Multi-criteria decision aiding to support stakeholder engagement in the electric transmission planning

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ABSTRACT

To meet the European 20-20-20 targets and the objective of a largely decarbonized energy sector by 2050, a considerable expansion of the electric transmission grid is considered necessary for a large-scale integration of renewable energy sources. At the same time, transmission lines can have environmental and socio-economic impacts during both the construction and the operation phases. This can lead to opposition from stakeholders and citizens, and therefore slow down or block the authorization and realization process.

Within the INSPIRE-Grid project, co-funded by the European Commission under the 7th Framework Programme (www.inspire-grid.eu), we propose Multi-Criteria Decision Aiding (MCDA) as an approach to support grid planning processes. Energy planning is a field that is quite suitable for MCDA methods because it is subject to many sources of uncertainty, long time frames and capital-intensive investments, along with featuring multiple stakeholders and conflicting criteria.

We structured a criteria tree to assess transmission alternatives, considering three main areas: (1) monetary costs, e.g. investment, operating, maintenance and decommissioning costs; (2) environment and health, e.g. air pollution, biodiversity, landscape, land use, noise, GHG emissions, electromagnetic fields; (3) socio-economic aspects, e.g. impacts on economy (agriculture, tourism, etc.), property values, security of supply, electricity prices, transmission grid losses, etc. We used an additive value function under imprecise information, using variable interdependent parameters subject to constraints. Within this framework, a precise elicitation of the trade-offs between the criteria is not necessary; therefore, stakeholders were asked to rank the criteria and, when sensible, to specify additional information about the relative importance of the criteria.

The proposed approach was used in two Norwegian real cases, i.e. the realization of the Bamble-Rød and Aurland-Sogndal lines, where we elicited the preferences of different stakeholders with the support of the national transmission system operator, Statnett. The interaction with the stakeholders was conducted in one case with single interviews, in the other one in a group discussion.

MCDA made transparent the preferences of all the stakeholders involved (e.g. planning authorities, transmission system operators, citizens) and helped to display the trade-offs among criteria, so that the stakeholders could consider the advantages and disadvantages of proposed alternatives. MCDA cannot claim to unify or synthesize different systems of values, in case of conflictual decision process. Nevertheless, MCDA may allow participants to structure the debate and facilitate negotiation, especially by supporting a climate of confidence and by providing a common understanding of the problem.

Keywords: Multi-criteria decision aiding, stakeholder engagement, conflict management, electric transmission planning, infrastructure assessment

Introduction

To meet the European 20-20-20 targets and the objective of a largely decarbonized energy sector by 2050, a considerable expansion of the electric transmission grid is considered necessary for a large-scale integration of renewable energy sources. At the same time, transmission lines can have environmental and socio-economic impacts during both the construction and the operation phases. This can lead to opposition from stakeholders and citizens, and therefore slow down or block the authorization and realization process (Cain, & Nelson, 2013).

Because of their large scale and technical complexity, the realization of new energy infrastructures involve disparate risks, costs, and benefits for stakeholders, affected populations, and surrounding environments (Keeney, 1980). The asymmetric distribution of project impacts has often fueled intense local opposition and compounded already complex technical and economic considerations.

In particular, the transmission of electricity involves large areas and can produce negative effects (Cain & Nelson, 2013; Doukas et al., 2011; Tempesta et al., 2014) including: visual impact, damage to wildlife, risk for health due to electric and magnetic fields (EMF), noise, farmers' income reduction, effects on property values, on archaeological sites and sites of special scientific interest. Some of such effects may be perceived differently by the public, according to their perceptions and concerns (Furby et al., 1988). When examining how High-Voltage Transmission Lines generate oppositional attitudes, the issue of risk perception is important to consider. In terms of public opposition, perceived risks are often more important than actual risks and the difference between perceived and actual risk can be large (Cain & Nelson, 2013; Furby et al., 1988). For instance, the following risks may present a particular challenge in the siting of energy infrastructures: risks from unfamiliar technology are less acceptable than risks from familiar technology; risks from things that are undetectable (such as the potential risk from EMFs) are less acceptable than risks that are detectable; and risks that are involuntarily assumed (such as living near a transmission line) and not under personal control are less acceptable to most people than risks that are voluntary and controllable (Schively, 2007).

Transmission lines are built in order to obtain benefits in the energy system operations; the main potential positive effects are the following (ENTSO-E, 2013)

- improved security of supply, i.e. the ability of a power system to provide an adequate and secure supply of electricity under ordinary conditions;

- improved market integration, i.e. the ability of a power system to reduce congestion and thus provide an adequate grid transfer capability so that electricity markets can trade power in an economically efficient manner[1];
- renewable energy sources (RES) integration, i.e. the ability of the system to allow the connection of new RES plants and unlock existing and future "green" energy generation, while minimising curtailments;
- reduction in losses in the transmission grid, i.e. the characterisation of the evolution of thermal losses in the power system (it is an indicator of energy efficiency and is correlated with the improved market integration);
- reduction of CO2 emissions in the power system, in particular due to the RES integration and the losses in the transmission grid;
- technical resilience/system safety, i.e. the ability of the system to withstand increasingly extreme system conditions (exceptional contingencies);
- flexibility, i.e. the ability of the proposed reinforcement to be adequate in different possible future development paths or scenarios, including trade of balancing services.

At the same time, transmission lines can have a significant impact on the environment and the society during both the construction and the operation phases. In particular, potential negative effects identified in the literature are the following (Bagli et al., 2011; ENTSO-E, 2013; Furtado et al., 2012; Soini et al., 2011):

- Landscape and visual intrusion
- Property values decrease
- Noise
- Risk for health due to electromagnetic fields (EMF)
- Land use
- Ecosystems alteration

Usually, the economic effects are valued during the various steps of the project building whereas the environmental/social ones are estimated during the environmental impact assessment (EIA) procedures. All these effects should be evaluated within an integrated and participated **assessment process**, which will take into account all the socio-economic, environmental and technical aspects of the project and its alternatives (included the zero-alternative of course).

It is seldom the case that there is an alternative, which completely satisfies all the objectives. Usually objectives are at least partially conflicting, so that satisfying one of them completely will imply that some other will be penalised. For instance, the need to solve congestion problems could imply building new lines in areas with high landscape value. In such cases it is necessary to abandon the idea of a solution which is optimal for all objectives, to look for a good compromise among the different needs expressed by the objectives, a compromise deemed acceptable by all the involved social groups. This is why this phase always needs to be based on a participatory process.

[1] Under the unrealistic assumption of "perfect market", the reduction of congestions is an indicator of social and economic welfare, assuming equitable distribution of benefits under the goal of the European Union to develop an integrated market.

So, how to choose? We propose the use of **Multi-Criteria Analysis** (MCA) methods. The main idea of MCA methods is exactly to create a formalized and better-informed decision making process, when multiple criteria have to be considered according to the needs and concerns of different stakeholders. Within the INSPIRE-Grid project, co-funded by the European Commission under the 7th Framework Programme (www.inspire-grid.eu), we propose Multi-Criteria Decision Aiding (MCDA) as an approach to support grid planning processes.

Multi-Criteria Decision Aiding (MCDA) approach

Over the years, many MCDA methods have been proposed. The methods differ in many respects: theoretical background, type of questions asked and type of results given (Hobbs & Meier, 1994). Some methods have been created particularly for one specific problem, and are not useful for other problems. Other methods are more universal, and many of them have attained popularity in various areas (Figueira et al., 2005).

Within INSPIRE-Grid, we focused on Multi-Attribute Value Theory (MAVT) (Keeney & Raiffa, 1976). In fact, we wanted to take advantage of its logical coherence, and of the possibility to explain all of its steps to non-technicians and to people without strong mathematical preparation. At the same time, we tried to overcome or at least mitigate its limits, in particular the difficulty for the stakeholders to give precise numerical answers to express their preferences in terms of marginal rate of substitution to elicitate the weights of the criteria.

We structured a criteria tree to assess transmission alternatives, considering three main areas:

- Monetary costs, e.g. investment, operating, maintenance and decommissioning costs;
- Environment and Health, e.g. air pollution, biodiversity, landscape, land use, noise, GHG emissions, electromagnetic fields;
- Socio-economic aspects, e.g. impacts on economy (agriculture, tourism, etc.), property values, security of supply, electricity prices, transmission grid losses.

The **tree structure** is more understandable and transparent for the stakeholders than a simple list of criteria, and more apt to guarantee that all the stakeholders concerns are taken into account. The criteria tree we proposed for a generic project is shown in Figure 1. For each leaf of the tree, we proposed one or more indicators to measure, quantitatively or qualitatively, the associated criterion (not shown in Figure 1). Of course, the proposed tree is only one of the possible options, but it can be considered a good starting point for any real case. In fact, depending on the stage of decision (e.g. need definition vs. spatial planning), on the stakeholder concerns and needs, and on the specificities of the project, there could be the need to add or remove some criteria. Furthermore, indicators can vary depending on how eventually criteria have been locally measured in past history, on the level of detail which is considered necessary in each case, on the existing budget and more generally on specific measurement difficulties or opportunities.

Figure 1: the general criteria tree we proposed to assess transmission alternatives

We then focused on the weights of the criteria. Assigning numerical weights rigorously is a difficult and someway tricky process, requiring a precise elicitation of the trade-offs between the criteria. Obtaining numerical weights allows attributing a value to each alternative, representing its overall performance, and therefore allows generating a precise ranking of the alternatives. However, since the weights are not so precise as they look, the result is not so precise as it looks, and most of the times the numerical values representing the overall performance of the alternatives have to be considered broadly as an indication and not as an exact assessment. A sensitivity analysis (checking how the result varies varying the weights) is therefore necessary.

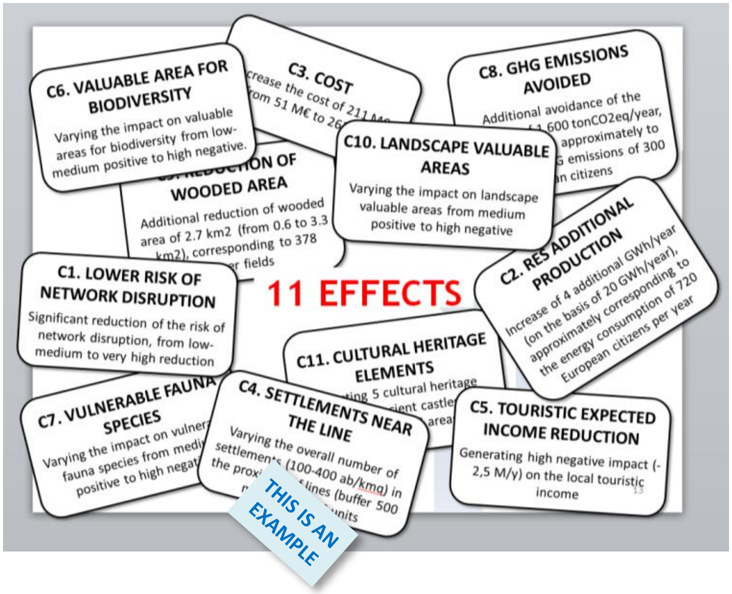
Assigning conditions on the weights by prioritizing or ranking them is easier for the stakeholders than assigning them numerically, and can therefore be done in a more certain way. The results that can be obtained by a ranking of the weights is of course weaker (i.e. less defined) than that obtained with numerical weights. For instance, for each alternative one does not find a single value representing its overall performance, but a range of values (from a minimum to a maximum) that an alternative could have, corresponding to all the sets of weights which respect the given conditions. The result is broader and apparently less precise, but directly meaningful, having in some way internalized sensitivity analysis. Furthermore, a more open result is more apt to show the negotiation margins, and makes it easier a compromise search.

Our choice was therefore to ask the stakeholders to do the "ranking exercise": on the basis of the range of the effects, assigning the different criteria to categories of importance, eventually arriving to a complete ranking of the criteria. The ranking exercise allows the stakeholders to express their value system and is less demanding than the attribution of numerical weights to the criteria. For more details see the box *The ranking exercise*.

The ranking exercise

The ranking exercise has been designed in order to be easily understood and rather quickly completed by all the stakeholders involved, from common citizens to TSOs or experts.

The exercise is built on 4 steps and it's based on the previous identification of potential environmental, economic and social effects attributed to the project.



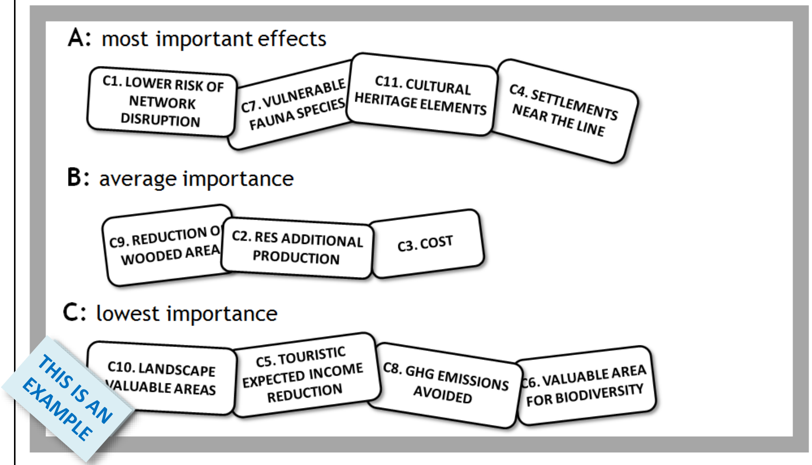
Briefly, the stakeholders have been asked to:

Step 1 - Indicate if there is one effect (eventually 2) definitely more important than the others, i.e. of outstanding relevance. If yes, indicate which effect.

Step 2 - Indicate if there are effects that are definitely less relevant than the others, i.e. almost negligible with respect to the others. If yes, indicate which effect.

Step 3 - Group the remaining effects (not outstanding and not negligible), in 3 categories:

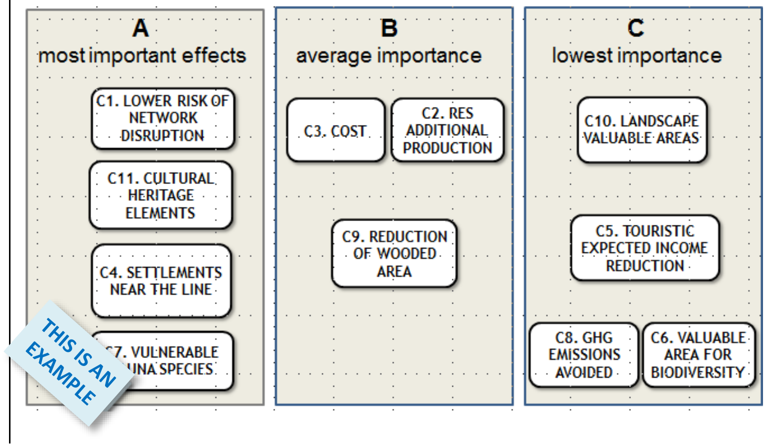
- Category A: most important effects
- Category B: average importance
- Category C: lowest importance



Step 4 – If there is time, eventually rank the effects within each category, or at least within Category A, according to their importance, from the most important to the least important. One or more effects could have the same importance.

In most cases, stakeholders have been asked to complete the exercise first individually then in groups. In this way, the individual ranking is useful as a basis for the group discussion.

The group discussion is facilitated by means of "cards" that contain the potential effects and their range values. The cards could be easily handled by stakeholders (on a board or on a table) in order to modify the ranking of effects and, eventually, reach a final compromise.



When doing the ranking exercise, it is necessary to focus the attention not only on the criteria but also on the range of values of the effects. In fact, the importance has not to be attributed to the absolute meaning of the criteria (e.g. nature or landscape or cost), but to the range of values that those criteria assume in the specific case.

We used the VIP Analysis software (Dias, & Clímaco, 2000), to compute the consequences of the rankings given by each stakeholder in terms of preferences on the alternatives (see box *The VIP Analysis software*).

The VIP Analysis software

The software VIP Analysis supports decision-making in choice problems where a Decision Maker (DM) wishes to select an alternative from a set of several potential ones, accounting for multiple criteria at the same time. The underlying model is that of additive aggregation of value functions (Multi-attribute value theory – MAVT, by Keeney & Raiffa), without needing to specify precise values for the weights that reflect the relative importance of each criterion. VIP Analysis implements a methodology to deal with Variable Interdependent Parameters presented in Dias, & Clímaco, 2000.

Every possible set of weights satisfying the given bounds and constraints are considered equally acceptable by the software. The role of VIP Analysis is to find which results can be drawn considering all the set of weights compatible with the constraints given by the stakeholders.

As a first result, VIP Analysis computes the **range of value** for each alternative, i.e. the minimum and maximum value (overall performance) that each alternative may have, subject to the constraints on the weights.

Having the range of value for each alternative, it is easy to verify if an alternative is **absolutely dominated**: alternative A1 is absolutely dominated by alternative A2, if its maximum value is less than the minimum value of A2, i.e. if the best possible overall performance of A1 is less than the worst possible performance of A2.

VIP creates a first ranking of the alternatives based on their **minimum value**: A2 is considered better than A1 if its minimum value is higher than the minimum value of A1, i.e. if it has a higher overall performance in its worst case (less favorable combination of weights which respect the given constraints). Note that other choices could be done, for instance rank the alternatives according to their average value, but the ranking based on the minimum value of each alternative is the guarantee against the most unlucky case.

Another result that VIP Analysis can compute is the **Pairwise Confrontation** Table, which indicates the maximum advantage (difference of value) of each alternative over each other one, for any combination of weights respecting the imposed constraints. If the maximum advantage of A2 over A1 is negative, then A2 is **dominated** by A1, since this means that the value of A2 is always lower than the value of A1, for any combination of the weights respecting the given constraints. **Maximum regret** is the maximum disadvantage of an alternative when compared with any other alternative. It allows computing a second ranking based on the minimization of the maximum regret.

The case studies

The proposed approach has been experimentally applied in Norway with local stakeholders in 2 cases of construction of a new electric grid, with the support of the national transmission system operator, Statnett:

- Bamble-Rød project, Norway
- Aurland-Sogndal project, Norway

And tested in three validation workshops, one in the UK based on a real case of construction of a new electric grid (with the support of the national transmission system operator, National Grid), the others in Italy and Germany, based on a fictitious case:

- Hinkley-Point C project, UK
- Utopia 1, fictitious, Italy
- Utopia 2, fictitious, Germany

MCDA cannot claim to unify or synthesize different systems of values, in case of conflictual decision process (Roy, 1999; Luè & Colorni, 2015). Our intention was to allow stakeholders to structure the debate and facilitate negotiation, especially by supporting a climate of confidence and by providing a common understanding of the problem and of the different points of view.

Each case was different from the others. Three cases were real and two fictional. Amongst the real cases, two were already closed and one on-going.

In the Bamble-Rød project, the interaction with stakeholders was carried out by means of individual interviews, while in all the other cases in the form of a workshop, including group interaction and eventually individual interviews.

Figure 2: Kongens Dam, one of the places in the Telemark region that would be affected by one of the alternatives of the Bamble-Rød project; the chosen alternative does not affect this place.

The logistic issues and the types of stakeholders involved were different. In Bamble-Rød and Aurland-Sogndal projects in Norway, where local stakeholders were involved, the activities have been located in the areas more interested by the project, in order to facilitate the participation: around the town of Skien in Telemark Region in the first case (see in Figure 2 Kongens Dam, one of the places that would be affected by one of the alternatives of the Bamble-Rød project), and in the town of Sogndal in Vestlandet Region in the second case.

In Hinkley-Point C case, a decision process regarding a new National Grid line, National Grid's technicians were involved in a workshop held in Birmingham, UK, at the venue of the TSO.

The Utopia 1 fictitious case was used in Milano during a conference organized jointly in the context of the INSPIRE-GRID project and the Intelligent Energy Europe BESTGRID project. A role-play game, involving the participants (technician and experts, like TSOs, researchers, environmentalists, etc.), was carried out (in Figure 3 a moment of the role-play game) .

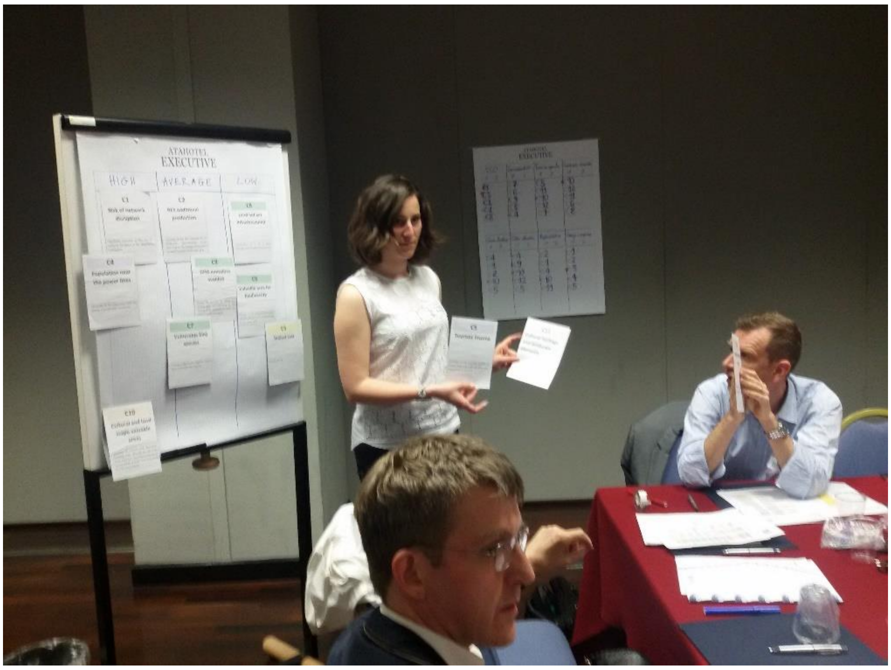


Figure 3: a moment of the role-play game held in Milano.

Finally, the Utopia 2 fictitious case was used in Schwäbisch Gmünd, in the Baden- Württemberg German Region, in order to involve local stakeholders (TSO, municipalities, citizens, etc.). In that area a decision process regarding new grid infrastructures had recently taken place, generating strong conflicts.

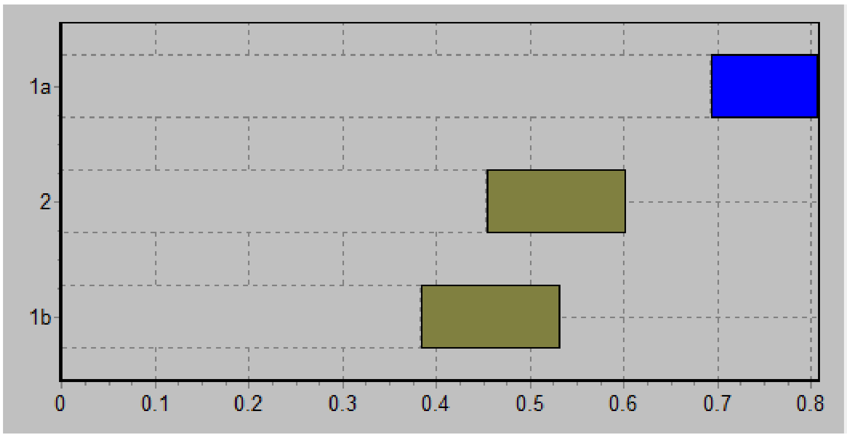
In Table 1 we summarize what we did in the case studies and validation workshops, with the main results and limitations of each one.

Case-study / Status of the project	**Stakeholders**	**N. of alternatives**	**How we applied the methodology**	**Outcome**	**Results**	**Limitations**
Bamble-Rød /Closed	Mixed (n. 10)	4	Ranking exercise, individual + survey	Individual preferences on the alternatives (calculated but not discussed with stakeholders),	All the stakeholders interviewed were able to do the ranking exercise without big difficulties and the information gained was sufficient to obtain a good deal of information about their value system and their preferences on the alternatives. This is a satisfactory result, when compared with the difficulties related to assigning numerical weights. The preferences calculated on the alternatives showed that the choice which had been done in the real process could be considered satisfactory for all the stakeholders interviewed and was not very conflictual	- Macro-criteria with many criteria of low importance could appear more important than other macro-criteria defined by means of only one or two criteria. - Only some steps of a complete MCA have been practiced - Stakeholders are asked to maintain their specific identity but at the same time to give weights for the choice of society. This attitude is very often different from the usual and more strategic attitude, according to which each one thinks of its own personal interests, with the assumption that society will mediate and find a way to prosper.
Aurland-Sogndal / On-going	Mixed (n. 7)	3	Ranking exercise: 7 Individuals & 2 working groups + survey	Preferences on the alternatives for the individuals and for the working groups (calculated but not discussed with stakeholders)	The results obtained by the computations show that one oft he alternatives (alt. 1a) seems definitely the best choice that can be done, and it also seems not to generate conflict. However, our results are obtained by the interaction with very few stakeholders, and more stakeholders should be involved to validate this conclusion.	Some difficulties in the ranking exercise: one stakeholder didn't return us his/her preferences, some stakeholders didn't classify all the criteria, only one of the 7 stakeholders ranked the criteria within each class according to their importance, only one group could agree on the classification of the effects. These difficulties can be due to limited time and to the difficulty of the task. However, also comparing with the other closed or fictitious cases, the main difficulty seemed to consist of taking a too sharp position in an open case, in which the real participation process still had to happen and was declaredly separate from our workshop. In fact, many stakeholders wanted a reassurance that their name would not be publicly associated with their answers. - A facilitator is usually necessary to obtain a result in on going cases, while we let the groups interact spontaneously after explaining them their task. - Stakeholders were asked to maintain their specific identity and at the same time to do the ranking exercise as if they were doing a choice for society. This is much more difficult in a real on-going case, because it requires to look at it with a large perspective. - the validation oft he results would require the involvement of more stakeholders

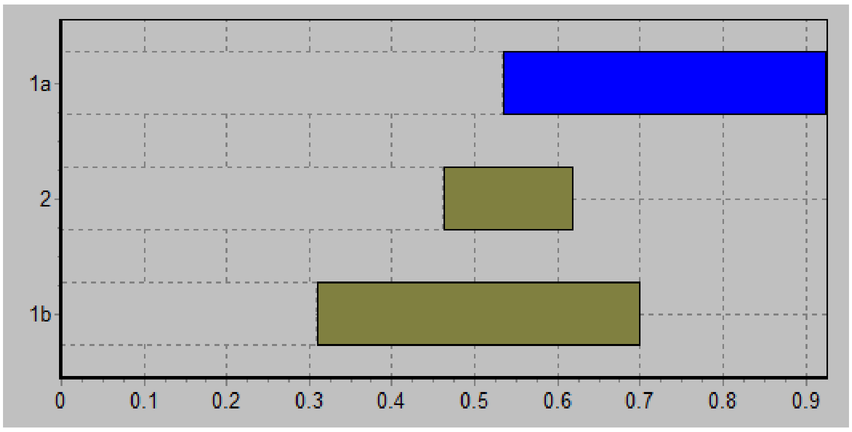
WS Utopia1 /Fictitious	TSO, technical people (n. 30 approximately)	9	- Role-play game (TSOs, environmentalists, citizens, etc.) -Role assumption and ranking exercise, Individual & 4 working groups. + survey	Presentation of the preferences on the alternatives, calculated from the outcomes of the ranking exercise for the 4 groups, and for individuals aggregated by role.	Even if the groups were not facilitated, all of them reached an agreement on the ranking exercise. The computed preferences on the alternatives allowed to show very clearly conflicts and possible negotiation margins From the survey, both the proposed methodology in general and focusing the group discussion on the ranking of the criteria were considered useful.	- The case was fictitious, and for some aspects oversimplified - Being in a role play game, people were probably not so deeply involved as in a real case, therefore reaching a compromise within the groups was probably easier than in a real case - One group could not completely finish the ranking exercise, due to lack of time. - The role game and the fictitious nature of the case could have distorted the discussion and the outcome of the participation process; however we were more interested in the process than in the exact outcome.
WS Hinkley-Point C /Closed	TSO (n. 10)	2	Structuring the problem, ranking exercise, 2 working groups + survey	Presentation, in terms of preferences on the alternatives, of the results deriving from the choices done by the two groups.	Discussion on the way the problem had been structured in the real process compared with a possible way to structure it with MAVT, in particular about the evaluation criteria (completeness and non-redundancy, agreement on criteria definition), and on the preferences associated to the impacts. From the survey, the way proposed to structure the problem was considered effective and useful to enhance public participation, the ranking exercise was considered useful, also to foster participation.	- In the discussion, participants had very limited time to reach conclusions, in particular if compared with the real process, which can lasts years - We didn't present all the possibilities to use an MCDA method, and all the possible different MCDA methods; we selected what seemed us most appropriate in the workshop context related tot he chosen case, to give the flavour of MCDA in conjunction with participation
WS Utopia2 /Fictitious	Mixed (n. 6)	8	Ranking exercise, individual and 1 working group + survey	Presentation, in terms of preferences on the alternatives, of the results deriving from the choices done by the group.	The group agreed on a common ranking of the criteria, without any difficulty. From the survey, the workshop was considered interesting and the methodology useful to facilitate participation.	- Stakeholders were very few and scarcely representative of society. There were no ordinary citizens. - TSO's representative decided not to take part in the prioritization of the criteria, because interested only in respecting law constraints within a reasonable budget.

Table 1: summary of the activities of the case studies and validation workshops, with the main results and limitations.

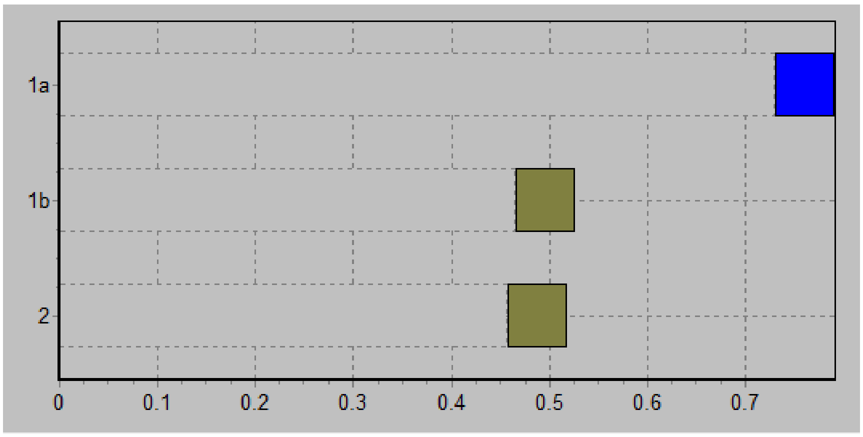
As an example of results obtained by the computations done with VIP Analysis based on the ranking exercise, in Figure 4 we show the range of value for each of the three alternatives (named 1a, 1b, and 2) considered in the Aurland-Sogndal case study.



Stakeholder A



Stakeholder B



Group

Figure 4: the range of value for each of the three alternatives (named 1a, 1b, and 2) considered in the Aurland-Sogndal case study. The results are shown for two different stakeholders and for one of the two groups

The results are shown for two different stakeholders and for the group which did the ranking exercise (the other group did not reach an agreement). Alternatives in each snapshot are ranked according to their minimum value. Opinions on the weights were different, but not very divergent, and this resulted in rankings of the alternatives qualitatively similar Although we don’t show here the results for all the stakeholders, all the results computed show that alternative 1a classifies first according to the minimum value of the range, and in many cases dominates the other two alternatives. The validation of this result would however require the involvement of more stakeholders than those who took part in the workshop.

Conclusion

The case studies and validation workshops gave positive evidence that our approach, and more generally a proper use of MCDA methodologies:

- can foster stakeholder participation.
- can be used to properly manage conflicts and support the choice of a good alternative, eventually reducing times and costs necessary to reach a satisfactory decision.

In particular, these effects are the result of:

- structuring the problem in a clear and rational way, that, if transparent, allows the stakeholders
    - to understand the case and the underlying conflicts
    - to express their value system within the proposed logical framework
- making computations, according to the chosen MCA method and based on the data obtained in the structuring phase, to highlight
    - which alternatives certainly do not constitute a good choice
    - which alternatives are more/less conflictual
    - possible margins of negotiations

We want to underline that the Inspire Grid project is still on-going, therefore all the results we presented here have to be considered as intermediate results.

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