E.ON Energy Research Center

fcn Institute for Future Energy Consumer Needs and Behavior

RWTH

FCN Working Paper No. 3/2008

The Influence of Social Preferences on Multi-Criteria Evaluation of Energy Scenarios

Ines Omann, Katharina Kowalski, Lisa Bohunovsky, Reinhard Madlener and Sigrid Stagl

August 2008

Institute for Future Energy Consumer Needs and Behavior (FCN)

Faculty of Business and Economics / E.ON Energy Research Center
RWTH Aachen University

FCN Working Paper No. 3/2008

The Influence of Social Preferences on Multi-Criteria Evaluation of Energy Scenarios

August 2008

Authors' addresses:

Ines Omann, Lisa Bohunovsky
Sustainable Europe Research Institute (SERI)
Garnisongasse 7/21
1090 Vienna, Austria
E-mail: ines.omann@seri.at, lisa.bohunovsky@seri.at

Katharina Kowalski
Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft
Abteilungen V/10
Stubenbastei 5
1010 Vienna, Austria
E-mail: katharina.kowalski@lebensministerium.at

Reinhard Madlener
Institute for Future Energy Consumer Needs and Behavior (FCN)
Faculty of Business and Economics / E.ON Energy Research Center
RWTH Aachen University
Templergraben 55
52056 Aachen, Germany
E-mail: rmadlener@eonerc.rwth-aachen.de

Sigrid Stagl
SPRU-Science and Technology Policy Research
Freeman Centre
University of Sussex
Brighton BN1 9QE, UK
E-mail: s.stagl@sussex.ac.uk

Publisher: Prof. Dr. Reinhard Madlener
Chair of Energy Economics and Management
Director, Institute for Future Energy Consumer Needs and Behavior (FCN)
E.ON Energy Research Center (E.ON ERC)
RWTH Aachen University
Templergraben 55, 52056 Aachen, Germany
Phone: +49 (0) 241-80 97 162
Fax: +49 (0) 241-80 92 206
Web: www.eonerc.rwth-aachen.de/fcn
E-mail: post_fcn@eonerc.rwth-aachen.de

On the use of social preferences in evaluating energy scenarios[1]

Ines Omann[1*,] Katharina Kowalski[2,]

Lisa Bohunovsky[1], Reinhard Madlener[3], Sigrid Stagl[2]

[1] *Sustainable Europe Research Institute, Vienna, Austria*

[2] *University of Sussex, SPRU - Science & Technology Policy Research, Brighton, UK;*

[3] *Institute for Future Energy Consumer Needs and Behavior, E.ON Energy Research Center, Faculty of Business and Economics, RWTH Aachen University Germany*

*Corresponding author: Ines Omann, ines.omann@seri.at, *Garnisongasse 7/27, 1090 Vienna.* Phone: +43 1 9690728, fax: +43 1 969072817

Abstract

Participatory multi-criteria evaluation (MCE) is increasingly used for the integrated assessment of future scenarios. Determining weights of the different criteria constitutes one of the biggest challenges of MCE. This paper investigates the influence of weights on the ranking of scenarios and reflects critically on the use of weights as representations of social preferences in participatory MCE. Conceptually, this exercise builds on the literature on integrated assessment and decision making under uncertainty; empirically, insights are drawn from two case studies of renewable energy scenario assessment for Austria at the national and local level. The analysis exhibits a robust ranking for the local level, especially for the highest ranked scenarios. In the national case study, the analysis finds two robust scenario clusters which never switch ranks, whereas the

[1] This paper is based on a presentation given at the Participatory Approaches in Science & Technology conference, Edinburgh, June, 4-7, 2006.

ranking of the scenarios within the clusters flips with minor alters in weights. This paper argues that in participatory MCE different sets of stakeholders' priorities can be taken into account in a transparent and robust manner. The discussion explores inhowfar weights represent social preferences better than direct ranking of alternative scenarios by stakeholders on the basis of scenario presentations.

Keywords: social preferences, participatory multi-criteria evaluation, renewable energy, scenario analysis, sustainable energy systems

1 Introduction

Stakeholder participation is an important feature of transdisciplinary research, in particular in sustainability science (Kasemir et al., 2003). The right of people to voice their opinions and to take part in the process of environmental policy making is also granted in the international Aarhus Convention[2]. The main reasons for involving stakeholders in research in preparation for public decision making are: (1) gathering extended information and knowledge about uncertain issues, (2) increasing legitimacy, and (3) including multiple perspectives of the affected citizens and stakeholders (Fiorino, 1990).

Stakeholder perspectives (or social preferences) are captured in MCE through criteria weights. While it is widely accepted to apply criteria weights in MCE, the way of assigning weights remains a much debated issue in decision analysis. Common options include indifference trade-offs, relative contribution of swing from worse to best on each criterion and relative functional importance of the criteria (Choo et al., 1999). Beyond these more technical questions of how to elicit weights from individuals or groups, Munda raises larger questions about the role of science in democratic decision processes. For him weighing different criteria implies giving weights to different groups in society. Weights therefore cannot be derived through participatory techniques because it is technically very difficult and pragmatically not desirable, but by a plurality of ethical positions (Munda, 2004). In this paper we reflect critically on the ways how social preferences inform weights in participatory MCE. Specifically, we examine how social preferences are normally translated into weights (either as absolute numbers or percentages), and how they influence assessment results.

The analysis in this paper draws on case studies about the assessment of renewable energy scenarios for Austria on the national and the local level (Bohunovsky et al., 2007; Kowalski et al., 2008; Madlener et al., 2007). The ARTEMIS research project (www.project-artemis.net) applied and developed further a methodology for evaluating scenarios and for determining their expected socio-

[2] UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, http://www.unece.org/env/pp/.

environmental-economic impacts and applied the methodology to the use of renewable energy technologies by 2020. The assessment was integrated in a participatory process. In the two-level ARTEMIS case study, the social preferences expressed by stakeholders were first transformed into weights by employing the SIMOS method. For each criterion a weight was calculated, representing the perceived importance of the criterion for a sustainable energy system. In a second step these weights were used as an input in an MCE (using PROMETHEE I).

We analyse how preferences can influence the evaluation in three key steps of MCE. (1) Identifying and exploring social preferences, (2) transforming preferences into weights, and (3) aggregating impacts of scenarios and criteria weights into a ranking of scenarios. This allows us to assess the usefulness and quality of the evaluation process and the role of preferences, in particular by studying whether issues of systems' characteristics, principles of sustainable development, and features of process orientation were adequately addressed.

The paper is organised as follows: Section 2 links the idea of transdisciplinary research to sustainable energy systems and explains the evaluation process. Section 3 explains in more detail the three MCE stages mentioned in the last paragraph. Section 4 provides an interpretation of the results by looking at methodological and process-related issues. Section 5 concludes.

2 Transdisciplinary approach for analysing sustainable energy systems

2.1 Transdisciplinary research

The challenges involved when attempting to move towards sustainable development in complex systems (e.g. energy systems) call for transdisciplinary research, i.e. the adoption of an application-guided, problem-solving, dialogue-oriented, and participative model of science (Brand, 2000; Funtowicz et al., 1997).

Transdisciplinary research typically begins with the identification of a socially relevant and often complex problem and aims at providing a solution. A complex problem is one that is difficult to structure and to translate into scientific questions (Scheringer et al., 2005). In socio-economic systems complexity is an outcome of the freedom of agents to change their behaviour. Because these decisions are governed by the subjective experiences of each agent, then agents cannot know what the other agents will decide, and hence will experience interactions and events that they are unable to predict. This may involve the spontaneous appearance of a collective structure with emergent global properties and functionalities. Creativity, innovation and emergence characterize the real, open, non-linear systems that make up our world (Allen, 2001). These conditions change our definition of knowledge and the role of the analysis for decision-making.

Transdisciplinary research is problem-driven and requires the cooperation of researchers from different disciplines. Persons from beyond the realm of science (i.e. stakeholders, decision makers, citizens) are involved in the problem formulation as well as in the research process itself; their needs, interests, preferences and knowledge are gathered and considered in a systematic way. The data and information collected and analysed does not only comprise hard facts, but also soft facts, and is prone to uncertainty. Transdisciplinary research is situated at the science-policy interface and is embedded in social discourses. Transdisciplinarity is understood as being complementary to disciplinary and interdisciplinary research and thinking (Max-Neef, 2005; Kastenhofer et al., 2003; Hirsch Hadorn, 2003; Funtowicz and Ravetz, 1991).

Knowledge produced in a transdisciplinary way, in the context of an application, by people with heterogeneous skills and experiences, oriented towards social accountability, and with extended quality control, is often referred to as ‘Mode-2 knowledge’ (Gibbons et al., 1994). Most of the issues under the heading of transdisciplinarity are not only issues of Mode-2 Science, but also considered important in Post-Normal Science (PNS). However, PNS can also be seen as a special case of Mode-2 science, as it focuses on environmental issues (Müller, 2003). PNS, first developed by Funtowicz and Ravetz (1991), shows a new type of scientific practice, which can manage complex science-related issues and thus provide a scientific foundation for sustainability and for multi-criteria decision aid (see Funtowicz, 1994; Funtowicz et al., 1997; Luks, 1996; Luks, 1999). One key issue of PNS is uncertainty – which needs to be recognised and tackled in the research process.

The advantages of an extended group of participants are manifold. Two often cited ones are: (1) the experiences and knowledge of laypersons and the public can provide additional information that serves to create new ideas for solutions, and that can provide insight into possible impacts which would otherwise have been neglected; and (2) only those who are integrated in the whole process, those who can state their preferences and needs, who can bring in their knowledge and experiences will feel bound by and responsible for the agreed actions. They will be willing to accept the results, even though they might have to face negative impacts and incur unavoidable costs in the transformation phase (Brand, 2000).

Participatory research is not only accompanied by positive effects. The biggest problem is probably the risk of failure (which of course can also occur in non-participatory research). Participation can fail and lead to less trust in research and policy making, and less acceptance of the results. No result might be obtained or several possible results, where no agreement exists upon. It might be that some groups do not feel properly involved and thus begin to exert resistance which might slow down or even threaten the whole process. Risks related to the exclusion of important stakeholders, or the fact that due to social learning processes the representatives involved are much more acquainted with the issue at hand than the groups they represent, do exist. Another problem is the sceptical perception of participants. They might see the process as a waste of time, as their arguments are not properly taken into account. Thus, instead of collaborating in a constructive way, they often either do not show up or give rein to their resentments in case of participation. It is important to assure them that their ideas are being considered and to apply appropriate control mechanisms. In citizens' participation the group of people joining is often a small selection, typically comprising better educated and more engaged citizens ('the usual suspects'). By contrast, single parents, workers etc. rarely participate.

Despite these challenges, there is nevertheless a need for participation of stakeholders in research and decision processes to solve complex problems in sustainability science, because of the reasons mentioned above and because it is the only possibility to include multiple perspectives.

2.2 Transdisciplinary research on sustainable energy systems

For assessing the sustainability of energy systems a large range of interests and potential consequences has to be taken into account. Large sections of social and natural systems are affected by energy policy. To account for the multidimensional nature the research methodology needs to include stakeholders' interests, and put a comprehensive set of assessment criteria together that covers a broad variety of aspects (incl. social criteria). In the three-year project ARTEMIS, we adopted a participatory approach, thus acknowledging that cooperation between scientists and stakeholders is essential in order to advance towards a more sustainable energy system. ARTEMIS focused on renewable energy scenarios, rather than on individual renewable energy technologies (RETs) in order to account for the technical and institutional context and for the level of implementation of technologies.

The use of renewable energy can help creating new businesses and local employment, enhancing social and economic cohesion and improving the security of supply by reducing the dependence on imported energy sources. It is one key strategy to mitigate CO_2 emissions and to meet reduction targets. However, the electricity or heat generated by renewables tends to be more expensive and the technologies are not as ripe as e.g. gas turbines. Renewables face barriers, such as existing market distortions, capital-intensity of many RETs, various types of uncertainty, issues of public acceptance, etc.

Participatory approaches can help to identify and tackle such barriers, and to better exploit driving factors, in a way that allows achieving a high level of understanding, leading to compromises and thus the chance for more durable decisions and policies geared towards a more sustainable development of the energy system. As a result, decision-makers are better prepared to decide about measures for sustainability-oriented energy policies. The participatory multi-criteria evaluation of RETs and RET scenarios helps the political decision-makers to better understand the relevant issues, to design policies and policy instruments. In the face of uncertainty, participatory MCE processes offer stakeholders the opportunity to develop an improved shared understanding (social learning) and an appreciation of merits and problems of different courses of action.

In the following, we briefly describe how transdisciplinary research was realised in the ARTEMIS project. At the *local level*, the focus was on two adjacent local communities in the Southeast of Austria. The participatory process included three workshops and individual interviews of local experts. The first workshop was held with 18 local energy experts and politicians. The aim was to discuss and specify four energy scenarios pre-developed by the research team (the outcome of which is depicted in table 1). In the two following workshops citizens and politicians were asked to name those criteria that are most important to them with regard to the local energy system and to rank these criteria according to their preferences.

At the *national level*, two workshops were organised with stakeholders associated with renewable energy in Austria. The first workshop aimed at discussing the pre-developed scenarios (the outcome of which is shown in table 2) and shaping their narratives, and to roughly weigh the evaluation criteria. The aim of the second workshop was to further elaborate on the scenarios and discuss the intermediate results of the national ARTEMIS case study. Face-to-face and telephone interviews were conducted with energy experts and stakeholders to offer an individual setting for further involvement in the selection of criteria, scenarios, and to get a better grasp on the social preferences.

Although starting from the same research question, the different spatial levels resulted in diverse approaches regarding stakeholder involvement and scenario development:

- <u>Stakeholder involvement</u>: at the national level representatives from different interest groups were invited (e.g. ministries, NGOs) to a stakeholder participation process whereas at the local level community stakeholders and local energy experts (e.g. mayors, community councillors, and plumbers) took part in the participatory process.
- <u>Scenario development</u>: The different role of the scenarios in the participatory process, discussion process on the national level and a decision support process for project realisation on the local level resulted in different kinds of scenarios. At the national level exemplary scenarios based on

existing renewable energy scenarios have been developed, whereas the scenarios on the local level have been oriented towards the implementation of concrete projects.

	Scenario 1 *"Electricity from renewable energies"*	**Scenario 2** *"Renewable energy from small, privately owned plants"*	**Scenario 3** *"Reduction in energy demand and heat supply from large RETs"*	**Scenario 4** *"Reduction in energy demand and heat supply from small, privately owned plants"*
Short narrative	The communities focus on large-scale electricity generation from RE.	The communities promote all kind of small-scale RETs.	The focus is on energy-saving measures and local initiatives for centralised heat generation systems.	The focus is on energy-saving measures and small-scale heating RETs.
Energy demand	increasing, 2% p.a.	increasing, 2% p.a.	constant, 0%	constant, 0%
RETs for heating	baseline	household based RETs: mainly pellets, wood chips, solar thermal	wood chips-fired heating plants for several households, large-scale solar thermal systems	household based RETs: mainly pellets, wood chips, solar thermal
RETs for electricity	small hydropower, photovoltaics, biogas	small-scale PV	biogas	none
Share of RE achieved	64%	67%	81%	74%

Table 1. The 2020 energy scenarios at the local level.[a]

[a]For further details see Bohunovsky et al., 2007; Kowalski et al. (forthcoming) and the detailed local case study description at www.project-artemis.net

	Scenario A *"Fast and Known"*	**Scenario B** *"Extension of Competitive Advantage"*	**Scenario C** *"Investments into the Future"*	**Scenario D** *"Extensive Use of Biomass"*	**Scenario E** *"Large Impact in Small-Scale Use"*
Short description	Large plants, very short-term oriented, few new institutions	Large plants, high technical efficiency, few new institutions	High system efficiency, very long-term oriented, new institutions	Biomass energy plantations (SRC), new institutions	Small plants, extensive use of residue, new institutions
Additional electricity production from renewables (GWh)	9,086	8,931	7,642	9,631	9,725
Additional heat production from renewables (PJ)	66.4	61.6	34.4	93.4	53.0
Amount of renewable energy in 2002 (PJ)*	125	125	125	125	125
Additional amount of renewable energy in 2020 (PJ)	99	94	62	128	88
Percentage increase of renewable energy supply	80%	76%	50%	102%	71%

Table 2. The 2020 energy scenarios at the national level[b].

[b]For further details see Madlener et al. (2007). * Data based on IEA (2003)

Differences occurred also regarding the number and organisation of the workshops and the restrictions that applied with respect to the participation processes.

Workshop organisation: at the *national level*, two workshops were complemented by several expert and stakeholder interviews, in order to receive collateral information and to get a better sense of individual perspectives. At the *local level* the participation process consisted of three workshops, as well as meetings and interviews for considering open questions. It also comprised an event at the end of the process, with the purpose to present and discuss the results and implications of scenario implementation with the stakeholders. Therefore, the participatory process on the local level was more intense with respect to group works.

Different restrictions to the participation processes could be observed during the processes:

On the *national level* stakeholders generally represent interest groups. Since the research project has been independent from official governmental renewable energy programmes, attendance was not very high (in the first workshop seven stakeholders and in the second six stakeholders attended; there was a strong discontinuity in the sense that the first and the second workshop were attended by different stakeholder representatives). Nevertheless it was obvious that the stakeholders were acting in the area of their professional expertise, and not hesitant to express their stakes and to question other people's interests and motivations (including that of the research team).

At the *local level* the attendance in the workshops and the commitment to actively participate was higher. Stakeholders took part due to personal interest in realising a project with RETs, interest in ecological matters, general interest in their community's future or because of an obligation they felt toward their mayors. One important reason was the perspective of starting the "e5" process and being nominated as an e5 candidate community[3]. On the other hand, their commitment to participate in the process was on top of job requirements and other obligations, which resulted in evening workshops (and the use of precious spare time).

At the *national workshops* the discussions were held by using essentially the same terminology as within the project team, and participants have been very critical and demanding concerning the scientific methods applied. This might be attributable to the fact that participants at the national workshops, on average, probably had a higher level of education and more routine in such tasks. At the *local level*, though, all working papers and presentations had to be "translated" into a non-scientific language, in order to avoid misunderstandings and the stigmatisation of the process as being overly academic and aloof. The participants questioned the scientific method only to a very

[3] "e5 communities" is a programme for assessing and certifying local communities with respect to their attempts to use energy more efficiently and to intensify the use of renewable energy as a contribution to a sustainable development, cf. www.e5-gemeinden.at.

limited extent, even though much effort had been put in motivating the participants to ask questions freely.

In general, the participative approach towards the given research question was positive and fruitful. On the local level, a discussion process on the pros and cons of using renewable energy was induced, and the results now form the basis for the ongoing implementation of the energy award programme “e5 community”. On the national level, an input to the discussion process about possible energy futures was given, providing further insight into concrete impacts and into the structure of the different - and sometimes conflicting - interests. The stakeholders indicated that the approach is useful for them to structure the decision problem and to better understand the appropriateness of the different scenarios in view of specific interests.

3 Description of the sequential procedure

3.1 The importance of social preferences

Besides substantive reasons for participation (benefits of participation for increasing the breadth and depth of the information underlying decision making and so enhancing the ‘quality’ of the decisions themselves) and instrumental reasons (ability credibly to claim a commitment to broad based public engagement is an important way to sustain or restore public credibility and trust), participation also responds to a normative call for engaging all possible constituencies in making decisions over technological choices and environmental policies (Fiorino, 1989; Stirling, 2006). This right to participate in the decision process implies the right of access to information and of explicitly stating their preferences. These preferences can be expressed with regard to the assessment options, the impacts of the options, or the assessment criteria used. In MCE approaches preferences are generally related to the evaluation criteria in the form of weights (see section 3.3). This allows stakeholders to express their preference for specific sustainability dimensions and indirectly for specific options. The social preferences can either be used on an individual basis or on a group basis, in case a group agreement can be reached. Integrating different sets of preferences in an analysis allows deepening the understanding that one best solution to a problem does not necessarily exist, but that the answer depends on the prevalent structure of interests. A basic assumption of this approach is that there are several, also contrasting, legitimate perspectives. In the ARTEMIS evaluation process, social preferences are captured by criteria weights. They have been elicited in workshops and interviews and integrated in the multi-criteria aggregation. On the national level the social preferences were collected and reported on an individual basis (an MCE was undertaken for each participant separately), while on the local level data collection and analysis were on group level (an agreement could be reached in the workshops).

3.2 Eliciting the social preferences on both levels

As discussed in the last section the social preferences of the stakeholders are an indispensable element for a transdisciplinary integrated sustainability evaluation process. It is thus important to choose a method that enables to elicit these preferences carefully.

On the *local level* this was done in a two-step workshop. The evaluation criteria were known by the participants in the workshop beforehand, as they developed them jointly with the research team. In this 'weights workshop' the first step was to find a ranking of the criteria according to the social preferences of the participants, which was agreed upon by the entire group. This first step was realised in a playful manner by asking the participants (who stood in a circle around a table) to put the criteria (which were written on cards) in a rank from the least important to the most preferred one or changing the order, allowing for equal preferences and gaps. These gaps were achieved by means of blank cards between preference levels, enabling to put more weight on the criteria above this blank card and less weight on those below.

This process was repeated in several rounds, whereby one participant after the other could change the ranking according to certain pre-defined rules until the group agreed in principle upon the ranking of the criteria. The rule followed was silent negotiation (Pictet and Bollinger, 2005). Verbal influence was discouraged, since no one should dominate by talking a lot or in a very assertive way in order not to unduly influence others. Questions relating to understanding could of course be asked.

The second step consisted of an individual process by assigning ranks to the criteria. The individual social preferences served to check the correlation of the individual perceptions with the group result and thus to check the robustness of the latter. By forming the average weights of the individual rankings and applying different approaches of cluster analysis, it turned out that the individual rankings of a group of five participants (45%) correlated strongly with the group result. Four participants differed considerably in their individual rankings from the group result, and two of them differed very strongly.

One important issue in this process was the order of the two steps (individual versus group ranking). We decided to start with the group weighting process, as one aim of the project was the inducement of a *social learning process*. By discussing the importance of the criteria for a sustainable energy system in the group, the participants were motivated to rethink their opinion, and they got more information about the opinion of the others and possible consequences of their preferences. We estimated this advantage higher than the disadvantage of having some of the participants influenced by dominating ones.

On the *national level* the social preferences have been revealed by (1) defining the set of evaluation criteria in stakeholder telephone interviews and a stakeholder workshop dedicated to discussing the suggested criteria set and to adding missing aspects; and then (2) ranking of the criteria in individual stakeholder interviews.

The basic process for revealing the social preferences was different to the one at the local level. Only individual preferences have been collected in individual interviews. The interviews have been organised in a similar mode as on the local level: criteria have been printed on cards that have been put in order of priority given by the stakeholders.

The resulting ranking of criteria has been rather diverse among the different stakeholders. Nevertheless, the aim to contribute to climate change mitigation has been ranked very highly all across the variety. It was also obvious that certain criteria were given similar priority, e.g. if the economic aim to have minimal costs was ranked highly, then other economic criteria were ranked highly as well.

3.3 From social preferences to weights

The ranking of the criteria according to the social preferences of the stakeholders can be used directly and be put into PROMETHEE, or it can be transformed into weights (by normalising). For this step we applied a revised version of the SIMOS method (Maystre et al., 1994; Figueira and Roy, 2002) on both levels. In the SIMOS method, by having the criteria in an order, including blank cards, the weights for all criteria can be calculated. On each rank there is either a blank card or one or more cards (criteria). Each card receives a position number starting from 1 for the least important card, to the number *n* for the most important card, where *n* is the total number of cards. The sum of the positions of this rank divided by the total number of criteria belonging to this rank gives the basic or non-normalised weight. The blank cards get a position number but no weight is calculated for them as they do not represent criteria. The calculated weights do not sum up to 100%. To norm them, they are divided by the sum over all positions excluding the blank cards and multiplied by 100.

The so-called revised SIMOS method (Maystre et al., 1994) goes one step further. The ratio between the most and least important criterion is not fixed anymore. It is important that stakeholders are encouraged to express their perception of this ratio, by saying how much the first criterion is considered more important than the last one in the ranking. This is usually a number between three and 20 and is needed to calculate the weights with the revised SIMOS method. So if this number is five and the first criterion has got a weight of 20%, the last must get a weight of 4% (see Maystre et al., 1994, for further details).

The weights for the group preferences on the local level and the range of the weights on the national level are reported in tables 3 and 4 in the Appendix.

3.4 From weights and the impact matrix to the scenarios ranking

The weights are one element of the applied multi-criteria analysis PRMOETHEE. Impacts of the scenarios in the form of a matrix are another element of MCE. Together with preference functions for the criteria they are needed to run DecisionLab (software that was used for applying

PROMETHEE). Preference functions deliver key information that has to be specified in the particular MCE tool and potentially affects the results. For both case studies they were derived from an expert workshop and included in the sensitivity analysis of the results (but are not further discussed in this paper). PROMETHEE aggregates the information by an outranking procedure and finally ranks the scenarios both completely and partially (PROMETHEE I and II, see below).

PROMETHEE is a widely used multi-criteria assessment method (Brans et al., 1986). With this algorithm alternatives are compared in pairs for each criterion. Alternative options are ranked by a positive flow (the flow summarising the outranking and thus preference power of the option) or a negative flow (the flow summarising how strongly this option is less preferred than others). The higher the positive flow and the lower the negative flow the better is the option. Two versions of PROMETHEE exist, PROMETHEE I and PROMETHEE II. PROMETHEE I allows for incomparability, if the positive and the negative flow of one option is higher than those of another one. These two options are not comparable. PROMETHEE II uses the net flow (the difference of positive minus negative flow), which permits a ranking of all actions. In addition to the ranking, the Decision Lab software has got different features. One is the image of the stability intervals. They show the intervals for weights, which do not lead to a change of ranks. The higher these intervals the more stable is the result. Here we defined a criterion to be stable if the stability interval exceeds +/- 50% of the weight given to the criterion (see figures 5 and 6 in the Appendix).

As mentioned earlier, in the ARTEMIS case studies local and national renewable energy scenarios were the options evaluated in the multi-criteria participatory research framework.

The impact matrix for the *local level* is mainly based on four sources: (1) GEMIS 4.3 (Ökoinstitut 2005; UBA 2005), a German/Austrian database on life cycle analysis data for a large number of RETs. It delivers environmental data such as greenhouse gases, cumulated energy/material inputs, etc. In those cases where the data from GEMIS were not specific enough, or did not fit the local situation, they were supplemented with or replaced by (2) information from expert interviews. In these cases all available information was used as a basis for a qualitative appraisal; (3) The information for social criteria was gained from interviews with 11 inhabitants of the case study communities and transformed into a qualitative rating by the project team. Table 3 in the Appendix shows the impact matrix applied that contains the impacts along each criterion for the four scenarios considered, as well as the group weights; (4) Data on costs were derived from Neubarth and Kaltschmitt (2000).

On the *national level* two types of data sources were employed: (1) GEMIS 4.2 Austria and GEMIS 4.3 (Ökoinstitut, 2005; UBA, 2005) as the main sources for environmental impacts of technology, and some other sources (Neubarth and Kaltschmitt, 2000; Haberl et al. 2002), were used to assess costs and ecological justice (land requirements). Furthermore, two expert interviews with an energy economist and sociologist were conducted to reveal the expected social and some of the expected techno-economic impacts of the scenarios. Table 4 in the Appendix depicts the national impact matrix.

Having developed the impact matrix, the weights and the preference functions for the criteria, PROMETHEE was applied to aggregate the given information and results in a ranking of the scenarios. The resulting ranking of the *local scenarios* based on the group weighting is depicted in figure 1.

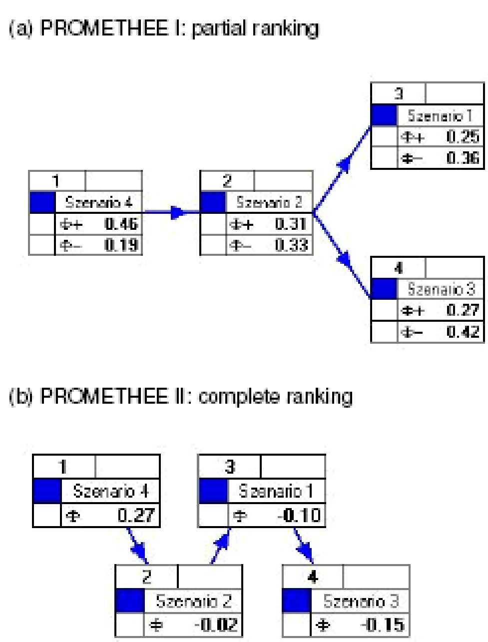

Figure 1. Ranking of scenarios at the local level (based on group weights)

As can be seen, Scenario 4 is ranked first, since it fulfils the criteria best. It focuses on the reduction of energy demand and the support of small, privately owned RET systems. Scenarios 1 and 3 (both including large power plants) are ranked last because their environmental and social impacts are valued more negatively than for other options. However, if costs or regional economic development are given very high weights (more than 26% for costs and more than 35% for regional economic development) they rank first or second.

For all participants' weighting schemes Scenario 4 is ranked first, Scenario 2 is ranked second (in 8 out of 11 cases), and Scenario 3 is ranked second in 3 cases. Scenario 1 is always ranked last, except for one participant who ranked it third. The results of the participants give a first idea of the stability of the results, in particular for the first rank. Further sensitivity analyses and their interpretation are provided in section 4 below.

Table 3 in the Appendix reports on the stability intervals for the group weighting evaluation. It can be seen that the interval exceeds ± 50% of the weight for all criteria, except for the lower limit of dust (the range is 0.26% points to small), the upper limit of import dependency (by 1.8% points), for the upper limit of costs (0.74% points), and for the lower limit of diversity of technologies (2.3% points).

On the *national level* the results of the MCE rankings are more diverse, depending on the specific sets of weights derived from 16 individual stakeholder interviews. The most common ranking is that Scenario E "Large impact in small scale use" is ranked first, followed by scenarios C "Investment into the future". Scenario B "Extension of competitive advantage" is in a middle position. Scenario A "Fast and known" and Scenario D "Extensive use of biomass", two scenarios with rather centralised production systems, are clearly ranked lower. The increase of the share of renewable energy in the total energy supply for Austria (heat and electricity supply) varies between plus 50% and 102% from 2002 to 2020 and is highest for Scenario D "Extensive use of biomass".

The performance of the national scenarios along the evaluation criteria, summarised in the impact matrix, suggests already a basic ranking (see sensitivity analysis with all weights set equal). The weights are additional information put on top of that and do influence the ranking. They can potentially change the ranking, and especially where the differences between the scenarios' performances according to the impact matrix are small, the additional weight on the criteria can make a difference. If the differences are large enough it becomes visible in a change of scenario ranking. It is crucial to treat the 'exact' results of Decision Lab with caution since there is uncertainty in the data and the method to reveal and transform social preferences into weights. For that reason we define the stability of the result according to a minimum stability interval, which is relative to the weight. Figure 2 represents the partial ranking of the national ARTEMIS scenarios if all weights are set equal. This reveals the pattern of the impact matrix itself. All changes in the order and form of ranking in the other rankings are due to the impact of weights. Figure 6 in the Appendix shows the stability intervals of the ranking and indicates that it is not a very stable ranking in the sense that Scenarios E and C are very close together and changes of the weights of less than ±50% are changing the relative ranking of Scenarios E and C.

The insights from the comparison of the different weighting schemes in the sensitivity analysis can be summarised as follows:

- One group of scenarios, Scenarios C and E, rank very closely together on the top;
- There is a distinct distance between the other scenarios in the ranking;
- We find a parallel ranking of Scenarios E, C in the partial ranking, since none of them is better in both the positive flow (Φ+) and in the negative flow (Φ-);
- The scale on which the scenarios are ranked is rather low (± 0.25) which represents the range of the net flow (Φ), which is the result of adding the positive and the negative flow.

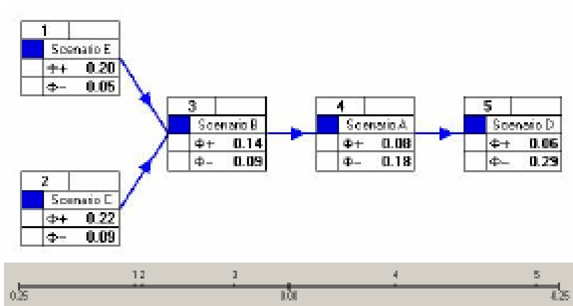

Figure 2. Partial ranking of the scenarios at the national level (based on equal weights)

4 Analysing the impacts of the weights

In this section the influence of the method chosen (MCE, PROMETHEE) is analysed in three categories. In each of them we start with the local level, followed by the national level.

The most important finding on the *local level* is that weights do have an influence on the MCE results, albeit the first rank (Scenario 4) turns out to be extremely stable. In sensitivity analyses (see below), Scenario 4 always remains ranked first, except if the weights of certain criteria (costs, regional economic development) are increased substantially, i.e. to a level of more than 25% in the basic run.

4.1 From weights and the impact matrix to the ranking of scenarios.

Although the local impact matrix (see Table 3 in the Appendix) provides some first ideas about the result, it is nevertheless necessary to see how robust the result is and how social preferences can influence it. The following *sensitivity analyses* were applied:

- Certain groups of criteria were given a high weight. For giving 70% to the *social criteria* the result is similar to the basic result. Scenario 4 remains first, but there is no incomparability between the least ranked Scenarios 1 and 3 anymore, as Scenario 1 is clearly ranked last. The stability intervals (see Figure 5 in the Appendix) are very wide, thus extreme weights are needed to change the first rank in favour of Scenario 3 (for instance more than 51% for social justice, 26% for costs or 35% for regional value added). It has to be said, however, that the sum of the weights for the social criteria was only 16% in the basic group weighting schemes, thus the increase of weights in this sensitivity analysis is very strong.

If 70% weight is put on the *environmental criteria* the result equals that of the basic result, the stability intervals are even a bit higher.

When weighting the *technological* and *economic criteria* very strongly (about 70%) the result changes. Scenario 4 is still ranked first, but the other three scenarios are now very close together. Thus, Scenarios 1 and 3 are no longer considered worse than Scenario 2. The result is less stable, and the intervals are very small, but only for the ranks 2 to 4. Scenario 4 loses its first rank to Scenario 3 again, with a bit lower changes in weights than in the basic run, such as more than 30% for the criterion “social justice” or more than 22% for the criterion “costs”.

The net flow, which yields the preference index, is distinctively smaller for the analysis with high weight on techno-economic criteria than in the other sensitivity analyses, which means that the differences in the preferences are small in this case. For the other two analyses the range is larger than for the basic result, indicating big differences of preferences for the scenarios.

- Adapted versions of two scenarios: Scenarios 1 and 3 were changed by using liquid manure for the biogas plant instead of maize. Their evaluation is better but they still remain on 3rd and 4th rank. However, the stability intervals for the weights do change; the rank of the first scenario does switch earlier, e.g. if costs are weighed higher than 20%, or if regional economic development is weighed higher than 28%. The same is true if in Scenarios 1 and 3 the heat produced by biogas plants is actually used instead of wasted (cogeneration).
- Five criteria turn out to be instable rather often (based on the group result and single results with the individual weights). They are either weighted highly or moderately, but never lowly. One can see below that the same is true for the national level. As we define stability as depending on the weight (+/-50%), criteria with high weights require a higher interval to be stable and are thus slightly discriminated.

On the *national level* sensitivity analyses indicate that weights have an influence on the MCE rankings. Considering the 16 scenario rankings we find that they differ compared to the ranking with equal weights in the following points:

- There are still the same two scenarios, viz. Scenarios C and E, on top of the ranking whereas Scenario B is basically always in a middle position and Scenarios A and D always rank lower than scenarios B, C and E;
- The distance between the scenarios' rankings gets smaller, especially between Scenarios A and D;
- Consequently more parallel rankings appear in the partial ranking;
- 17% of the stability intervals do not exceed the ± 50% and quite a few of the resulting rankings cannot be seen as stable;
- The scale is getting smaller in most cases (range of net flow is smaller). A smaller range of net flow indicates that the scenarios are closer together according to their impacts, so consequently they do not differ that much from each other.

Only five out of the 16 resulting individual rankings are stable in every respect, meaning according to all indicators. Certain indicators appear to be more often instable. The methodological assumption is that these indicators represent criteria, which have rather similar impacts across the scenarios compared to the other criteria; they are: "security of supply" (11 out of 16 which means all the rankings where instability occurs), "technological leadership" (7 out of 16), "employment" (5 out of 16), and "import dependency" (5 out of 16). This means that according to these criteria the ranking of scenarios changes easily if the weights are altered.

It is noticeable that the most highly weighted criteria are among the most instable criteria. This is even stronger here than in the local case.

Further sensitivity analyses on the effect of weights on the ranking show that if the *block of social criteria* (regional self-determinacy, social cohesion, social justice, quality of landscape, and noise) is dominant, the ranking changes in a very stable manner to E-C-B-D-A. The social criteria correlate strongly with the degree of decentralisation of the energy system, which is highest in

Scenarios E ("Large impact in small scale use") and C ("Investment into the future"). If the *block of economic criteria* (costs, effect on public spending, and employment) is dominant, certain observations of change can be made but no uniform ranking is produced as is the case with the social criteria. A general effect is, though, that Scenario D ("Extensive use of biomass") is ranked distinctively higher (on the second highest rank) and Scenario C ("Investment into the future") is ranked lowest with dominant weight on economic criteria. The net flow is distinctively smaller than in the other sensitivity analyses, which means that the scenarios do not differ as much. The foremost weight on the *block of environmental criteria* (climate change properties, air quality properties, water quality properties, rational use of resources, ecological justice) shows the opposite effect, namely that Scenario D is ranked lowest and Scenario C ranked highest in all rankings. The rankings are in a slightly larger net flow range. When weighting the *block of technological criteria* (diversity of technology, import dependency, technological advantage, and security of supply) very high, the ranking changes in the sense that scenario C ranks first and no other systematic changes of the rankings appear. The range of net flows is clearly larger.

4.2 The data in the impact matrix

From the *local level* impact matrix it is already possible to recognise the good evaluation of Scenario 4. Except for 'costs', Scenario 4 never gets the worst evaluation, but for most criteria the best. For Scenarios 1 and 3 it is the other way round. This explains the basic result without applying a multi-criteria aggregation, i.e. that Scenario 4 is considered the best and Scenarios 1 and 3 are rather poorly rated.

The data of the impact matrix in the *national level* case study do suggest the final ranking in a similar manner as on the local level (see section 3.4) but is a bit more ambiguous. It is obvious from the impact structure that Scenario D "Extensive Use of Biomass" performs badly along most of the environmental criteria, which is due to the fact that we have been using life-cycle analysis data (which also account for emissions from processes and transport prior to the final energy conversion). The generation of biomass as an energy resource involves, in contrast to other renewable energy sources, a lot of fossil-fuel based transport and environmentally harmful production processes, such as fertilising etc. In contrast to that, Scenario D has the best performance in the criterion 'costs'. Furthermore, the data of the impact matrix suggests that, generally, the social criteria discriminate against a more centrally organised energy system (Scenarios A, B and D). This indicates a trade-off between aims geared towards more sustainable energy systems.

4.3 From social preferences to weights

As mentioned in section 3.3 above, we used the revised SIMOS method to normalise the preferences given in a certain order.

On the *local level*, a sensitivity analysis that gives the rank of the criterion instead of weights (the first one has the highest rank, 13 in our case) leads to the same result as the basic one.

The MACBETH method (Bana e Costa and Vansnick, 1999) offers another option to obtain weights from ordered criteria. We used this method to obtain the weights for the criteria in the local case study; they were very close to the original ones and did not deliver any other result of the scenarios' evaluation.

A way to present results graphically in Decision Lab is by means of GAIA planes (Brans and Mareschal, 1990), shown in figures 3 and 4. In GAIA planes the criteria, options and a decision axis are mapped onto a two-dimensional plane. In figures 3 and 4, the line between the origin and point 'pi' is the decision axis (also referred to as 'decision stick'), which represents the condensed weighing of the criteria (Geldermann and Zhang, 2001). The decision stick can be moved by changing the weights. The criteria, represented by squares, are plotted along axes that show synergies and conflicts among criteria. If criteria are oriented in the same direction, they exhibit synergy potentials, whereas if they look in opposite directions, then they present trade-offs (potential conflicts). If options and criteria are located in the same direction, then the options are good options, judged by the criteria concerned. While the GAIA plane is a useful tool for visualising results, and for undertaking sensitivity analysis, it has shortcomings (e.g. Omann, 2004). For instance, it is only valid for PROMETHEE II (complete ranking), and it can only be used for a subset of the total information.

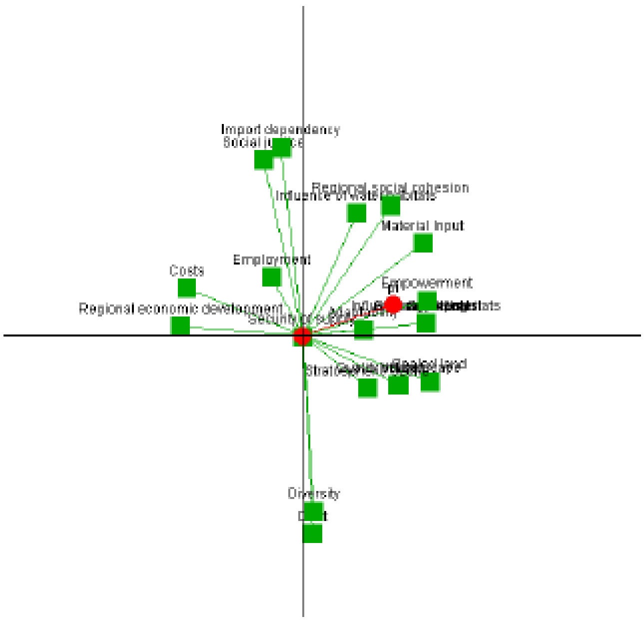

Figure 3. GAIA plane for local level criteria, group weights

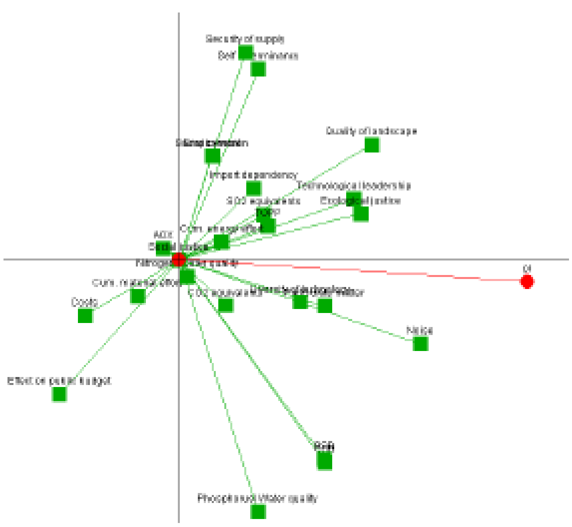

Figure 4. GAIA plane for national level criteria, equal weights

Figure 3 (GAIA plane on the local level for the group weights) shows that while a great many criteria pull in one direction, the economic criteria point in the other direction, so that trade-offs with the other criteria exist. This means that by fulfilling economic sustainability (good regional economic development, low costs of the energy system, high employment) it is hardly possible to reach environmental and social sustainability.

In contrast figure 4, the analysis of the GAIA plane for equal weights on the national level, suggests that many criteria were pulling in the same (or at least a similar) direction, so that apparently significant synergy potentials among the criteria exist.

5 Discussion and conclusions

In this paper we have tackled the potential role and influence of weights reflecting social preferences in participatory MCE studies. Sensitivity analyses show that the rankings are quite robust at the local level, especially regarding the highest ranked scenario, whereas the stability of the rankings at the national level is essentially restricted to a certain robustness.

Content related discussion and conclusion:

A direct comparison between the two levels of analysis is hampered by differences in the sets of criteria used (i.e. the impact matrix), the different application of weights (i.e. the lack of group weighting at the national level), and different patterns in the participation of stakeholders, respectively. Conclusions drawn from comparing the two levels should therefore be treated with great caution.

Nevertheless, comparing the weights set on the criteria in the national and the local level, the different priorities are obvious. On the *national level* the ‘impact on climate change’ is clearly ranked highest, followed by the ‘effect on public spending’, and ‘security of supply’. These could be characterised as macro issues. On the *local level* the highest priority was attributed to ‘regional economic development’ followed by ‘air quality’, ‘impact on climate change’ and ‘employment’ (note that all these criteria are measured at the micro-level, except for climate change which is a criterion valid on all spatial scales). Different issues are predominant in the discussions on the different geographical and institutional levels.

For the sensitivity analysis we grouped the criteria into blocks (economic, technological, social, and environmental) and also looked at visualisations of the relevance and direction of criteria in GAIA planes. The analysis of the GAIA plane for equal weights on the national level (figure 4) shows that a great many criteria were pulling in different directions, pointing to significant conflicting interests among the criteria used. The GAIA plane on the local level (figure 3) for the group weights shows also a lot of criteria being pulled together in one section, except for the economic criteria which show in the opposite direction, building thus trade-offs with the other criteria. This phenomenon is also indicated by the sensitivity analysis putting a high weight on the economic criteria, which favours the scenarios otherwise ranked low.

Methodological discussion and conclusions:

An integrated assessment process, such as an MCE, is usually applied to support decision-making. An evaluation process ought to be appropriate in the sense that it leads to 'good' decisions. But what is a good decision in the case of sustainable development, and how can we judge whether evaluation processes and decision-making procedures for sustainable development are appropriate or not?

First of all, an evaluation is not just a single action, but the interplay between the evaluation process, the possible evaluation results and resulting decisions and problem solving capacity. Therefore, in deciding what is appropriate, emphasis needs to be put not only on the results of the evaluation, but equally on the processes that accompany the evaluation (Omann, 2004). In the context of the present paper, successful evaluation aims at supporting those energy system(s) considered as most adequate for moving towards sustainable development. The evaluation is inextricably linked to the peculiarities of sustainable development, to the characteristics of complex systems (such as the energy system), and to the related challenges in the research processes. We can thus find requirements for successful evaluation and categorise them into three groups: (1) systems characteristics and functions; (2) principles of sustainable development; (3) decision making procedure (cf. Omann, 2004). Successful fulfilment of these categories is likely to guarantee an appropriate and successful evaluation. They serve for analysing the MCE processes in ARTEMIS and for drawing conclusions about their quality and success.

(1) Starting from a systems perspective of energy systems and their sustainability impacts and not from perceiving sustainability as being three-dimensional. The dimensions used involve linkages to other systems (above and below in the hierarchy) and interconnectedness, needs and wants of subsystems and actors in the energy system, resilience of the addressed systems and efficiency. That way we aimed for taking into account the relevant criteria as well as different spatial scales. Energy systems are not static, they are dynamic and evolving. When evaluating scenarios leading up to 2020, this dynamic factor (e.g. changing political conditions) ought to be taken into account. Unfortunately, this was hardly done in the research underlying this paper, due to lack of appropriate literature, data and models. Data for many of the criteria used are highly uncertain, limiting the confidence that can be put in the results obtained. We tried to address the issue of uncertainty by using indifference ranges that were quite large and high preference thresholds in the preference functions. Tackling this uncertainty and integrating it in the MCE leaves room for further research, for instance by using fuzzy data and an MCE method allowing for fuzziness.

(2) The evaluation process needs to be designed in such a way that the energy systems under consideration support sustainable development. Therefore, principles and characteristics of sustainable development have to be considered. By setting a sustainable energy system as overall objective of the evaluation and then operationalising this objective by defining criteria and indicators, the normative aim of sustainable development was accommodated.

Two important components of sustainable development, social justice and democracy, were explicitly taken into account. The first one by having it as one evaluation criterion and the second by inserting a strong participative element in the process and thus respecting multiple perspectives as well as by defining empowerment (of citizens) as one evaluation criterion.

(3) It is important to focus on the whole process of the evaluation, starting with problem identification and ending with the evaluation or the actual decision. In our analysis, we have placed the focus on both, the process of the evaluation as well as on the results. Concerning the issues of group processes we allowed for non-agreement within the group (which was the case on the national level). The participatory process was accompanied by an evaluation of the social learning of the participants (for results see Stagl and Garmendia, 2006). By means of questionnaires the cognitive, social and process learning was captured before and after workshops and the changes analysed.

The MCE results were accepted by the stakeholders on both levels, but direct implementation actions were only foreseen on the local level. The support of decisions on the local level can be seen as a contribution to bridge the gap between science and policy, which is an aim of transdisciplinary research. The applied evaluation process was flexible and adaptive by rendering a redesign of the scenarios and criteria possible and thus allowing for feedback loops.

To conclude, we found that the use of weights reveals a better founded display of social preferences, compared to a direct ranking of the alternative scenarios by stakeholders; this helps to avoid strategic behaviour of stakeholders and allows for a more complex assessment of alternative options than a mere presentation or description of the impacts of the options. The latter is an increasing danger as government bodies acknowledge difficulties of monetising all relevant dimensions and thus extend assessment frameworks by non-monetary impacts without conducting an evaluation across monetary and non-monetary impacts (e.g. Regulatory Impact Assessment in the UK).

Acknowledgements

The research reported in this paper was financially supported by the Austrian Science Fund (FWF) under research grant no. P16734-G04, which is gratefully acknowledged. We would also like to thank the participating stakeholders and experts for their active participation in both case studies.

Appendix

	Unit	Scen. 1	Scen. 2	Scen. 3	Scen. 4	Weight (in %)
Climate change impact	t/TJ EE	31.9	15.7	33.3	15.5	9.5
Energy input	GJ/TJ EE	2,587.2	1,274.1	2,793.7	1,310.9	2.9
Material input	kg/TJ EE	55,823.3	15,167.5	49,883	11,864.3	2.9
Sealed land	m²	8,100	0	8,900	100	2.9
SO2-equivalents	kg/TJ EE	295.9	181.9	326.7	193.2	1.9
Stratospheric ozone	kg/TJ EE	406.2	360.7	456.5	369.8	2.85
Dust	kg/TJ EE	94.4	120.8	263.8	143.1	4.75
Noise	Qualitative	Low	None/Hardly	Moderate	None/Hardly	0.97
Smell	Qualitative	Moderate	None	Moderate	None	0.97
Influence of water habitats	Qualitative	Moderate	None	No	None	0.97
Influence of soil habitats	Qualitative	Moderate	None	Moderate	None	0.97
Empowerment	Qualitative	Low	Moderate	Low	High	0.69
Social justice	Qualitative	Low	Low	High	Moderate	1.49
Regional social cohesion	Qualitative	Low	Moderate	Moderate	High	5.49
Costs	€ / TJ EE	25,113	28,664	21,447	28,777	4.69
Regional economic development	Qualitative	High	Low	High	Moderate	10.3
Employment	Employed	4.82	4.3	5.45	5.8	9.5
Diversity	Qualitative	High	Moderate	Low	Moderate	8.7
Adaptability	Qualitative	Moderate	High	Moderate	High	3.09
Import dependency	%	64	67	81	74	7.89
Quality of landscape	Qualitative	Low	Moderate	Moderate	None	7.89
Security of supply	Qualitative	Good	Good	Good	Good	8.7

Table 3. Local impact matrix including weights and preference function

	Unit	Scen. A	Scen. B	Scen. C	Scen. D	Scen. E	Weight (in %)
Climate change impact							
CO2 equivalents	(t/ TJ)	18	16	17	21	18	7.77 - 12.74
Air quality							
SO2 equivalents	(kg/ TJ)	276	236	179	289	265	1 - 3.53
TOPP	(kg/ TJ)	359	312	240	399	353	1 - 3.53
Particulate matter	(kg/ TJ)	94	78	69	124	72	1 - 3,53
Rational resource use							
Cum. energy input	(GJ/ TJ)	2,365	2,099	1,822	2,444	2,274	1.56 - 6.37
Cum. material input	(kg/ TJ)	81,441	83,182	105,203	78,311	75,468	1.56 - 6.37
Water quality							
Phosphorus	(mg/ TJ)	30	31	56	77	33	0.6 - 2.03
Nitrogen	(g/ TJ)	4	4	5	6	5	0.6 - 2.03
AOX	(mg/ TJ)	25	24	22	20	33	0.6 - 2.03
CSB	(kg/ TJ)	33	36	51	92	31	0.6 - 2.03
BSB	(g/ TJ)	967	1,040	1,467	2,598	899	0.6 - 2.03
Costs	E3 €/ TJ	43	41	51	40	46	2.59 - 12.5
(Reg.) Self determinacy	Qualitative	Rather low	Low	Rather high	Medium	High	0.79 - 7.81
Social cohesion	Qualitative	Rather low	Rather low	Medium	Medium	Rather high	0.79 - 10.6
Diversity of technologies	Qualitative	Rather low	Medium	Medium	Low	Medium	1.27 - 9.75
Employment	Qualitative	Rather low	Rather low	Medium	Medium	Rather high	0.79 - 8.43
Effect on public budget	Qualitative	Low	Rather low	Rather high	Rather low	Medium	0.79 - 18,56
Import dependency	Qualitative	Medium	Medium	Low	Medium	Medium	0.93 - 12.74
Quality of the landscape	Qualitative	Low	High	High	Medium	High	1.01 - 7.77
Noise	Qualitative	Medium	Low	Low	High	Low	0.79 - 7.77
Social justice	Qualitative	Medium	Medium	Medium	Medium	Medium	0.59 - 10.24
Technological leadership	Qualitative	Low	Medium	High	Low	Low	0.79 - 8.75
Ecological justice	Qualitative	Low	Medium	Rather high	Low	Medium	0.79 - 10.06
Security of supply	Qualitative	Low	Low	Medium	Medium	High	2.96 - 15.72

Table 4. National impact matrix including weights

Stability Intervals

Stability Level 4 first actions

	Weight	Interval		% Weight	% Interval	
		Min	Max		Min	Max
CO2-Äquivalent	9.5000	3.0316	Infinity	9.50%	3.24%	100.00%
Energy input	2.9000	0.0000	Infinity	2.90%	0.00%	100.00%
Material input	2.9000	0.0000	9.3883	2.90%	0.00%	8.81%
sealed land	2.9000	0.0000	Infinity	2.90%	0.00%	100.00%
SO2 equivalents	1.9000	0.0000	Infinity	1.90%	0.00%	100.00%
stratospheric ozo	2.8500	0.0000	Infinity	2.85%	0.00%	100.00%
Dust	4.7500	2.5872	17.6868	4.75%	2.64%	15.66%
Noise	0.9725	0.0000	Infinity	0.97%	0.00%	100.00%
Smell	0.9725	0.0000	Infinity	0.97%	0.00%	100.00%
Influence of wate	0.9725	0.0000	4.2187	0.97%	0.00%	4.08%
Influence of soil h	0.9725	0.0000	Infinity	0.97%	0.00%	100.00%
Empowerment	0.6900	0.0000	Infinity	0.69%	0.00%	100.00%
Social justice	1.4900	0.0000	4.0853	1.49%	0.00%	3.98%
Regional social cc	5.4900	0.0000	9.8155	5.49%	0.00%	9.41%
Gestehungskoste	4.6900	0.0000	10.9939	4.69%	0.00%	10.34%
Regional economi	10.3000	0.0000	15.4747	10.30%	0.00%	14.71%
Employment	9.5000	0.0000	22.4368	9.50%	0.00%	19.86%
Diversity	8.7000	6.5372	17.3245	8.70%	6.68%	15.95%
Adaptability	3.0900	0.0000	Infinity	3.09%	0.00%	100.00%
Import dependenc	7.8900	0.0000	10.2073	7.89%	0.00%	9.97%
Landscape quality	7.8900	1.4017	Infinity	7.89%	1.50%	100.00%
Supply security	8.7000	0.0000	Infinity	8.70%	0.00%	100.00%

Figure 5. Stability intervals of the aggregation on the local level using group weights

Stability Intervals

Stability Level 5 first actions ☑ AutoLevel

	Weight	Interval		% Weight	% Interval	
		Min	Max		Min	Max
CO2 equivalents	1.0000	0.0000	4.7526	4.17%	0.00%	17.12%
SO2 equivalents	1.0000	0.0000	1.3030	4.17%	0.00%	5.36%
TOPP	1.0000	0.0000	1.3113	4.17%	0.00%	5.39%
Particulate matter	1.0000	0.0000	5.7983	4.17%	0.00%	20.13%
Cum. energy effort	1.0000	0.0000	1.6679	4.17%	0.00%	6.76%
Cum. material effort	1.0000	0.5463	6.9991	4.17%	2.32%	23.33%
Phosphorus/Water quality	1.0000	0.7439	3.8403	4.17%	3.13%	14.31%
Nitrogen/Water quality	1.0000	0.0000	74.7284	4.17%	0.00%	78.47%
AOX	1.0000	0.0000	2.2816	4.17%	0.00%	9.02%
CSB	1.0000	0.4744	9.2072	4.17%	2.02%	28.59%
BSB	1.0000	0.4562	9.4057	4.17%	1.95%	29.02%
Costs	1.0000	0.5516	4.2905	4.17%	2.34%	15.72%
Self determinancy	1.0000	0.4511	11.0176	4.17%	1.92%	32.39%
Social cohesion	1.0000	0.4511	11.0176	4.17%	1.92%	32.39%
Diversity of technology	1.0000	0.0000	Infinity	4.17%	0.00%	100.00%
Employment	1.0000	0.4511	11.0176	4.17%	1.92%	32.39%
Effect on public budget	1.0000	0.4511	4.2768	4.17%	1.92%	15.68%
Import dependency	1.0000	0.0000	1.2744	4.17%	0.00%	5.25%
Quality of landscape	1.0000	0.0000	6.0088	4.17%	0.00%	20.71%
Noise	1.0000	0.0000	Infinity	4.17%	0.00%	100.00%
Social justice	1.0000	0.0000	Infinity	4.17%	0.00%	100.00%
Technological leadership	1.0000	0.0000	1.1372	4.17%	0.00%	4.71%
Ecological justice	1.0000	0.0000	1.5489	4.17%	0.00%	6.31%
Security of supply	1.0000	0.7256	6.0088	4.17%	3.06%	20.71%

Figure 6. Stability intervals of the aggregation on the national level using equal weights

References

Allen, P., 2001. Knowledge, ignorance and the evolution of complex systems, in J. Foster and J. S. Metcalfe (eds) Frontiers of Evolutionary Economics - Competition, Self-Organization and Innovation Policy, Cheltenham: Edward Elgar.

Bana e Costa, C. A., Vansnick, J. C., 1999. The MACBETH Approach: Basic ideas, software, and an application. In N. Meskens and R. Roubens (Eds.), Advances in decision analysis. Dordrecht: Kluwer, 131-157.

Bohunovsky, L., Madlener, R., Omann, I., Bruckner, M., Stagl, S., 2007. Lokale Energiesysteme der Zukunft. Integrierte Nachhaltigkeitsbewertung von lokalen Energieszenarien. In: Ökologisch Wirtschaften, 2/2007, 47-50.

Brand, K.-W., 2000. Nachhaltigkeitsforschung - Besonderheiten, Probleme und Erfordernisse eines neues Forschungstypus. In K.-W. Brand (Ed.), Nachhaltige Entwicklung und Transdisziplinarität. Berlin: Analytica, 6-25.

Brans, J-P, Mareschal, B., et. al., 1986. How to select and how to rank projects. The PROMETHEE method, European Journal of Operational Research 24 (2), 228-238.

Brans, J.P., Mareschal, B., 1990. The PROMETHEE Methods for MCDM; the PROMCALC, GAIA and Bankadvisor Software. In Bana e Costa, C.A. (Ed) Readings in Multiple Criteria Decision Aid, Berlin: Springer, 216-252.

Choo, E. U., Schoner, B. and Wedley, W. C. 1999. Interpretation of criteria weights in multicriteria decision making, Computers & Industrial Engineering 37: 527-541.

Figueira, J., and Roy, B., 2002. Determining the Weights of Criteria in the ELECTRE Type Methods with a Revised Simos Procedure. European Journal of Operational Research 139, 317-326.

Fiorino, D., 1990. Citizen Participation and Environmental Risk: A Survey of Institutional Mechanisms. Science, Technology, & Human Values 15 (2), 226-243.

Fiorino, D., 1989. Environmental risk and democratic process: a critical review, Columbia Journal of Environmental Law 14: 501-547.

Funtowicz, S., Ravetz, J., 1991. A New Scientific Methodology for Global Environmental Issues. In R. Costanza (Ed.), Ecological Economics. The Science and Management of Sustainability. New York: Columbia University Press, 137-152.

Funtowicz, S., and Ravetz, J., 1994. The Worth of a Songbird: Ecological Economics as a Post-normal Science. Ecological Economics 10 (3), 197-207.

Funtowicz, S., O'Connor, M. and Ravetz, J., 1997. Emergent Complexity and Ecological Economics. In J. C. J. M. van den Bergh and J. van der Straaten (Eds.), Economy and Ecosystems in Change: Analytical and Historical Approaches. Cheltenham: Edward Elgar, 75-95.

Hirsch Hadorn, G., 2003. Gegenseitige Vorurteile in transdisziplinärer Umweltforschung. *GAIA* 12 (3), 232-234.

Geldermann, J., Zhang, K., 2001. Software Review: „Decision Lab 2000“. Journal of Multi-Criteria Decision Analysis 10, 317-323.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., Trow, M., 1994 The new production of knowledge: the dynamics of science and research in contemporary societies, London: Sage.

Haberl, H., Krausmann, F., Erb, K., Schulz, N., Adensam, H., 2002. Biomasseeinsatz und Landnutzung Österreich 1995–2020, Social Ecology Working Paper 65, im Auftrag des BMBWK.

International Energy Agency (IEA), 2003. Energy Policies of IEA Countries: Austria 2002 Review. IEA/OECD, Paris.

Kasemir, B., Jäger, J., Jaeger, C. C. (Eds.). 2003. Public Participation in Sustainability Science: A Handbook, Cambridge University Press

Kastenhofer, K., Omann, I., Stagl, S., Steininger, K., 2003. Science policy for transdisciplinary research. in UNESCO (Ed.) Knowledge for Sustainable Development: An Insight into the Encyclopaedia of Life Support Systems, Paris; London: Imprint (online version).

Kowalski, K., Stagl, S., Madlener, R., Omann, I., 2008. Sustainable energy futures: methodological challenges in combining scenarios and participatory multi-criteria analysis, *European Journal of Operational Research* (in print).

Luks, F., 1996. Post-Normal Science, Dematerialisierung und die Ökonomie. In J. Köhn and M. J. Welfens (Eds.), Neue Ansätze in der Umweltökonomie. Marburg: Metropolis, 89-106.

Luks, F., 1999. Post-Normal Science and the Rhetoric of Inquiry: Deconstructing Normal Science? Futures 31, 705-719.

Madlener R., Kowalski, K., Stagl, S., 2007. New ways for the integrated appraisal of national energy scenarios: the case of renewable energy use in Austria, Energy Policy, 35(12), 6060-6074.

Mareschal, B., 1988. Weight stability intervals in multicriteria decision aid, European Journal of Operational Research, 33(1), 54-64.

Max-Neef, M.A., 2005. Foundations of transdisciplinarity, Ecological Economics 53 (1), 5-16.

Maystre. L., Pictet, J., Simos, J., 1994. Méthodes multicritères ELECTRE - Description, conseils pratiques et cas d'applications à l gestion environmentale. Lausanne, Presses Polytechniques et Universitaires Romandes.

Müller, A., 2003. A Flower in Full Blossom? Ecological Economics at the Crossroads between Normal and Post-Normal Science. Ecological Economics 45 (1), 19-27.

Munda, G., 2004. Social multi-criteria evaluation (SMCE): methodological foundations and operational consequences. European Journal of Operational Research 158 (3), 662–677.

Neubarth, J., Kaltschmitt, M. (Eds.), 2000. Erneuerbare Energien in Österreich. Systemtechnik. Potenziale, Wirtschaftlichkeit, Umweltaspekte. Springer: New York

Omann, I., 2004. Multi-criteria decision aid as an approach for sustainable development analysis and implementation. Ph.D. thesis. University of Graz, Austria.

Pictet, J., Bollinger, D., 2005. The Silent Negotiation or How to Elicit Collective Information for Group MCDA Without Excessive Discussion. Journal of Multi-Criteria Decision Analysis 13, 199-211.

Ökoinstitut, 2005: Global Emission Model for Integrated Systems (GEMIS) Version 4.3 (http://www.oeko.de/service/gemis/en/index.htm). Institute for Applied Ecology e.V., Freiburg/Darmstadt, Germany.

Scheringer, M., Valsangiacomo, V., Hirsch Hadorn, G., Pohl, C., Ulbrich Zürni, S., 2005. Transdisziplinäre Umweltforschung: eine Typologie. GAIA 14 (2), 192-195.

Stagl, S., Garmendia, E., 2006. Social learning in public particiaption for sustainabiltiy: Measuring the quality of participatory approaches. Paper presented at the Participatory Approaches in Science and Technology Conference, Edinburgh, 4 – 7 June 2006.

Stirling, A., 2006. 'Analysis, participation and power: justification and closure in participatory multi-criteria analysis', Land Use Policy 23: 95–107.

UBA, 2005. GEMIS. Globales Emissionsmodell integrierter Systeme. Version 4.2. Wien.

E.ON Energy Research Center

fcn Institute for Future Energy Consumer Needs and Behavior

RWTH

List of FCN Working Papers

2008

Madlener R., Gao W., Neustadt I., Zweifel P. (2008). Promoting Renewable Electricity Generation in Imperfect Markets: Price vs. Quantity Policies, FCN Working Paper No. 2/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Madlener R., Wenk C. (2008). Efficient Investment Portfolios for the Swiss Electricity Supply Sector, FCN Working Paper No. 1/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Omann I., Kowalski K., Bohunovsky L., Madlener R., Stagl S. (2008). The Influence of Social Preferences on Multi-Criteria Evaluation of Energy Scenarios, FCN Working Paper No. 3/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

FCN Working Papers are free of charge. They can mostly be downloaded in pdf format from the FCN / E.ON ERC Website (www.eonerc.rwth-aachen.de/fcn). Alternatively, they can also be ordered from the Secretariat of the Institute for Future Energy Consumer Needs and Behavior, c/o Chair of Energy Economics and Management (Prof. R. Madlener), Templergraben 55, 52056 Aachen, Germany.