Fuzzy-Set Decision Support for a Belgian Long-Term Sustainable Energy Strategy

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Summary. This chapter addresses the methodological challenges of developing relevant scientific knowledge for a sustainable energy system transition in an innovative way. We argue that scientific contributions to sustainable development do not follow the 'linear' procedure from empirical knowledge production to policy advice. Instead, they consist of problem-oriented combinations of explanatory, orientation- and action-guiding knowledge. Society and policy makers not only have to be 'provided' with action-guiding knowledge, but also with an awareness of the manner in which this knowledge is to be interpreted, and where the inevitable uncertainties lie. Since the sustainability question is inherently multi-dimensional, participation of social groups is an essential element of a strategy aimed at sustainable development. Multi-criteria decision support provides a platform to accommodate a process of arriving at a judgment or a solution for the sustainability question based on the input and feedback of multiple individuals. At the same time in practice, multi-criteria problems at tactical and strategic levels often involve fuzziness in their criteria and decision makers' judgments. Therefore, we argue in favor of the use of fuzzy-logic based multi-criteria group decision support as a decision support tool for long-term strategic choices in the context of Belgian sustainable energy policy.

1 Introduction

It is difficult to imagine our lives (i.e. the lives of people in rich, industrialized countries) without all the services made possible by the provision of commercial energy: the heating of our houses, electricity for our appliances, fast

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transportation modes (train, tram, bus, car, airplane), the industrial manufacture of consumer goods, and so on. All of these technologies have completely changed our way of life, but they rely on the uninterrupted supply of huge amounts of energy. And energy consumption is still on the rise – in Belgium, Europe, and certainly on a global scale. Especially our dependence on fossil fuels (oil, gas, coal) – supplied from the four corners of the world if necessary – is growing. Our 'addiction to energy' comes at a heavy price. Next to the obvious problems of long-term energy security and geo-political risks, there are also risks for the safety and health of people and the environment all the way from the extraction of oil, gas, coal and uranium, to the final consumption. Problems can be local (e.g. noise pollution from airplanes), regional (e.g. acid rain), or even world-wide (e.g. anthropogenic climate change, proliferation risks). And besides the environmental problems and security risks, there are also social problems. Access to clean energy is a fundamental right for everyone in order to satisfy basic needs such as shelter, food and hygiene. Hence, the global energy situation raises a number of ethical questions, such as: '*What would happen if everyone in the world used as much energy as we do in rich, industrialized countries*?'; '*Can we guarantee access to clean, reliable and affordable energy sources for the next generations*?'; and '*Will the resource depletion, pollution and other risks remain manageable*?'. By now, the recognition that development should become more sustainable is widespread.

The realization of sustainable development is a monumental challenge, not only for politics and society. Strategic scientific information is needed to support opinion formation and decision-making processes. However, the services which science has to provide to support the transition to a sustainable energy system have – in part – other characteristics than the 'traditional' scientific outputs (e.g. technological innovations, new explanatory knowledge about causal processes, etc.). The normative character of sustainability, its inseparable connection with deep-rooted societal structures and value patterns, the long-term nature of many relevant developments, as well as the necessary inclusion of societal actors, result in specific demands on scientific policy support [7]. Scientific knowledge for sustainable development has to consist of targeted and context-sensitive combinations of **explanatory knowledge** (i.e. energy system knowledge or knowledge of the interactions between societal activities, energy service demands, energy technologies – supply and demand – and the resulting impacts); **orientation knowledge** (i.e. knowledge of justification arguments which operate with normative premises); and **knowledge for action** (i.e. scientific contributions to the 'therapy' of unsustainable situations). Furthermore, this kind of knowledge will always be provisional and incomplete in its descriptive aspects, as well as dependent on changing normative expectations [9]. Therefore, science for sustainability needs to be **reflexive** – i.e. sensitive to the conditions of knowledge production. Society and policy makers not only have to be 'provided' with action-guiding knowledge, but also with an awareness of the manner in which this knowledge is to be interpreted, and where the inevitable uncertainties lie. In other words, strategic knowledge for sustainability needs to be **transparent** (i.e. all decision criteria should *a priori* be presented in their 'original' form, without converting them to frequently used common measurement rods such as energy inputs/outputs or money).

In order to meet these challenging conditions for strategic knowledge production, a PhD research project was carried out at the Belgian nuclear research centre (SCK•CEN) and the University of Leuven (KULeuven) which aimed at innovative methodological developments in the field of policy support for a long-term sustainable energy strategy in Belgium [12]. The project put an emphasis on the following essential aspects of 'knowledge for sustainability':

- **Long-term energy foresight from a normative perspective** by using a 'back-casting' approach;
- **Planetary scope** in the sense that the global universalizing perspective is an essential element of the sustainability logic;
- **Feasibility as part of a governance process** in the sense that, if embedded in an appropriate institutional context, the required knowledge should be developed in such way that it can play a role in a more open-ended learning approach to energy policy – i.e. strategic knowledge should be flexible and adaptive in nature, in response to changing assessments regarding the political relevance of items, alternatives or impacts. Furthermore, the development of knowledge should not be too demanding (e.g. in terms of the theory behind it), expensive to implement, unduly protracted, etc.;
- **Integrated assessment** in the sense that all life-cycle stages of energy technologies – from energy services to primary energy demands – should be taken into account;
- **Interdisciplinarity** in the sense that strategic knowledge should not put any artificial boundaries on the type of issue or measurement that can be taken into account in the analysis – i.e. the analysis needs to support arguments coming from technological, economic and sociological perspectives;
- **Uncertainties in the long run** in the sense that strategic knowledge should incorporate some form of uncertainty management.

At this point, if we accept the multi-dimensional nature of the sustainability question, we also have to accept that the evaluation of strategic policy options has to be based on procedures that explicitly recognize the integration of a broad set of (possibly conflicting) points of view, taking into account the principles set out above. Elsewhere, we have argued that multi-criteria evaluation techniques can in principle (i.e. providing certain conditions are met) provide an appropriate policy framework for setting long-term strategic priorities [14]. This chapter sets out a proposal to use a fuzzy multi-criteria group decision support system (FMCGDSS) as a possible framework for the application of strategic choice to an intractable policy problem such as sustainable development. Fuzzy multi-criteria decision making has been one of the fastest growing areas in decision making and operations research during the last three decades [18,23,29,35]. A major reason behind the development of fuzzy multi-criteria decision making is due to the large number of criteria that decision makers are expected to incorporate in their actions and the difficulty of expressing decision makers' opinions by crisp values in practice [30–32]. Group decision making takes into account how people work together in reaching a decision. Uncertain factors often appear in a group decision process, namely with regard to decision makers' roles (weights), preferences (scores) for alternatives, and judgments (weights) for criteria. We will illustrate some of the main points of interest in the application of the FMCGDSS by drawing upon our case-study of Belgian long-term energy policy. First, we set out the policy context and the positions of major energy policy stakeholders at the time when the multi-criteria evaluation took place (Sect. 2). Next, we discuss the application of the FMCGDSS according to the principal phases in any multi-criteria evaluation: identification of the stakeholders to take part (Sect. 3); generation of decision alternatives (Sect. 4); selection of evaluation criteria (Sect. 5); and scoring, weighting and application of an aggregation convention (Sect. 6). We conclude with general observations on the use of multi-criteria decision aiding methods (and the application of the FMCGDSS in particular) in the context of sustainability (Sect. 7). As our main aim in this chapter is to discuss the methodological issues of multi-criteria decision support in the context of sustainable energy policy, we will not discuss in detail the substantive results of the 'Belgian case'. For this, we refer the interested reader to Laes [12].

2 The (Nuclear) Energy Debate in Belgium

Of course, policy making for sustainability is not a one-shot activity. On the contrary, policy measures are shaped by a highly dynamic process taking place at multiple levels (e.g. international guidelines, European directives, national legislation) and crossing the boundaries of institutionally separated policy domains (e.g. fiscal measures impacting on consumer behavior, liberalization of European energy markets and the rules of the 'free market', climate change policy, environmental regulations, etc.). Furthermore, policy making is inevitably bound to the normal rules of the democratic game, so that political judgments regarding the salience of certain problems or impacts may change (sometimes drastically) over time. Therefore, before entering into the details of the particular application of a multi-criteria decision aid to the development of strategic knowledge for a sustainable energy strategy, it is necessary to give some more details about the policy-making context at the time when this multi-criteria exercise was organized (Oct.–Dec. 2003). At that time, the Belgian parliament had only just voted a law entailing the gradual phase out of nuclear energy (Sect. 2.1). This decision roused quite some contestation between a number of historically active social groups on the Belgian energy policy scene. The resulting debate stretched the scope of arguments outside the boundaries of political (parliamentary) decision making, as it opened up to (sometimes highly ideologically colored) arguments about the strategic direction of Belgian energy system development involving at the same time a discourse about the cognitive (i.e. concerning the availability and use of existing scientific knowledge), reflexive (i.e. concerning the issue of framing and interpreting scientific knowledge in a policy-making context) and planning (i.e. concerning the organization of a politico-scientific debate) dimensions of the policy process configuration at the time [13] (Sect. 2.2).

2.1 Policy-Making Context

In Belgium – as in many other industrialized countries – the energy sector has been shaped in the past (roughly before 1990) by the dominant importance accorded to the diversification of energy sources (in order to minimize the geo-political risks of dependence on oil-exporting countries) and security of supply at a reasonably competitive price for all concerned. This post-war 'social pact' formed the core of energy policy: representatives of both employers and employees recognized the need for a growing economic output in order to maximize welfare, and direct state intervention in the energy sector was encouraged. From a historical point of view, the bargaining process among the interested parties has led to a low priority for measures to promote a rational use of energy (because this interest was not directly advocated, or even implicitly opposed). From the 90s on, the policy-making context was gradually changed mainly by the combined forces of an increasing prominence of environmental issues on the (international, regional and national) political agenda (e.g. climate change) and the liberalization of European energy markets.

The attitude of the Belgian political class towards nuclear power in the 90s was generally characterized by a great deal of reticence. Starting from 1988, subsequent governments upheld the moratorium on the construction of new nuclear capacity; options preferred by the nuclear sector which were taken earlier (e.g. reprocessing and use of mixed-oxide fuel in Belgian power plants) were questioned and revised; and decisions regarding rather pressing nuclear issues ran into a complete gridlock and were postponed (e.g. the siting of a waste disposal for low-level wastes). All in all, it seemed as if the safest political strategy for the major political parties (Liberals[5], Socialists, Christian-democrats) was to be as quiet as possible about nuclear issues. This is not surprising as more than 30 years of nuclear controversy resulted in deeply polarized positions and an almost complete gridlock[6]. Under these circumstances, it is safe to assume then that the nuclear phase out (as opposed

[5] In the European-continental sense of the word – i.e. central-right on socio-economic issues and more progressive on moral issues.

[6] Gridlock can, in this sense of the word, be characterized as a condition where technological policy has faced major obstacles, due to an emphasis on hardware and technological fixes to the neglect of citizen or political concerns. When one

to a continuation of the moratorium on new nuclear construction) was directly placed on the political agenda as a result of the participation of the Green parties (AGALEV/ECOLO) in the 1999–2003 federal government (a coalition of Liberal, Socialist and Green parties)[7]. These parties have, since their origins in the early 80s, consistently rejected the reliance on nuclear power as an element of energy policy. The other partners in the coalition (Liberals and Socialists) apparently were not willing to turn the proposed nuclear phase out into a breaking point in the political negotiations preceding the formation of the new government[8].

In the context of profound change provoked by the Kyoto commitments and the (at that moment still embryonic) liberalization of the electricity market, the nuclear phase out was first announced as an intention in the government policy statement of 7 June 1999 (at the beginning of the legislature of the previous government), together with a confirmation of the political willingness to comply with the Kyoto agreements. The phase-out scenario means that the Belgian nuclear power plants would effectively be taken out of service in the period 2015–2025 (after 40 years of operation), whereas Belgium now provides for some 55% of its electricity needs by nuclear power generation. It took almost four years before the original government intention was translated into law. During this period, some policy documents were published which provide a deeper insight in the political negotiation of problem structuring and the justifications given to support the decision. In Laes [12] we argue that these justifications were based on an attempt to **recast the policy problem in a well-structured technical mould**. This was evident from a self-proclaimed reliance on expert opinion, limitations on the possibilities for ethical debate, treatment of the policy question within the mandate of existing bureaucratic organizations, etc. A detailed analysis showed however that this technical treatment could only be achieved by leaving some 'white spots' and/or ambiguities in the justifications given. Conflict rather than mutual exchange was the dominant dynamic in the debate surrounding

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encounters gridlock, or in other words an almost complete loss of trust, cooperation on any issue involving the technology in question seems almost impossible [25].

[7] Other political parties never went further than advocating an enlarged moratorium, concerning as well other activities in the nuclear sector (i.e. not only the production of electricity, but also e.g. the production of mixed-oxide fuel elements) as the foreseen duration of such moratorium.

[8] The present government (2003–2007) – a coalition of Liberals and Socialists (without the Green parties) – has not altered the nuclear phase-out law. Nuclear power again figures prominently in the electoral campaign at the time of writing this chapter (May 2007), with the Socialist and Green parties proposing to stay on a nuclear phase-out course, the Liberal party agreeing to maintain the phase-out agreement for the present power plants whilst advocating increasing research efforts into new nuclear reactor concepts (the so-called 'GenIV' initiative), and the Christian-democrat party in favor of keeping the present power plants open longer than foreseen in the phase-out law.

the phase-out decision. Exclusive relations between the different perspectives were caused by competing rationalities on the one hand and the governance framework on the other. Our analysis revealed that social learning was mainly hindered by the following issues:

- Different **methodological approaches** (bottom-up vs. top-down analysis of the energy system);
- **Lack of data** (to perform the bottom-up analysis);
- Different perceptions of **relevant time scales** (or how to link short-term issues with long-term issues);
- Different **framing of the problem** (studying only the electricity system vs. embedding electricity needs in the wider energy system);
- **Institutional barriers** (e.g. to develop a much needed long-term vision);
- **Lack of communication** (between political decision makers and scientists, between scientists and stakeholders);
- **Strategic use** of scientific assessments by different stakeholders, or
- **Insufficient knowledge of scientific assessments**.

As a result, sustainable energy (and the role of nuclear power therein) proved to be an essentially contested concept, and furthermore there were virtually no 'connecting' or 'translating' links between the divergent concept and problem framings. This finding suggested that other possible views on the role of nuclear power in a sustainable development perspective existed which had to be actively 'suppressed' or 'blurred' (in order to proceed 'as if' there was a consensus). In the following section the major positions in the debate are reconstructed.

2.2 Patterns of Argumentation on a Sustainable Energy Strategy

To understand if other courses of action were possible then the highly discordant ones described above, an institutional analysis was carried out and consequently representatives of most of the organizations having a seat in the Belgian 'Federal Council for Sustainable Development' (FCSD) were invited for a personal interview session. For purposes of clarity, we made an attempt to reconstruct the different arguments used in the interviews into some coherent and consistent argumentation schemes. These argumentation schemes thus differ from each other in the assessment of different aspects of the sustainable energy policy question and in the resulting will to change the course of development. They are meant simply as frameworks for analysis and thus, essentially, as 'ideal' reconstructions. This implies that although participants will certainly recognize parts of their reasoning, they are not to be identified with the vision of a particular societal actor. This analytic approach is only meant to guide the process of reflection, by drawing particular attention to some aspects of the problem and by systematically positioning the collective choices between different options against each other. We have labeled the three perspectives the '**management**', '**controllist**' and '**reformist**' perspective.

These perspectives have been reconstructed in their structural dimensions, i.e. their communicated images of self and others (with respect to relevant actors), valid forms of communication, main problem focus, and main principal references. Boltanski and Thévenot's 'commonwealth model' [5] has served as an aid in identifying them.

The **manager** for a large part frames his arguments within the confines of industrial and market arguments. He sees economic growth and technological advance as the most important component of sustainable development, to the extent that actions that might seriously endanger possibilities of growth or competitiveness in general must be discouraged. Furthermore, economic growth will most likely be driven by higher demands for energy and electricity. The *manager* is quite content for the market for electric power to stand as a surrogate for societal consent. To be sure, he is of course worried about safety and health issues; however, these are considered to be part of a technical design. It is the government's responsibility to ensure standards and norms, based on 'objective' scientific rationality. Hence, sustainable development is at risk when the necessary long-term stability is undermined by a lack of (respect for) expert knowledge as an indisputable basis for the legitimacy of state action. Governments should set up a stable framework; business will then take up its responsibilities through 'sustainable entrepreneurship', ensuring relationships based on trust and consent with concerned parties (labor unions, stockholders, employees, local residents, etc.). There is no reason why electricity generators owning nuclear power plants could not be part of this.

The **controllist** seems to be caught in a paradox. His position on the role of nuclear power in sustainable development was perhaps best phrased by one interviewee: "*...As long as there is no real commitment to the development of a vision on long-term alternatives for nuclear power, a phase-out scenario is nonsense. But, if society does not want to consider the phase out of nuclear energy, the motivation to think about alternatives will also be very weak* ...". The *controllist* is not so much interested in the 'pro or contra' discussion about nuclear power; rather, attention should be given to the institutional embedding of this technology is society. Fear exists that in the future, nuclear power will be 'inevitable' if one wants to respect post-Kyoto commitments and still foster economic growth. Rather, acceptance (or rejection) should be based on a democratic debate with the representatives of concerned parties, under conditions of full transparency. For now, according to this position, these conditions have not been fulfilled as too much is left in the dark: costs of decommissioning, costs of high-level waste management, the real costs of the business-as-usual scenario, etc. – all 'great unknowns'. In other words, the *controllist* is mainly concerned with the maintenance of the democratic system of 'checks and balances'. Thus, more attention is given to the necessary framing of 'industrial' and 'market' values within the logic of a civic argumentation. The *controllist* prefers a real balance between economic, social and environmental development – for now, economic growth is too strongly favored. This perspective deplores the risk that in a liberalized market, the government's power of intervention could be limited.

The **reformist** sees the evolution of the Belgian electricity sector as an ongoing social process in which scientific knowledge, technological innovation (or the lack thereof in renewable energy technologies) and corporate profit reinforce each other in deeply entrenched patterns, patterns that, according to this perspective, bear the unmistakable stamp of political and economic power. In terms of Boltanski and Thévenot's commonwealth model, people and objects are artificially kept in a state of permanent 'misery': perfectly valid technical options (e.g. renewable energy options) are underdeveloped and 'rational' behavior (e.g. energy saving) discouraged, the true costs of energy use are being concealed, and people are kept in a state of political apathy. For the *reformist*, nuclear power is not merely the symbol of this social order; it is a true embodiment of that order. The concerns are broad and directed at ethical and socio-cultural levels for which even regulatory environments might not be suited. Moreover, this perspective challenges and stretches the limits of the established argumentations towards long-term and global ethical considerations. The *reformist*'s explicit agenda calls for a new social order that would make the current distribution of resources more equitable. Resources must be understood in the broadest sense: not only in a physical (e.g. distribution of health and environmental risks) or monetary sense (e.g. distribution of benefits from nuclear power generation), but also culturally, involving democratic and governance issues. Consent for a technological or development option must be based on explicitly revealed preference in a dialogical form of democracy. Small-scale participatory institutions are regarded with more trust than central government. The *reformist* also feels that, as a result of this socio-technological nexus centered on nuclear power, his perspective on sustainable energy has not been addressed sufficiently and calls for a new research agenda: there is no culture of long-term reflection, there are no sufficient scientific data to perform a bottom-up analysis of electricity demand, energy issues in general are not high on the political agenda, etc.

Once these general perspectives were identified the problem has to be structured in a multi-criterion framework. This means to identify stakeholders, generate strategic decision alternatives and to choose evaluation criteria. The next sections illustrate the multi-criterion approach used (i.e. the FMCGDSS) and the results obtained.

3 Identification of Stakeholders

The value of the so-called 'extended peer communities' [7] for the formulation of public policy measures is increasingly recognized, especially in contentious policy fields such as sustainable development. Such extended peer communities (e.g. citizen juries, focus groups, deliberative conferences, etc.) all have one thing in common: they assess the quality of policy proposals, not only by adding 'public values' to the mix, but crucially also by assessing the technical and scientific component of these proposals [4]. Banville et al. [3]

offer a convincing argument on the need to extend theoretical thinking about multi-criteria decision aid frameworks towards their role in upholding dialogue processes among many stakeholders – individual and collective, formal and informal, etc. While we agree that stakeholder participation is a *necessary* condition for a multi-criteria decision aid, we do not agree that it is a *sufficient* one. As we will explain in Sects. 4 and 5, we cannot simply take stakeholder perspectives for granted in the formulation of decision alternatives and criteria.

For the operation of our particular multi-criteria decision aid framework, we have chosen to continue our participation with selected members of the FCSD. In a way, the multi-criteria exercise can thus be regarded as a more mathematically formalized sequel to the interview sessions discussed in Sect. 2.2, with however a shift in focus towards future-oriented scenarios (whereas the interviews mainly discussed present problems). The individuals taking part in the multi-criteria exercise were approached on the basis of their wider interest in both sustainable development and energy (governance) issues. Often, this meant that they were representatives of protagonists in the current energy debate with large stakes in its outcomes. However, this was not always the case, as we also explicitly strove to involve other actors than the 'traditional' interest groups in the discussions. As such, each participant could be expected to hold a general knowledge of the issues raised in contemplating energy options and their general implications, whilst also sometimes holding specialist knowledge on particular issues. As a group, it was important to include a sufficient number of perspectives, so that no point of view would be excluded *a priori*. At least one representative of the major stakeholder categories (environmental NGO's, labor unions, employers' organizations, electricity generators, academia and advisory bodies) has participated in the multi-criteria exercise, with the exception of development NGO's[9]. However, due to busy schedules or other exigencies, most organizations did not participate in all research steps (interviews, generation of decision alternatives and assigning weights and scores). Also, in some cases different representatives from the same organization participated in the different research steps. Maintaining full participation by the same representatives would have been more desirable though, in view of ensuring participants' understanding of the logic behind each of the steps. In any case, this particular selection of participants for the limited 'pilot exercise' reported in this chapter should not be seen as a definite choice in favor of these groups for representing 'societal views' on sustainable energy. Deciding which groups should be involved in a concrete governance initiative would be a matter of further research and – above all – political negotiation. Also, in more realistic political settings, different individuals will

[9] The representative of the development NGO made it clear after the first interview session that he really did not consider his organization to be involved in the questions that were of interest to us (i.e. the role of nuclear power from a sustainable development perspective in Belgium), so he declined further participation.

have different degrees of influence for the selection of satisfactory strategies. This means that the relative importance of each stakeholder may not be equal in the group. Therefore, the FMCGDSS foresees the possibility to assign a weight to each stakeholder. Formally, these weights are described by linguistic terms $\widetilde{v}_k,\ k = 1,\ 2, \dots ,\ n$ (*normal, important, more important*, and *most important*) which could be arrived at through group discussion or assigned by a higher policy level (e.g. a minister in charge of developing a strategy for sustainable energy development).

4 Generation of Strategic Alternatives

One crucial part of decision-analytic methods is how the decision problem under scrutiny is constructed, and as a consequence, the alternatives for solving the problem. In the context of a long-term policy for sustainable energy development, however, it is clear that there is no 'single' decision involved, but rather a set of interlinked decisions, none of which taken on its own constitutes the policy, but which in combination produces a process which we could describe as a 'strategy'. Nevertheless, in order to use a decision-analytic procedure, we need to represent clearly distinctive 'alternatives for action' in a way that would allow participants in the exercise to choose between them. Hence, a possible conflict emerges between the 'complexity of the real world' and the 'simplicity' required for the purposes of decision-analytic modeling. In principle, there is no 'right' solution to this dilemma; one can only try to propose an acceptable (pragmatic) solution [8].

For instance, in a multi-criteria application to energy policy, Stirling [28] proposes to limit the selection of decision alternatives to a "*...conventionally recognized and highly aggregated set of options...*" (fossil fuels, nuclear power and renewable energy), whilst leaving the 'framing assumptions' for assessing these options open to the participants involved in the exercise. Stirling's view appears to be motivated by a concern that the multi-criteria analysis should not be unduly constrained or biased by an externally imposed framework. While this concern may be legitimate, it is also clear that leaving the framing assumptions entirely open to the participants' insights leaves the door wide open to strategic behavior – i.e. a participant simply assumes that 'the framing assumptions' function in accordance with the requirements for his/her preferred decision alternative performing optimally. While Stirling would of course contend that the purpose of a multi-criteria aiding technique is precisely to make such framings more transparent (and hence also possibly open to discussion at a later stage), we nevertheless see two fundamental objections. The first is that without at least proposing some scenarios as a common framework for communication and discussion, the multi-criteria exercise is likely to simply reproduce existing positions and statements. Hence, it is unclear to us what the precise added value of a multi-criteria exercise might then be in this case. Secondly, simply accepting these framing assumptions at face value implies that there is no possibility to check whether these assumptions are applied consistently and coherently to all options under scrutiny – an important advantage offered by a reliance on formal modeling. Jones et al. [11] offer another interesting solution to the dilemma. In their decision-analytic model, these authors propose the use of five contrasting energy policy scenarios (in their case developed for the UK), drawn from the publications of a variety of different organizations engaged in energy policy. Using existing scenarios has the advantage that participants in the exercise will likely already be familiar with these scenarios, thus greatly facilitating communication and discussion. However, as mentioned before, at the time we organized our multi criteria exercise (Oct.–Dec. 2003) long-term energy scenarios for the Belgian context were simply not yet available, so we had to develop our own scenarios.

Therefore, our solution has been to develop four broadly conceived technological options – namely (a) a continued reliance on nuclear power; (b) development of carbon capture & storage technology; (c) increased import of electricity; or iv) more energy conservation combined with renewables and/or cogeneration technology – and subsequently 'test' these options against a background of two different (summarily narrated) 'worlds' – (a) the 'market world' which imposed some barriers to the penetration of energy efficiency measures and renewable energy into the energy system; and (b) the 'rational world' where energy efficiency measures and renewable energy could penetrate more easily. The eight resulting scenarios were simulated with the aid of an energy system model (MARKAL). Figure 1 gives an example of the long-term evolution of the Belgian electricity sector under the assumption that nuclear energy is not phased out, and that market functioning continues to impose

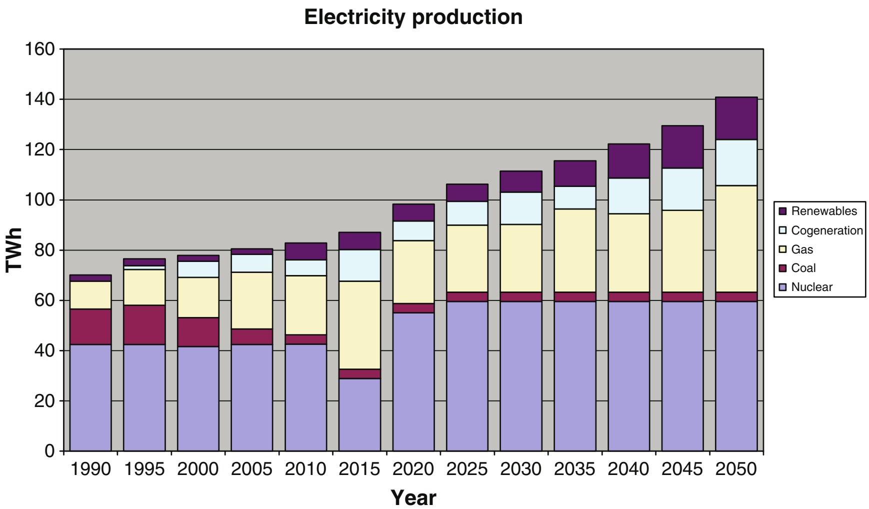

Fig. 1. Evolution of electricity production (TWh) in the case of a 'Market' scenario with continued reliance on nuclear power

barriers upon the penetration of renewables and energy conservation measures. A further characteristic of the scenarios under scrutiny is that although the principal focus concerned the relative merits of nuclear power, this option was nevertheless put in the context of alternative options for meeting the energy (and not only the electricity) needs of the future in a sustainable way. Our intention was thus not to make a specific pronouncement on the sustainability of the nuclear option as such, but rather to evaluate its relative (i.e. in comparison with other possible long-term options) performance under a number of different perspectives.

5 Selection of Decision Criteria

As argued by Munda [20–22], an effective application of policy support techniques should consider not merely the measurable and contrastable dimensions of the simple parts of a complex system, but should also deal with the 'higher dimensions' – e.g. those dimensions in which power relations, hidden interests, social participation, cultural constraints and other 'soft' variables become relevant. In practice however, the criteria in a multi-criteria appraisal exercise are often established according to the requirements of 'quantitative' sciences (e.g. ecology or economics). This approach often seems to be motivated by a concern for avoiding deep-seated value conflicts. For instance, multi-criteria discussions on sustainable development are often framed in terms of 'technical' criteria such as 'environmental impacts', 'social impacts', 'economic impacts', etc. (see e.g. Haldi et al. [10], Afgan et al. [1]). However, as demonstrated by Rauschmayer [24], establishing comparisons on a technical basis reflects in itself a deep link to a value system concerned only with efficacy, performance, and functional exigencies. If one wants to avoid scientific reductionism of this kind, there is a clear need to take into account policy dimensions using different 'languages' coming from different representations of the same system. It is clear that a multi-criteria approach, being inherently multi-dimensional in nature, seems an interesting framework to make this basic idea operational.

The decision criteria used in the FMCGDSS were derived from the interviews with members of the FCSD and a range of publications and policy documents in the field of (sustainable) energy policy. However, it is important to note that these criteria are a **technical translation** of the stakeholders' preferences and needs, operated by the research team. Such translation is a necessity since the technical formulation of decision criteria needs to show properties such as 'non-redundancy', 'legibility', etc. which cannot simply be 'extracted' from the rough material contained in interviews [6]. Decision criteria were subsequently structured into a 'combined value tree'. This combined value tree includes four important issues (high-level criteria): (a) 'Environmental and human health & safety', (b) 'Economic welfare', (c) 'Social, political, cultural and ethical needs', and (d) 'Diversification'. Just for the first dimension, seven aspects were defined (intermediate-level criteria):

(1) ‘Air pollution’, (2) ‘Occupational health’, (3) ‘Radiological health impacts’, (4) ‘Aesthetic’, (5) ‘Other environmental impacts’, (6) ‘Resource use’, and (7) ‘Other energy related pressures’. Each aspect had one or more low-level criteria.

For instance, the aspect of air pollution has both mid- and long-term impacts. Figure 2 shows the combined value tree for environmental and human health & safety, whilst Fig. 3 shows the main interface of the FMCGDSS with the left part representing the two top levels of the decision structure. In any case, this classification of the criteria does not affect the final results of the multi-criteria exercise, but is simply a matter of convenience: the possibility was left open to participants to choose between a smaller selection of criteria at a higher level of abstraction at any time in the exercise. For the purposes of a multi-criteria appraisal exercise, it is important that individual criteria are independent in the sense that, although different criteria might be related in various ways (e.g. policies aimed at reducing carbon dioxide emissions generally also lower emission of other air pollutants), the associated assessments of

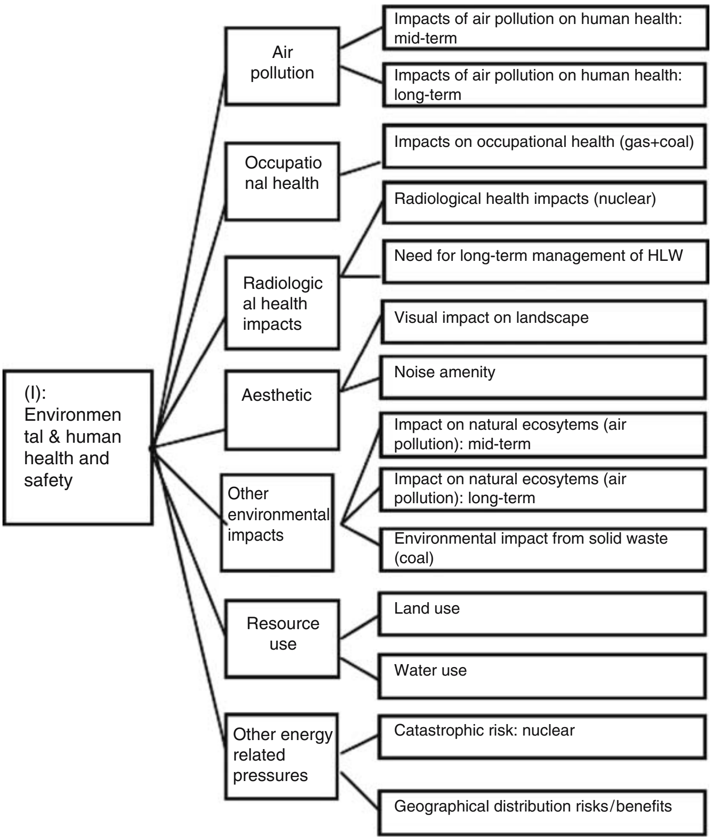

Fig. 2. Structured value tree ‘Environmental & human health and safety’

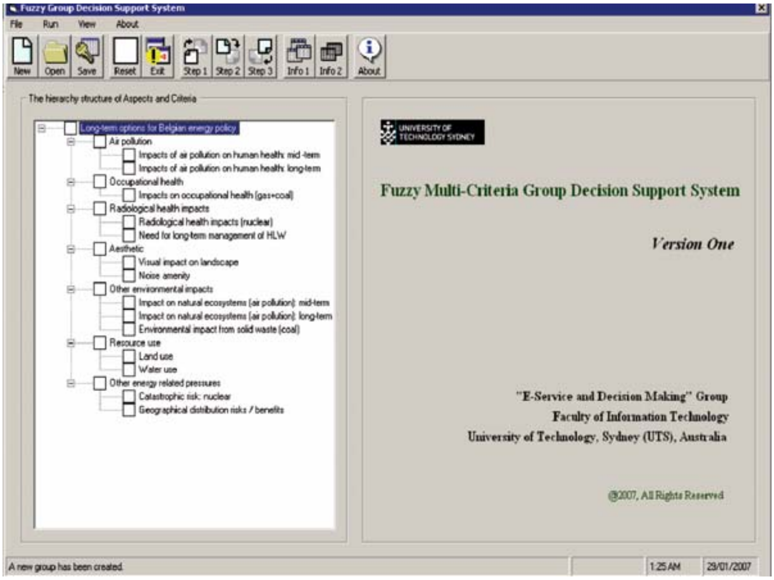

Fig. 3. Problem structure as represented in the FMCGDSS interface

performance do not depend on judgments of performance under other criteria (e.g. measuring carbon dioxide emissions can be done entirely independently of the measurement of any other air pollutant). We have tried to structure the 'combined value tree' in such way that this requirement was met. However, since the 44 bottom-level criteria were still phrased in a rather general way (particularly those relating to the 'social, political, cultural and ethical needs'), some degree of overlap could probably (at this stage) not be avoided[10]. Because working with 44 criteria at the same time would be generally unfeasible, we asked participants in the exercise to select from this list about 10–15 criteria which seemed to be most important to them. During the exercise, participants could also add new criteria or criticize chosen measurements for some of the criteria (and possibly even suggest others).

6 Scoring, Weighting and Application of an Aggregation Convention

The actual operation of the multi-criteria decision aiding system was framed in the context of individual interviews. Interviews usually lasted between 1 and 2 h. During the interview, an iterative process was undertaken, comprising: (a) a discussion of the scenarios developed for the multi-criteria exercise;

[10] Also as a result of the different framings of the same criterion adopted by participants in the exercise (as became apparent when questioned what a criterion precisely meant for them).

(b) a discussion of the combined value tree developed for the multi-criteria exercise (with possibilities for clarification and specification of new criteria); (c) the scoring of the performance of each scenario under a selection of criteria; and (d) the weighting of the criteria in terms of their relative importance as ‘matters of concern’ to the interviewee. The entire interview was organized in an iterative and reflexive way, so that participants were for instance able to add further comments on the scenarios while they were scoring criteria, or add new criteria along the way. In the context of this chapter, which deals mostly with methodological considerations, we will focus on the issue of scoring and weighting the decision criteria and aggregation procedures – since these often raise fundamental ethical questions (Sect. 6.1) – and explain how these issues have been dealt with formally (i.e. in a fuzzy-logic framework – Sect. 6.2).

6.1 Considerations on the Ethics of Scoring, Weighting and Aggregation

Since the aim of multi-criteria decision support is – obviously – to support (political) decisions, it is clear that procedural questions (‘who is making the decisions and how?’) in MC decision support carry an important ethical/political component which should be part and parcel of the reflection. These ethical considerations are discussed in depth in Laes ([12], Chap. 7); within the confines of this chapter we simply want to raise some of the most important questions and indicate the responses, without going into the details of the reasoning behind them.

With regard to scoring, we have already stressed that a policy support tool which aims to fulfill – at least up till a certain degree – standards of procedural fairness, must be able to integrate all sorts of interests and judgments of those stakeholders who stand to gain or loose from the outcomes of the decision. For a complex problem such as deciding on long-term strategies for sustainable energy, different legitimate representations of ‘the same’ system – using different (scientific) languages – co-exist. Engineers, economists, and stakeholders dealing with the ‘messiness’ of energy policy decisions in real-world political contexts will each have strongly divergent opinions on the framing of the decision problem[11]. Therefore, for the scoring of strategic options it is important to keep in that the ‘descriptive’ representation of a real-world system always depends on very strong assumptions about e.g. the purpose of the representation, the scale (local, regional, global) judged to be

[11] We might consider the example of nuclear safety (or conversely, the risk of a catastrophic accident in a nuclear power plant): the engineer will likely base his/her ‘scoring’ of this criterion on probabilistic considerations; the economist could base his/her opinion on the insurance premiums for nuclear power plant operation; while a politician or representative of a stakeholder organisation might base his/her opinion on e.g. testimonies from trusted sources, experiences with the effectiveness (or lack thereof) of regulatory organisms, social indicators such as the safety culture in nuclear power plants, etc.

relevant, and the set of dimensions used for the evaluation process. The experience in the context of Belgian long-term options for sustainable energy policy has shown that a multi-criteria framework can be a very effective tool for to implement a multi- or interdisciplinary approach. This is because the structuration of the decision problem in a multi-criterion fashion allows to set up a hierarchy of values (the decision value tree) coming from mixed information of the widest type (cf. Sect. 2.2) in which each stakeholder can recognize his/her perspectives and ability to pronounce meaningful scores on the different criteria. This also implies that stakeholders might very well be ignorant or indifferent about certain criteria scores (not each dimension will be equally relevant to all stakeholders), and that this aspect of the 'real-world' decision-making setting should also be addressed in the formal representation of it (cf. next section). Figure 4 gives the example of one particular stakeholder's input on all strategic alternatives under all criteria by linguistic terms. 'Cannot be determined' is a linguistic terms which is also accepted by the system.

The issue of criteria weighting is also hotly debated in the relevant scientific literature (see e.g. [2,20,26,27]. Broadly speaking, the debate often turns around the issue of 'commensurability'. Full commensurability means that an actor is able to rank all decision criteria using a principle of compensation showing an intensity of preference. This intensity of preference is revealed by indicating how much of an advantage on one criterion is sufficient for the

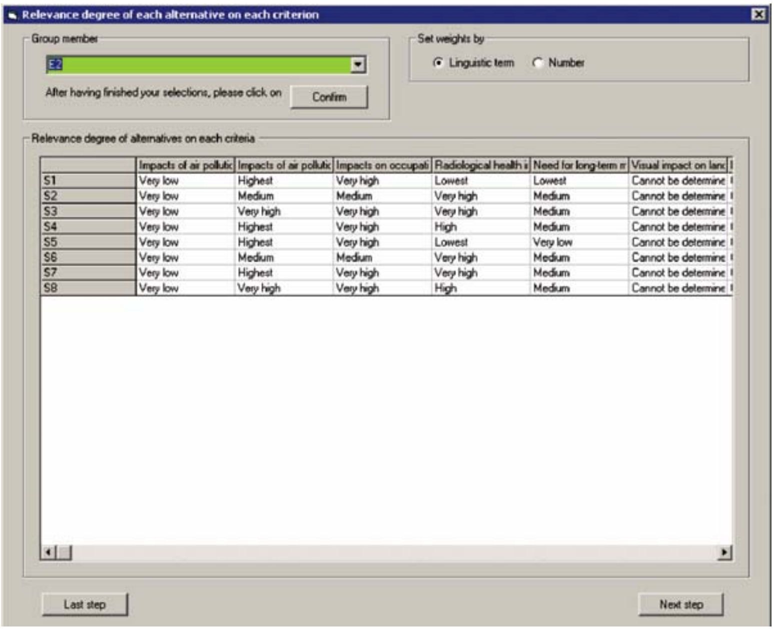

Fig. 4. Example of stakeholder 'belief matrix' (i.e. scores for all alternatives under all criteria)

actor to compensate a disadvantage on another criterion (one example might be the willingness to accept some health impact if it is compensated by a sufficiently high economic benefit). Incommensurability means that an actor is cannot be expected to attribute weights to criteria in any meaningful way, simply because the decision criteria are incomparable. Following Munda [21], we agree that full commensurability has to be rejected as a formal decision support principle. This is because any measurement of the 'intensity of preferences' (even in the sense of 'weak comparison' – e.g. pair-wise comparison of criteria as sometimes practiced in multi-criteria decision support) already implies an acceptance of the non-preferred, and therefore excludes deontological arguments of right or wrong which are omnipresent in our everyday ethical vocabularies (e.g. killing a person for most people is a matter of 'right or wrong') [24]. On the other hand, strict incommensurability also cannot be upheld in an ethically meaningful way, because in any act of decision making it is simply unavoidable to weigh different criteria, however implicitly this weighing might occur [19]. The position adapted in the framework we are proposing implies that weights can only be meaningful as 'importance coefficients'. In contrast to the trade-off approach, importance coefficients originate from non-compensatory elicitation procedures as they indicate how important a criterion is according to a particular actor without referring to compensation by means of another criterion. Figure 5 gives an example of the input of weights for different stakeholders and different levels of criteria.

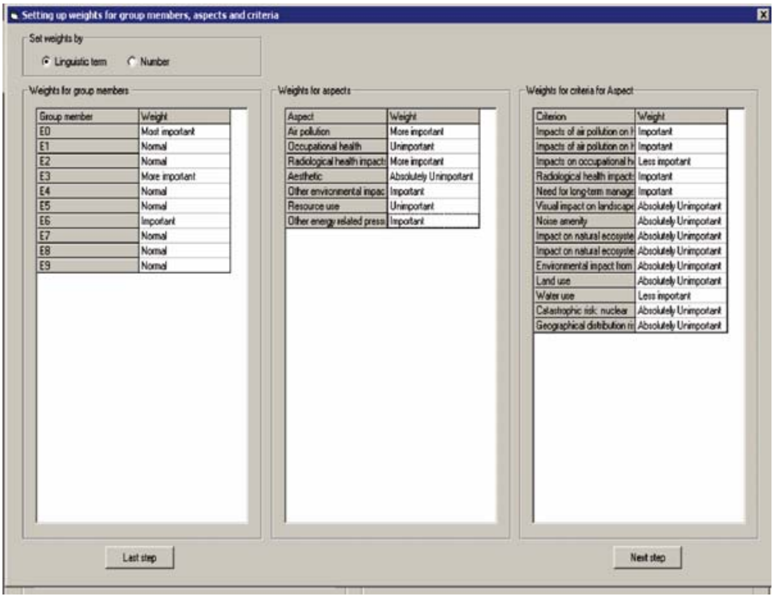

Fig. 5. Setting weights for stakeholders, aspects and criteria

Finally, the issue of ranking the decision alternatives is at least as contentious as the issue of deriving weights. Again, we can identify some 'extreme' positions in the debate. At one extreme, one might use decision support techniques to derive one 'most preferred' alternative, based on averaging scores and weights from all stakeholders. Having followed the argument in the previous sections, it will be clear to the reader that for pragmatic (since strong conflicts among various stakeholders are likely to occur) and ethical (since arriving at a 'most preferred' option necessarily relies on strong presumptions regarding the full commensurability of all criteria and stakeholder positions) reasons, presenting the results of the decision analysis *only* in these terms is less than desirable. On the other hand, one could also refrain from any analysis on the group (aggregate) level and just take each stakeholder position (as revealed in the criteria weightings and scores) separately. This kind of analysis can for instance reveal the structure of stakeholder reasoning, and can be used to check argumentative patterns for consistency and coherence. But of course, using a multi-criteria framework in this sense prevents one from tapping the potential wisdom of *group* decision making – the reason to use a group decision support tool in the first place! In view of the difficulties presented by both 'extreme' alternatives, we advocate a 'middle' position on the issue of ranking alternatives. This position includes: (a) a presentation of ranking results obtained by comparing the major ethical positions in the debate (e.g. the three 'narratives identified in Sect. 2.2) rather than presenting a single 'group result' or individual results for each stakeholder; (b) a check for possible 'social compromises' between different stakeholder positions[12]; and (c) sensitivity and robustness analysis based on the checking of the consequences on the final ranking of changing importance of criteria based on some clear ethical positions and not of all possible combinations of weights.

6.2 Formal Mathematical Representation in the FMCGDSS

This section discusses how the ethical requirements raised in the previous section are met by the formal representation of the decision-making process in a fuzzy multi-criteria group decision method. This method is developed based on previous studies in this field [15–17, 33, 34]. Put very briefly, 'fuzzy' multi-criteria group decision support is distinguished from more 'traditional' forms of multi-criteria analysis mainly because it uses fuzzy membership sets instead of crisp ones. Crisps sets are characterized by membership functions which assign a unique value to each individual member of a 'set' (e.g. members of the Belgian population can be either 'adult' or 'not adult' based on the 'crisp' criterion that they are either younger or older than 18 years). In contrast, a fuzzy set is a set whose elements have a continuum of grades of

[12] This can be done in formal mathematical terms by using a 'distance function' as a conflict indicator between different stakeholder positions for all possible pairs of stakeholders.

membership. In this case, the membership function assigns to each member of the set a grade of membership (e.g. based on more 'fuzzy' evaluation criteria prevalent in vernacular understandings of 'adultness' based on e.g. observable behavior, attitude, maturity etc. people anywhere between 0–30 years could conceivably be called 'non-adults'). It is clear that fuzzy sets allow for a better representation of vague concepts as expressed in natural language. Based on this philosophy, the FMCGDSS applied in the present case of long-term strategic options for the Belgian energy system can accept decision makers (group members)' input data (from interviews, questionnaires, databases, and direct entry) with or without uncertainties: numerical, linguistic, or missing values from a group of experts whose views may not agree with each other. It can also allow decision makers to give their evaluation criteria, which can be under a multi-level hierarchy structure. In a formal-mathematical sense, FMCGDSS's functioning is described as follows[13]:

Let $\boldsymbol{P} = \{\boldsymbol{P}_1, \boldsymbol{P}_2, \ldots, \boldsymbol{P}_n\},\ n \geq 2$, be a given finite set of decision makers to select a satisfactory alternative or identify a number of important issues with raking for a decision problem. The proposed method consists of 12 steps[14]:

Step 1: Generate Strategic Options

When a decision problem is proposed in a group, each group member can raise one or more possible strategies or alternative solutions. Let $S^* = \{S_1^{p_1}, S_2^{p_1}, \ldots S_{m_{p1}}^{p_1}, \ldots\ldots S_1^{p_n}, S_2^{p_n}, \ldots\ldots S_{m_{pn}}^{p_n}\}$, where $S_j^{p_i}$ is the jth alternative for the decision problem raised by group member p_i'. Through a discussion and summarization, $\boldsymbol{S} = \{\boldsymbol{S}_1, \boldsymbol{S}_2, \ldots, \boldsymbol{S}_m\},\ m \geq 2$ is selected from S^* as alternatives for the decision problem.

Step 2: Set up Weights for Stakeholders

As group members play different roles in an organization and therefore have different degrees of influence for the selection of the satisfactory group solution. That means the relative importance of each decision maker may not equal in a decision group. Some members are more important than others for a specific decision problem. Therefore, in the method, each member is assigned with a weight that is described by a linguistic term $\widetilde{v}_k,\ k = 1,\ 2,\ \ldots,\ n$.

[13] For illustrative purposes, here we discuss only the basic decision-making problem of arriving at a 'group satisfactory conclusion'. However, as discussed in Sect 6.1, other types of analysis (looking for social compromises, sensitivity and robustness checks, etc.) are for this type of decision problem at least as important. The FMCGDSS software is capable of supporting these kinds of analysis as well [16].

[14] Steps 1 and 2 - deciding on the strategic options for the decision problem at hand and deciding on the weights of the members of the decision-making group – have already been discussed in previous sections (Sects. 3 and 4); however we repeat them here for the sake of completeness.

These terms are determined through discussions in the group or assigned by a higher management level (say, the leader denoted as E0) before or at the beginning of the decision process. Possible linguistic terms used in the factor are *Normal, Important, More important*, and *Most important*.

Step 3: Set up Weights for All Aspects and Related Criteria

Referring to a set of aspects $F = (F_1, F_2, \ldots, F_n)$, let $WF = (WF_1, WF_2, \ldots, WF_n)$ be the weights of these aspects, where $WF_i \in \{$*Absolutely unimportant, Unimportant, Less important, Important, More important, Strongly important, Absolutely important*$\}$. Those weights are described by fuzzy numbers $\widetilde{a}_1, \widetilde{a}_2, \ldots, \widetilde{a}_n$.

For an aspect F_i, let $C_i = \{C_{i1}, C_{i2}, \ldots, C_{it_i}\}, i = 1, 2, \ldots, n$ be a set of the selected criteria with respect to the aspect F_i. Let $WC_i = \{WC_{i1}, WC_{i2}, \ldots, WC_{it_i}\},\ i = 1, 2, \ldots, n$, be the weights for the set of criteria, as shown in Table 1, where WC_{ij} will be signed a value from the same linguistic term list as WF_i above, which are described by fuzzy numbers $\widetilde{c}_1, \widetilde{c}_2, \ldots, \widetilde{c}_t$. For the example given in Fig. 2, '*Air pollution*' is an aspect of performance, two criteria to evaluate it are '*Impacts of air pollution on human health: mid-term,*' and '*Impacts of air pollution on human health: long-term.*'

Step 4: Set up the Relevance Degree of Each Alternative on Each Criterion

Let $A = (A_1, A_2, \ldots, A_m)$ be a set of alternatives, $AC_i^k = \left\{AC_{i1}^k, AC_{i2}^k, \ldots, AC_{it_i}^k\right\}$ be the relevance degree of alternative A_k on criterion $C_i,\ i = 1, 2, \ldots, n, k = 1, 2, \ldots, m$, where $AC_{ij}^k \in$ {Lowest, Very low, Low, Medium, High, Very high, Highest}, as shown in Table 2, which are described by fuzzy numbers $\widetilde{b}_1, \widetilde{b}_2, \ldots, \widetilde{b}_k$.

Table 3 further describes the relationships among these aspects, criteria, alternatives, their weights, and decision makers' evaluation values (scores).

Table 1. Linguistic terms and related fuzzy numbers for describing the weights of aspects and criteria

The importance degrees	Membership functions
Absolutely unimportant	a_1
Unimportant	a_2
Less important	a_3
Important	a_4
More important	a_5
Strongly important	a_6
Absolutely important	a_7

Table 2. Linguistic terms for preference of alternatives

Linguistic terms	Fuzzy numbers
Very low (VL)	b_1
Low (L)	b_2
Medium low (ML)	b_3
Medium (M)	b_4
Medium high (MH)	b_5
High (H)	b_6
Very high (VH)	b_7

Table 3. The relationships among the aspects, criteria, alternatives, their weights, and evaluation values

				A_1	...	A_m
		C_{11}	WC_{11}	AC_{11}^1	...	AC_{11}^m
F_1	WF_1	...	...	...	$\ddots$	...
		C_{1t_1}	WC_{1t_1}	$AC_{1t_1}^1$	...	$AC_{1t_1}^m$
...	...	...	...	...	$\ddots$	...
		C_{n1}	WC_{n1}	AC_{n1}^1	...	AC_{n1}^m
F_n	WF_n	...	...	...	$\ddots$	...
		C_{nt_n}	WC_{nt_n}	$AC_{nt_n}^1$	...	$AC_{nt_n}^m$

Step 5: Normalize the Weights for Criteria

The weights for the criteria $WC_i = \{WC_{i1},\ WC_{i2}, \cdots, WC_{it_i}\},\ i = 1, 2, \ldots, n$ are normalized and denoted as $WC_{ij}^* = \frac{WC_{ij}}{\sum_{j=1}^{t_i} WC_{ij_0}^R}$, for $j = 1, 2, \ldots, t_i,\ i = 1,\ 2, \ldots, n.$, where the $C_{ij_0}^R$ is the right end of 0-cutset.

Step 6: Calculate the Relevance Degrees

The relevance degree FA_i^k of the aspect F_i on the alternatives $A_k,\ i = 1, 2, \ldots, n,\ k = 1, 2, \ldots, m$, are calculated by using $FA_i^k = WC_i^* \times AC_i^k = \sum_{j=1}^{t_i} WC_{ij}^* \times AC_{ij}^k,\ i = 1, 2, \ldots, n,\ k = 1, 2, \ldots, m.$

Step 7: Normalize the Relevance Degrees

The relevance degrees FA_i^k of the aspect F_i on the alternatives $A_k,\ i = 1, 2, \ldots, n,\ k = 1, 2, \ldots, m$ are normalized based on $FA^k = \left\{FA_1^k,\ FA_2^k, \ldots, FA_n^k\right\},\ k = 1, 2, \ldots, m.$

$$\overline{FA}_i^k = \frac{FA_i^k}{\sum_{i=1}^{n} FA_{i\ 0}^{k\ R}},\ \text{for } i = 1, 2,\ \ldots, n, k = 1, 2, \ldots, m.$$

Step 8: Calculate the Aspect Relevance Degrees

The relevance degree S_k of the aspects F on the alternatives $A_k,\ k = 1, 2, \dots,\ m$ is calculated by using $S_k = \overline{FA}^k \times WF = \sum_{i=1}^{n} \overline{FA}_i^k \times WF_i\ k = 1, 2, \dots, m$. Here, S_k is still a fuzzy number.

Step 9: Normalize Weights for Decision Makers

Each member $\boldsymbol{P}_k$ has been assigned with a weight already that is described by a linguistic term $\widetilde{v}_k,\ k = 1,\ 2, \dots, n$ as shown in Table 3. A weight vector is obtained:

$$V = \{\widetilde{v}_k, k = 1, 2, \dots, n\}.$$

The normalized weight of a decision maker $\boldsymbol{P}_k$ $(k = 1,\ 2, \dots,\ n)$ is denoted as

$$\widetilde{v}_k^* = \frac{\widetilde{v}_k}{\sum_{i=1}^{n} v_{i\ 0}^{R}},\ \text{for } k = 1, 2,\ \dots, n.$$

Step 10: Construct the Normalized Fuzzy Decision Vector

Considering the normalized weights of all group members, we can construct a weighted normalized fuzzy decision vector

$$(\widetilde{r}_1, \widetilde{r}_2, \dots, \widetilde{r}_m) = (\widetilde{v}_1^*, \widetilde{v}_2^*, \dots, \widetilde{v}_n^*) \begin{pmatrix} \bar{b}_1^1 & \bar{b}_2^1 & \dots & \bar{b}_m^1 \\ \bar{b}_1^2 & \bar{b}_2^2 & \dots & \bar{b}_m^2 \\ \vdots & \vdots & \ddots & \vdots \\ \bar{b}_1^n & \bar{b}_2^n & \dots & \bar{b}_m^n \end{pmatrix},$$

where $\widetilde{r}_j = \sum_{k=1}^{n} \widetilde{v}_k^* \bar{b}_j^k$.

Step 11: Calculate the Positive and Negative Solution Distances

In the weighted normalized fuzzy decision vector the elements $\widetilde{v}_j,\ j = 1, 2,\ \dots, m$, are normalized as positive fuzzy numbers and their ranges belong to the closed interval [0, 1]. We can then define a fuzzy positive-ideal solution (FPIS, r^*) and a fuzzy negative-ideal solution (FNIS, r^-) as:

$$r^* = 1 \text{ and } r^- = 0.$$

The positive and negative solution distances between each $\widetilde{r}_j$ and r^*, $\widetilde{r}_j$ and r^- can be calculated as:

$$d_j^* = d(\widetilde{r}_j, r^*) \text{ and } d_j^- = d(\widetilde{r}_j, r^-),\ j = 1, 2,\ \dots, m,$$

where d (.,.) is the distance measurement between two fuzzy numbers.

Step 12: Calculate the Closeness Coefficient

A closeness coefficient is defined to determine the ranking order of all alternatives once the d_j^* and d_j^- of each $\boldsymbol{S}_j (j = 1, 2, \ldots, m)$ are obtained. The closeness coefficient of each alternative is calculated based on:

$$CC_j = \frac{1}{2}\left(d_j^- + (1 - d_j^*)\right),\ j = 1, 2, \ldots, m.$$

The alternative $\boldsymbol{S}_j$ that corresponds to the $Max(CC_j, \mathrm{j} = 1, 2, \ldots, m)$ is the best satisfactory solution of the decision group, and the top N issues that correspond to the top N higher raking CC_j are the critical issues to consider for the decision problem.

7 Conclusions

Decision support tools for a complex policy problem such as the assessment of long-term strategic options for sustainable energy has to face a number of complex challenges. On the empirical side, the tool has to face conditions of imperfect knowledge (e.g. lacking data), different problem framings, strained relations between major stakeholders involved in the policy issue, uncertainties over long-term evolutions, etc. On the normative side, the tool has to support basic principles of sustainability, e.g. developing a global long-term view, supporting meaningful participation by stakeholder groups, enabling transparency and accountability, etc. In this chapter, we argue that the software tool FMCGDSS is able to meet these fundamental methodological requirements. It can accept input data (from interviews and questionnaires from various sources) with or without uncertainties: numerical, linguistic, or missing values from a group of experts whose views may not agree with each other. From the input data, FMCGDSS can generate overall evaluation and any individual expert evaluation in any category or subcategory. All the outcomes can be displayed graphically. If there are different weights assigned to criteria, alternatives, and stakeholders, the FMCGDSS software can automatically deal with all conflict situations. We strongly believe the FMCGDSS tool will be useful for the sustainability impact assessment of energy systems in particular and for any complex decision problem in general.

Acknowledgements

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