the MCDA tool of Cesena, and the corresponding rankings are shown.

- A different working group (weights based on the preferences of 19 participants)

Rank	Alternative	Phi	Phi+	Phi-	Diff. with the default case
1	Alternative F	0.2188	0.4121	0.1933	=
2	Alternative A	0.1746	0.3598	0.1852	=
3	Alternative C	0.0513	0.3849	0.3336	=
4	Alternative B	-0.0734	0.2451	0.3185	=
5	Alternative E	-0.0742	0.3635	0.4377	=
6	Alternative D	-0.2971	0.2257	0.5229	=

Tab. 7. Ranking of the alternatives – sensitivity analysis 1

Although the relative distances (ΔPhi) among the alternatives are different from the default case, very similar findings can be reported as the ranking is the same in both the variants. Alternatives F, A and C are the only planning hypotheses with a positive net preference flow value. At the same time, alternative D reports the worst performance.

- Only quantitative criteria

Rank	Action	Phi	Phi+	Phi-	Diff. with the default case
1	Alternative F	0.333	0.4883	0.1553	=
2	Alternative E	0.237	0.464	0.2269	+3
3	Alternative A	0.1236	0.3285	0.2048	-1
4	Alternative C	0.0861	0.3714	0.2853	-1
5	Alternative B	-0.1927	0.1846	0.3773	-1
6	Alternative D	-0.5871	0.0712	0.6583	=

Tab. 8. Ranking of the alternatives – sensitivity analysis 2

This sensitivity case aims to show the response of the multi-criteria analysis of the decision planning problem for Cesena when only “quantitative” criteria are taken into consideration (when the level of “subjectivity” in the assessment of the alternatives is minimised/null). It is not meant to suggest that qualitative criteria should be excluded from the decision problem, rather it aims to test and show the sensitivity of the default ranking (robustness of the shortlist) when only the outputs of the modelling exercises undertaken in the previous WPs are used.

The changes generated by such assumption are now more significant, but some elements of robustness are still evident. Alternative F and A keep a positive value of the net preference flow, and alternative D and B are, as before, at the bottom of the ranking. Without considering the qualitative criteria, alternative E (which includes new transport infrastructures, and a significant switch in transportation modes from road to rail) also performs very well (2nd position of the complete ranking), suggesting that the energy-emissions related benefits of such a strategy would be very high. Hence, in order to make this strategy competitive against the "complete" set of criteria, a big work of simplification of the procedure and minimisation of the visual impact of the new infrastructure seems to be necessary.

- Exclusion of the onsite renewable production criterion

Rank	Action	Phi	Phi+	Phi-	Diff. with the default case
1	Alternative A	0.3128	0.4538	0.141	+1
2	Alternative F	0.1576	0.3826	0.225	-1
3	Alternative B	0.0431	0.3311	0.288	+1
4	Alternative E	-0.0537	0.3955	0.4492	+1
5	Alternative C	-0.1127	0.2838	0.3965	-2
6	Alternative D	-0.3472	0.2344	0.5816	=

Tab. 9. Ranking of the alternatives – sensitivity analysis 3

In Cesena the possibility to use land for the installation of utility-scale PV is regulated (not allowed), so that the only available "surface" for PV and solar thermal installations is on the roofs and facades of the buildings. Among the "actions" which have been simulated (modelled) to compose the alternative planning hypotheses, the one that imposes an increase of a percentage of the onsite renewable production (solar energy from buildings) looks slightly less controllable from the municipality.

Based on this consideration, a further sensitivity analysis has been ran to check the final/complete ranking when the criterion about onsite generation is removed. Alternatives F and A are still the two best options, but A is ranked in the top position in this case. The alternatives C and D (so designed) are, one more time, not enough valid.

According to the outcome of the modelling analysis, and in agreement with the local stakeholders, the two planning hypotheses "**F**" and "**A**" will be further assessed and explored in their key components in order to formulate the most robust and "comprehensive" strategic energy action plan (WP6) for the municipality of Cesena.

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Appendix I – Visual Promethee

Visual Promethee[5] is a multicriteria decision aid (MCDA) software, designed to help the analyst to:

- evaluate several possible decisions or items according to multiple often conflicting criteria,
- identify the best possible decision,
- rank possible decisions from the best to the worst one,
- visualize decision or evaluation problems to better understand the difficulties in making good decisions,
- achieve consensus decisions when several decision-makers have conflicting points of view,
- justify or invalidate decisions based on "objective" elements.

The Promethee methods are designed to analyze data within a multi-criteria "table" including:

- a number of actions,
- several criteria

In mathematical terms the problem is the following:

$$max\{F_1(a), F_2(a), \ldots, F_k(a) | a \in A\}$$

where A is a finite set of n actions (or alternatives) and F_1 to F_k are k criteria. $F_j(a)$ is the evaluation of action a on criterion F_j. If we suppose that all criteria have to be maximized, the multicriteria table (or evaluation matrix) would look like as follows:

$$\begin{vmatrix} \cdot & F_1 & F_2 & \ldots\ldots & F_k \\ a_1 & F_1(a_1) & F_2(a_1) & \ldots\ldots & F_k(a_1) \\ a_2 & F_1(a_2) & F_2(a_2) & \ldots\ldots & F_k(a_2) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_n & F_1(a_n) & F_2(a_n) & \ldots\ldots & F_k(a_n) \end{vmatrix}$$

The objective of MCDA is thus to identify the best compromise decisions.

One very common way to try to solve multicriteria decision problem is to aggregate all the criteria into a single summary score. This can be done in several ways. A good way to obtain solutions with a more balanced compromise is to use outranking methods.

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[5] It is developed by Professor Bertrand Mareschal from the Solvay Brussels School of Economics and Management of the Université Libre de Bruxelles (ULB). The first implementation of the Promethee method dates back in the 1980's. In the following decades several software implementing the methodologies were developed: PromCalc, Decision Lab, and finally D-Sight (2010) and Visual Promethee (2012).

The basis of outranking methods is very simple: instead of trying to define what is good and what is bad, which can be very difficult especially when facing a new problem for which very few reference points are known, it is usually much easier to compare one solution to another. The first outranking method developed was **Electre**, back in the 1970s; other outranking methods were implemented: Promethee elaborates and improves Electre, introducing also a new graphical descriptive tool (Gaia).

To perform the pairwise comparison which is at the basis of the outranking methodology, implementation of **preference functions**, which take into account the differences existing between the two actions/alternatives being compared, is needed. For each criterion F_j, we have a preference function $\boldsymbol{P_j (a,b)}$ and a normalized weight $w_j > 0$.

A multicriteria preference index is computed as:

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

In the Promethee software there are a series of predefined preference functions, which can be used to shape the relative distance among the alternatives. With normalized weights, $\pi(a,b)$ is a number between 0 and 1. It expresses how much a is preferred to b taking into account all the criteria and their weights. For instance:

- if $\pi(a,b) = 0$, all the P_j (a,b) values are equal to 0, which means that a is never even slightly preferred to b on any criterion.
- if $\pi(a,b) = 1$, all the P_j (a,b) values are equal to 1, which means that a is strongly preferred to b on all the criteria.

The result of this procedure is a table hosting the **preference flows**. Three different types of preference flows are computed:

- **Positive** or leaving **flow**: it measures how much an action a is preferred to the other n-1, alternatives (in other words, how alternative a is outranking the others). It is a global measurement of the "strengths" of action a.

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

- **Negative** or entering **flow:** it measures how much the other n-1 alternatives *are* preferred to the action a. It is a global measurement of the "weakness" of action a.

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

- **Net flow**, which is the algebraic sum of the previous: it is a balance between the positive and negative preference flows, *thus it takes onto account and* *aggregates both strengths and weaknesses of the alternative into a single figure*.

$$\Phi(a) = \Phi^{+}(a) - \Phi^{-}(a)$$

The larger $\Phi(a)$ is, the better the alternative performs.

Pairwise comparison is based on the concept of deviation, or distance between alternatives: the larger the deviation, the larger the preference degree is.

The preference flows can be computed for each criterion separately (**unicriterion flows**) and the **multicriteria flow** is the sum of the unicriterion flows weighted over the w_j given to each criterion:

$$\Phi(a) = \sum_{j=1}^{k} w_j \Phi_j(a)$$

With the unicriterion net flow for the criterion *j*:

$$\Phi_j(a) = \frac{1}{1-n} \sum_{b \in A} \left[P_j(a,b) - P_j(b,a) \right]$$

By calculating this type of flows, preferences can be ranked from best to worse based on the partial rankings (considering *Phi+* and *Phi-*), and on the complete ranking taking into account the net *Phi*.