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SCIENCE FOR A SUSTAINABLE DEVELOPMENT

SUSTAINABLE ENERGY POLICY INTEGRATED ASSESSMENT

"SEPIA"

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ENERGY

FINAL REPORT

SUSTAINABLE ENERGY POLICY INTEGRATED ASSESSMENT "SEPIA"

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ACRONYMS

EC	European Commission
EU	European Union
ISA	Integrated Sustainability Assessment
LEAP	Long-Range Energy Alternatives Planning system
MC	Multi Criteria
OR	Operational Research
SA	Sustainability Assessment
SBG	Scenario Builders Group
SD	Sustainable Development
SHP	Stakeholder Panel
SIA	Sustainability Impact Assessment
SMCE	Social Multi-Criteria Evaluation

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SUMMARY

1. Context

Enabling the transition towards a more sustainable energy future represents a huge challenge requiring strategic scientific information. Scientific support of opinion formation and decision making on sustainable development has however important different characteristics than the ones of 'traditional' science for policy. Sustainability's normative character, inseparable connection with deep-rooted value patterns, long-term nature of most relevant developments, and necessary inclusion of societal actors, result in specific demands on science for sustainability. SEPIA addresses such needs in the field of long-term energy policy. Although part of the project results were contingent on specifics of the Belgian context, the project is embedded in the wider context of European and global energy system governance debates.

2. Objectives

The goal of the study is to make accessible and discuss the feasibility of performing an integrated sustainability assessment of Belgian long-term energy system development, in order to identify consensus and dissent in the possible integrated sustainability assessment design among different stakeholder groups, and thus to provide the basis for an integrated sustainability assessment procedure adapted to the context of Belgian energy governance (as embedded in a multi-level governance structure). The SEPIA project is guided by the following methodological principles:

- Long-term energy foresight from a normative perspective (using a back-casting approach);
- **Planetary scope** by using the global perspective as the point of departure for defining sustainability criteria;
- Stakeholder participation in all project phases (from problem definition to evaluation of policy proposals);
- **Integrated energy system assessment** – from energy services to primary energy demands, covering full life-cycle stages of energy technologies;
- **Interdisciplinary** by integrating expertise in economics, engineering, sociology and ethics;
- **Systematic attention for uncertainties**.

The SEPIA methodology unfolded in three phases:

In a **first phase**, we analysed the methodological ‘state of the art’ in the domains of (international, European, national or regional) energy foresight, criteria & indicators of sustainable development (necessary for ‘measuring’ energy system progress towards a more sustainable state) and the development of an integrated ‘value tree’ of sustainability criteria encompassing arguments stemming from diverse value premises.

A **second phase** led to the (qualitative) definition of a ‘manageable’ number of representative long-term energy scenarios for a sustainable development of the Belgian energy system by a group of expert scenario builders. This phase was supported by a series of in-depth deliberative discussions (workshops) using a range of qualitative research techniques (expert panel, scenario workshop, focus group) involving both stakeholders and energy experts.

In a **third phase**, the scenarios and the integrated value tree were used together in a multi-criteria evaluation by the stakeholder panel. Two transparent, user-friendly and real-time tools contributed to the project in a participative way: an energy accounting simulation model (LEAP) and a multi-criteria group decision support tool (DECIDER).
In parallel to phase 1-3, a case study was elaborated on the past, present and possible future of Belgium’s nuclear energy policy.

3. Conclusions

Sustainability assessment of energy policy strategies is performed at the interface between scientific theory-building and political practice. Therefore, practical sustainability assessments are judged by criteria like scientific soundness, political legitimacy and practicability (in a real political setting). In this section, we offered a reflection on how such criteria could be met by a discursive approach using a combination of decision support tools. However, the ‘burden of proof’ for such a discursive approach is heavy. Indeed, we hereby presume that deciding on an appropriate (i.e. sustainable) long-term energy strategy is at least a suitable ‘test case’ for a more deliberative (discursive) governance arrangement, *ergo* that it is not *a priori* better handled by alternatives such as (a combination) of free market competition, lobbying and/or direct government regulation (top-down ‘government’ as opposed to bottom-up ‘governance’). Further in-built presuppositions include that some particular composition of actors is thought to be capable of making decisions according to (voluntarily accepted and consensually deliberated) rules, that will resolve conflicts to a maximum extent possible and (ideally) provide the resources necessary for dealing with the issue at hand. Moreover – next presupposition – that the decisions once implemented will be accepted as legitimate by those who did not participate and who have suffered or enjoyed their consequences. All together, substantiating the quality of the SEPIA approach is challenging, in theory and in practice, as documented by the following observations.

On a theoretical level, the SEPIA methodology aligns with insights derived from ecological economics, decision analysis, and science and technology studies, favouring the combination of analytical and participatory research methods in the field of ‘science for sustainability’. This view is motivated by sustainability problems being multi-dimensional (thus limiting the use of only monetary cost-benefit analysis), of a long-term nature (thus involving significant uncertainties) and applying to complex socio-economic and biophysical systems (thus limiting the use of mono-disciplinary approaches). SEPIA shows the advantages of combining a (hybrid backcasting) scenario approach with a (fuzzy logic) multi-criteria decision aiding tool. Scenario exploration allows taking into account the (socio-economic and biophysical) complexities of energy system development so that uncertainties on the long term can be explored. Multi-criteria methods, and especially those based on fuzzy-set theory, are very useful in their ability to address problems that are characterised by conflicting assessments and have to deal with imprecise information, uncertainty and incommensurable values. Both methods are supported by a large body of scientific literature, ensuring that an effective check of ‘scientific soundness’ can be made through the peer review process. However, the application of these methods, and especially their participatory nature, are challenging in practice. For instance, the combination of narrative scenario building and quantitative modelling in theory necessitates the need for a deliberative consensus on all parameters used in the model, which in practice turns out to be impossible to organise (the LEAP model requires hundreds of inputs). The scenario development phase as it was already turned out to be time intensive for stakeholder participants. We struggled with non-participation and dropouts of stakeholders; without proper investigation we cannot explain why participation fluctuated as it did. However, at least part of the explanation can probably be found in the general impression that the potential players in the Belgian energy system transition landscape – how limited their number may be – are rather scattered. In Belgium (as in many other countries), energy problems cross a varied set of policy domains and agendas, such as guarding the correct functioning of liberalised energy markets, promoting renewables, environmental protection, climate policy etc. These are dealt with by different administrative ‘silos’ and analysed by separate groups of experts and policymakers. As a result of this fragmentation, a lot of the key players struggle with overloaded agendas, organisation specific expectations and performance criteria and hence find no time for explicit reflective/exchange moments in the context of a scientific project not directly connected to any actual decision-making process. There may be many contacts on the occasion of events and by communication means, but there is not a structured exchange of experiences, knowledge and mutual feedback (‘structured’ in the sense of embedded in a culture of working methods). This impression of fragmentation sharply contrasts with the high priority assigned to institutionalised networks and collaboration as advocated in the above-mentioned theoretical strands of literature. Perhaps the best way to sum up the findings so far is: assessing scenarios in the form of transition pathways towards a sustainable energy future with the aid of a participatory fuzzy-logic multi-criteria decision aiding tool certainly has the potential to support a more robust and democratic decision-making process, which is able to address socio-technical complexities and acknowledges multiple legitimate perspectives. However, these methods are time- and resource intensive and require the support of adequate institutional settings for a proper functioning in real political settings. Participation in integrated energy policy assessment should therefore not be taken for granted. We hope that the experience gained so far in the context of the SEPIA project will allow future initiators of similar participatory projects to level the project objectives, the participants’ expectations and the political backing with each other, a prerequisite for successful participation in foresight exercises.

4. Contribution of the project in the context of decision support for sustainable development

Project results include a structured value tree to assess the sustainability of energy system development; a set of visions and scenarios for sustainable energy development and a reflection on the policy measures which could be implemented to realise those visions. In addition, the project delivered important methodological insights in the field of sustainability assessment. Also, in the course of the SEPIA project, a LEAP-based model of the Belgian energy system was built.

5. Keywords

Sustainability assessment, long-term energy scenarios, multi-criteria assessment, participation

1. INTRODUCTION

In common with all industrialised nations, Belgium is currently ‘locked’ into an energy- and carbon intensive economic system. All of our most important energy technologies, institutions, infrastructure and networks have evolved in the context of this system. Keeping this in mind, achieving a sustainable and low-carbon energy future will require new ways of thinking about the energy system, our levels of demand for energy services and how this demand is met. This in turn requires the development of long-term energy scenarios, which are needed to support the development of well-founded and coherent policy decisions, to direct long-term investments, and to anticipate the necessary societal change. To this end, the SEPIA approach has developed an ‘integrated sustainability assessment’ (ISA) methodology to evaluate possible energy system developments, and has applied this in the Belgian context. This overall aim encompasses a number of more specific objectives:

- To integrate the findings from the wide range of sustainability assessment theory and practice and apply this to the context of energy system development;
- To consider the transition to a sustainable (and hence substantially decarbonised) Belgian energy future in 2050 with the input of energy experts and stakeholders, starting from defined endpoints (‘visions’) in order to articulate scenario ‘pathways’ by which these visions could be achieved;
- To investigate less constrained approaches to scenario development than those which inform the majority of current long-term energy scenarios (foresight methodologies based on economic optimising calculations), allowing for an input from a variety of perspectives, knowledge and disciplines enriching them;
- To assess the consequences and implications of the different scenarios and the trade-offs between them by means of a suitable multi-criteria assessment framework;
- To reveal preferences of different stakeholders for the different scenarios, and to reveal possible opinion clusters & coalitions.

Energy system foresight is of course not new in the Belgian context. Relevant research includes:

- A study of the Fraunhofer Institute concentrated on the role of the demand reduction to achieve the Kyoto targets. According to this institute, Belgium can reach those targets by an efficient implementation of existing – in the EU –

measures (minimum energy performance standards, voluntary agreements, benchmarking covenants, energy/CO_2-taxation…) (Fraunhofer Institute, 2003);

- A study of the Federal Planning Bureau (FPB) used a combination of a macro-economic forecasting methodology (horizon 2020) and a normative back-casting methodology (horizon 2050) to formulate recommendations for Belgium’s long-term climate policy (Federaal Planbureau, 2006);
- The “Commission Energy 2030” (CE2030) has provided the Belgian government with guidelines and recommendations so as to guarantee a ‘reliable, clean and affordable’ energy provision system. (www.ce2030.be). The CE2030 relies on macro-economic modelling to analyze the long-term evolution of the Belgian energy system. As a base scenario, it uses the existing demographic and economic trends, and, based on those trends, the CE2030 makes a projection of the evolution of the energy demand, production capacity and technology, emissions, etc. In alternative scenarios, the impact of changing parameters like fuel prices, energy policy measures, cancelling the nuclear phase-out law, etc. is analyzed (CE2030, 2007);
- The directorate Energy of the Belgian federal public service “Economy” in cooperation with the Federal Planning Bureau has published a prospective analysis of electricity supply over the period 2008-2017 (FOD Economie / Federaal Planbureau, 2009). This analysis uses a range of energy system models to study electricity demand and supply variants for the next decade.

However, none of these analyses is carried out from a transition management perspective: there is no construction of visions preceding strategy development; the timeframe adopted is frequently to short for transition planning; and stakeholder participation is only conceived of in terms of traditional consultation processes once the study has been finalized. The long-term energy future envisioning and scenario building proposed in SEPIA is thus certainly innovative in the Belgian context, while many lessons were learnt from practices in other countries (e.g. in the UK, the Netherlands, Finland).

2. METHODOLOGY AND RESULTS

2.1. Introduction

SEPIA investigates decision support methodologies, procedures, structures and tools for a sustainable energy policy with a focus on stakeholder involvement. It combines participatory fuzzy-set multi-criteria analysis with narrative scenario building and (quantitative) energy system modelling using the LEAP model[1]. The goal of SEPIA is to develop and discuss the feasibility of the main components of sustainability assessment in the Belgian energy policy context. Identifying elements of consensus and of dissent across stakeholder groups about possible designs of sustainability assessment provides a basis for a sustainability assessment procedure adapted to the Belgian energy governance, particularly embedded in a multi-level governance structure. SEPIA explicitly acknowledges socio-political and normative backgrounds of participants in the debate on energy issues and choices, including sustainable energy.

The project encompassed 4 phases, running over three years (Jan. 2008 – Dec. 2010): i) methodological reflections on sustainability assessment (Jan. 2008 – June 2008); ii) participatory construction of long-term sustainable energy futures and a value tree including sustainability criteria (July 2008 – June 2009); iii) deliberation on these futures with the aid of a fuzzy-set multi-criteria decision support tool (July 2009 – June 2010); and iv) reporting and dissemination of results (July 2010 – Dec. 2010). Sustainability assessment of long-term energy scenarios using qualitative and quantitative data and multi-criteria decision tools requires both a ‘holistic’ and a ‘partial’ assessment (i.e. an assessment of both the ‘whole picture’ presented by a scenario storyline as well as the different dimensions of sustainability). Also stakeholders must accept the assessment as methodologically sound and legitimate. This chapter discusses from a conceptual and methodological perspective the challenges in providing explanatory, orientation and reflexive knowledge for devising sustainable energy strategies.

We proceed from an overview of the ‘state-of-the-art’ of sustainability assessments as the general framework for our work (Section 2.2). The following sections discuss the methodological choices made in the project w.r.t. foresight (Section 2.3) and multi-criteria decision support (Section 2.5). Section 2.4 discusses the scenarios

[1] LEAP stands for ‘Long range Energy Alternatives Planning system’. LEAP is an integrated modelling tool that is used to track energy consumption, production and resource extraction in all sectors of an energy economy. More information on LEAP is available at <www.sei-international.org/leap-the-long-range-energy-alternatives-planning-system>.

developed in the course of the project, while Section 2.6 gives details on the results of the multi-criteria assessment of these scenarios by stakeholders. Section 2 ends with conclusions and observations and offers reflections on future research needs (Section 2.7).

2.2 Integrated sustainability assessment as a general framework for reflection

By now, sustainable development has become widely accepted as an overarching long-term objective figuring high on international, regional and national policy agendas. Notwithstanding this widespread institutional success, the international policy-making process and that of individual countries remains largely sectoral in nature – i.e. a wide variety of (inter)national policies continues to pursue narrow sectoral concerns and do not consider in an integrated way their contribution to the achievement of broader sustainability targets. At the interface between science and policy, progress has been made to address this problem. New policy evaluation tools such as 'Sustainability Impact Assessment' (SIA) have been adopted by the European Union (EU) to ensure that sectoral policies can be evaluated in relation to their wider sustainability impacts. However, *avant-garde* academic thinking on the subject maintains that what is really needed is a cross-sectoral approach to assessing sustainable development at a higher, much more strategic level: 'Integrated Sustainability Assessment' (ISA) (see e.g. the EU-sponsored MATISSE project[2], or at the Flemish regional level the scientific support work done for the "Steunpunt Duurzame Ontwikkeling")[3]. Put very briefly, SIA can be conceptualised as a sequential, linear process aimed at assessing and mitigating the potential adverse (social, environmental and economic) impacts of certain policy instruments (i.e. policy measures, plans, strategies, objectives, standards, etc.), whereas ISA is conceived of as an iterative, long-term, pro-active and explorative framework for the *ex ante* assessment of policy instruments against fundamental sustainability objectives. Therefore, SIA is intended to be a short-term and practical approach, whereas ISA should be seen as a long-term explorative framework, which (in view of the more innovative character of this approach) in turn prompts the need for new assessment tools and methods.

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[2] The MATISSE (Methods and Tools for Integrated Sustainability Assessment) project is funded by the European Commission, DG Research, within the 6th Framework Programme. The project is interested in the role that Integrated Sustainability Assessment (ISA) could play in the process of developing and implementing policies capable of addressing persistent problems of unsustainable development and supporting transitions to a more sustainable future in Europe. The core activity of MATISSE is to develop, test and demonstrate new and improved methods and tools for conducting ISA. This work is carried out through developing and applying a conceptual framework for ISA, looking at the linkages to other sustainability assessment processes, linking existing tools to make them more useable for ISA, developing new tools to address transitions to sustainable development and applying the new and improved tools within an ISA process through a series of case studies.

[3] The "Steunpunt voor duurzame ontwikkeling" operates a website: <http://www.steunpuntdo.be/SDO_engels.htm>. See in particular Research Project 8, co-ordinated by VUB-MEKO, on the evaluation of SA approaches and their applicability in the Flemish context.

The energy sector, with its historic (worldwide) one-sided focus on the development of the supply system (at the detriment of a demand-side approach) and the resulting social and environmental problems can certainly be seen as an appropriate 'test-case' for sustainability assessment.

2.2.1 Planning, networking and ‘futuring’

Integrated assessment in the context of sustainability is necessarily predicated (to a greater or lesser extent) on ‘foresight’ abilities, i.e. of thinking, shaping or debating the future. This is quite clear on an intuitive level: despite the obvious uncertainties inherent in any attempt at ‘foreseeing’ the future, some form of future anticipation is simply implied in human decision making of all sorts, as is evident in associated notions of intentionality, accountability, responsibility, etc. which are all necessarily predicated on assumptions of a (certain degree of) anticipation. More specifically, according to Meadowcroft (1997, pp. 429-431) foresight in integrated sustainability assessment relates to a mix of planning, networking, and futuring activities:

- Planning is needed because it is generally assumed that sustainable development (in any field) is unlikely to be achieved by spontaneous social processes, or as the ‘unintended consequences’ of seeking other ends (e.g. maximising profits in markets). Therefore, sustainable development requires the explicit attention and intervention of some ‘governing agency’. The foresight component of planning relates to exploring possible futures or developing visions for the future, identifying possible impacts of certain policy measures, testing the robustness of policy measures under different imaginable futures, etc.;
- Networking is needed because governments alone cannot bring about the sweeping changes needed for a (more) sustainable development, but depend on a host of other actors (e.g. business, labour unions, NGOs, the media, etc.). The foresight component of networking relates to deepening dialogue on problem framings, mapping different problem definitions and checking for societal support, looking for future possibilities to surpass or reconcile conflicting views, etc.;
- Futuring (defined as the ensemble of methodologies or support tools to help reflecting on the future) is needed because the realisation of sustainable development requires ‘methodological attitudes’ to deal with an uncertain future, since governments must act in a consistent way over time to realise policy objectives.

Integrated sustainability assessment involves different types of knowledge flows within each activity and across activities; therefore different types of information, audiences and processes are expected, as illustrated in the next section.

2.2.2 ‘Policy as calculus’ and ‘policy as discourse’

The different approaches to integrated sustainability assessment can be illustrated further by situating them within the wider governance framework in which these assessment processes play a role. Paredis et al. (2006) make a useful distinction between two ideal-typical governance ‘styles’ – called respectively “**Policy as calculus**” and “**Policy as discourse**”. These ‘styles’ illustrate the two extremes of a spectrum of choices available to policy makers interested in setting up governance mechanisms for sustainability. They see sustainable development as a wider process of change engaging with an entire network of (policy, commercial, civil society, etc.) actors, institutions, technical artefacts, etc. However, both perspectives differ in the way they approach the generation of strategic (i.e. explanatory, orientation and reflexive) knowledge needed for steering this change process in the direction of a sustainable future. Put very briefly, ‘Policy as calculus’ represents a ‘closed’ process heavily predicated on expert input and agreement, whereas ‘Policy as discourse’ ‘opens up’ to a wider range of actors, disciplines and concerns. Both perspectives are compared on a number of attributes in Table I. A SWOT analysis is made in Table II.

“Policy as calculus” assumes that knowledge-based decision support – and the decision processes built on this support – can be conceptualised separately from its ‘socio-technical object’ (e.g. the energy system). For recommending how to steer socio-technical change in more sustainable directions, expert analysts should ‘step outside’ the system to objectify its workings. Governance is characterised in terms of exogenous ‘mechanistic’ interventions. In all of this, an important role is attributed to ‘expert input’. This does not exclude stakeholder involvement for providing ‘inputs’ to the assessment process. But separate stakeholders are assumed of holding a ‘jigsaw puzzle’ piece that experts collect and layout to compose a picture of the ‘socio-technical object’. As such stakeholders are no more than ‘carriers’ of policy alternatives, information, and value judgements. It is assumed that all stakeholders observe ‘the same’ object, but they each tend to prioritise or focus on a limited set of aspects related to this object. Once the relevant pieces of the puzzle are collected (i.e. e.g. objectives are clearly defined and agreed upon, all necessary data are available, cause-effect relations are established, etc.), the ‘solution’ to the governance problem follows ‘logically’ from aggregating the different perspectives by using for example economic optimisation models, multi-attribute utility theory, etc.

Table I. Two different views on governance for sustainability (based on Paredis et al., 2006; Smith & Stirling, 2007)

	Policy as calculus	Policy as discourse
Role of sustainability assessment	**Sustainability assessment as a tool for selecting the best alternatives in order to reduce negative sustainability impacts**	**Sustainability assessment as a framing process of deliberation on ends and means**
What matters for political planning?	**Uniform solutions based on technical and economic expertise**	**'Framings', deliberation, perspective-based testing of hypotheses involving a wide range of disciplines (including but not limited to economics and engineering)**
Leading actors (networking)?	**Context-dependent, with a focus on academics (with demonstrable expertise in the relevant scientific disciplines) and government actors**	**Context-dependent, with a focus on experts (e.g. academics, professionals with experience in relevant fields, etc.), stakeholders (representative of the different 'problem framings'), and government actors**
Foresight methods?	**Mostly quantitative (i.e. modelling), explorative trend analysis (based on 'what if' reasoning)**	**Mostly qualitative (i.e. sociological) analysis (based on 'what is desirable' reasoning) with quantitative analysis as a support**
	Government actors and/or stakeholders as 'clients'	**Government actors and/or stakeholders providing crucial inputs**
Methods and tools (futuring, planning, networking)	**'Standard' scientific methods, e.g. mathematical models, cost-benefit analysis, cost-effectiveness analysis, checklists, matrices**	**Deliberative methods (e.g. scenario workshops, expert panels, focus groups, etc.) with 'standard' scientific methods as supportive**
What is maximised?	**Planning – i.e. simple anwers to complex problems, clear-cut recommendations about specific proposals**	**Networking – i.e. interdisciplinary scientific knowledge, participation, deliberation, individual and societal learning effects**
Procedurally effective if…	**The optimal alternative has been identified** **Trade-offs are based on scientifically tested methodologies** **The proposal is of better quality (in the sense that negative impacts are avoided or mitigated) after the realisation of the assessment**	**Ideally, the deliberative process produces consensus by actually changing minds through reasoned argument** **A political community has been created around an issue** **Decision-making culture and practice have changed** **Sustainability assessment is iterative and fully integrated within the policy process, giving adequate and timely inputs to policy formation** **Transformative effect – acceptance of new goals and guiding principles for the energy transition**

Procedurally efficient if...	**A solution is found with minimum expenditure of available resources (time, money) and expertise (state-of-the-art knowledge) for the sustainability assessment**	**The sustainability assessment is carried out according to a clear and achievable timetable, giving enough time and resources for preparation of the process and stakeholder engagement**
Procedurally fair if...	**The recommended alternative(s) are justified by established expert authority, e.g. accredited research institutes, peer review, lauded academics, etc.**	**No legitimate point of view is excluded a priori from the assessment** **Power differentials between social actors are neutralised**

Table II. SWOT of 'policy as calculus' and 'policy as discourse'

	Policy as calculus	Policy as discourse
Strengths	**Practical instrument resulting in univocal recommendations from a 'narrow' framing perspective** **Part of the existing decision-making process in many countries**	**Sustainability raised as a collective concern** **Improved decision-making process**
Opportunities	**Political demand for this kind of exercises** **Use of existing knowledge and know-how** **Practical experience with similar exercises (Environmental Impact Assessment, Regulatory Impact Assessment)**	**Can build on existing participatory arrangements** **Scientific and political momentum in favour of sustainable development; acceleration of global change signals calls for ambitious action**
Weaknesses	**Attempt to include all aspects of sustainability in quantitative models faced with difficulties: unavailable data, uncertainties, etc.** **Environmental, governance and equity concerns are marginalised** **Acceptance of unlimited substitutability implies 'weak sustainability'**	**Representativeness of involved and missing stakeholders** **Potential to yield practical recommendations in due time** **Difficult to institutionalise** **Additional (and multidisciplinary) expertise, data, tools and time required compared to 'policy as calculus'**
Threats	**Technocracy and bureaucracy** **Reductionist perspectives are encouraged** **Risk of imbalance towards incremental approaches and consequent marginalisation of long-term sustainable development objectives**	**Lack of practical experience in conducting sustainability assessment exercises, leading to unrealistic expectations** **Manipulative interventions by some participants, eventually ending in demagogy** **Resistance against potentially transformative power of the sustainability assessment**

The appraisal process ‘closes down’ on the single socio-technical object – i.e. it is about “…*finding the right questions, recruiting the appropriate actors (actors with ‘relevant’ insights), highlighting the most likely outcomes and therefore also defining the best options*…” (Smith and Stirling 2007, p.6). Once the appraisal procedure has aggregated all relevant information, the instruments for intervening in the dynamics of socio-technical objects follow mechanically (e.g. when economic evaluation finds nuclear power as ‘best option’ policy instruments must clear the ‘barriers’ of a full nuclear deployment). Politically this approach implies that ‘relevant actors’ bring their commitments in line with the recommendations from the appraisal. The alignment job is left to the political decision makers, in devising appropriate tools to persuade, entice or simply force actors to realize the path set out by ‘the experts’.

“Policy as discourse” starts from the premise that there is no unique ‘objectively rational’ position from which a ‘socio-technical object’ (e.g. the energy system) can be observed. System boundaries, interrelations between system components, opinions on what causes change, etc. (in short: ‘framings’) vary according actor perspectives, and may change during various stages of the appraisal. Because different ‘framings’ imply different methodologies for arriving at ‘relevant’ knowledge about the ‘socio-technical object’, input to the sustainability assessment cannot be ‘imposed’ but has to be negotiated. The same applies for the criteria guiding the sustainability assessment, which have to be checked for legitimacy and acceptance. Assessment does not identify the ‘best possible’ pathway for the evolution of the ‘socio-technical object’, but rather tests its evolution under the different ‘framings’ brought to the table by stakeholders. As a consequence, no unique set of ideal policy instruments can be identified; recommendations will always be much more ‘conditional’ (e.g. ‘*option x is the preferred option under framings a and b, but does not score well under framing c*’, ‘*option y scores rather well under all framings, and can therefore be considered as a robust option*’, etc.).

The difference between ‘policy as calculus’ and ‘policy as discourse’ should not be conceived along the lines of a stark dichotomy between “…*established, narrow, rigid, quantitative, opaque, exclusive, expert-based, analytic procedures tending to privilege economic considerations and incumbent interests*…” and the “…*new, relatively unconstrained, qualitative, sensitive, inclusive, transparent, deliberative, democratically legitimate, participatory processes promising greater emphasis on otherwise marginal issues and interests such as the environment, health, and fairness*…” (Stirling 2008, p. 267). To support this point of view, Stirling points out some examples of ‘bottom-up participatory initiatives’ by design which in their practical implementation and outcomes are better understood as ‘top-down exercises in legitimation’, and conversely also of ‘expert-based analytic processes’ which are more conducive to enhanced social agency than their participatory counterparts. In other words, according to Stirling (2008) the detailed context and implementation of a particular governance approach are more important factors to understand what happens in practice. Instead of an illustration of the opposition between an ‘expert-based’ and a ‘deliberative’ governance approach, the difference between ‘policy as calculus’ and ‘policy as discourse’ should be seen as illustration of how assessments and/or commitments can be ‘closed down’ (in the case of ‘policy as calculus’) or ‘opened up’ (in the case of ‘policy as discourse’) in an institutional environment which is structured and pervaded by power relationships. If appraisal is about ‘closing down’ the formation of commitments to policy instruments or technological options, then the aim of the assessment is to assist policy makers by providing a direct means to justify their choices. If, on the other hand, the assessment is aimed at ‘opening up’ a process of social choice, then the emphasis lies on revealing to the wider policy discourse any inherent indeterminacies, contingencies or capacities for action. Of course, expert-based analytic approaches such as cost-benefit or cost-effectiveness assessment are frequently practiced as part of a ‘policy as calculus’ approach, but these techniques might equally lend themselves to an ‘opening up’ philosophy (Stagl 2009).

In order to define adequately which features of both ‘philosophies’ SEPIA should adopt, a thorough analysis of the existing energy policy context and the institutional landscape is a prerequisite. In practice, the dominant approach in Belgium to decision support in energy policy has followed more or less the ‘policy as calculus’ philosophy. Therefore, we consider there is both in academic discussion as in policy practice some scope for a more symmetrical interest in processes for ‘opening up’ the debate on long-term sustainable energy strategies. SEPIA had to find an adequate balance between moment of ‘opening up’ and ‘closing down’ assessments, and choose the appropriate methods accordingly. These methodological choices are explained further in section 2.3 (regarding the choice of foresight methodology) and section 2.5 (regarding the choice of multi-criteria decision support methodology).

2.3 Choice of foresight methodology in SEPIA

2.3.1 Overview of futuring methods

The term ‘*futuring*’ (cf. Section 2.2.1) refers to the ensemble of scientific tools used to support foresight, for example forecasting techniques, envisioning workshops, modelling tools, brainstorming sessions, etc. Broadly speaking, futuring activities aim at deliberate and systematic thinking, debating or shaping of the future. In practice, futuring approaches come in many different shapes and forms (van Notten et al. 2003). A first distinction is between **predicting** and **exploring** the future. Earlier attempts at forecasting (prediction) have proven to be largely unsuccessful (particularly in the case of long-term energy foresight) and are increasingly being abandoned by foresight practitioners – although expectations of correct prediction on the part of policy makers are still apparent. Next, there is the difference between **quantitative** (modelling) and **qualitative** (narrative) traditions with the former prevailing in the field of energy. Hybrid approaches combine narrative scenario development with quantitative modelling. Also are distinguished descriptive or **exploratory** futuring approaches describing possible developments starting from what is known about current conditions and trends, from normative, **anticipatory** or backcasting approaches constructing scenario pathways to a desirable future. Neither approach is ‘value free’, since both embody extra-scientific judgments, for example about ‘reasonable’ assumptions. But the objectives of the scenario development exercise determine the choice between exploratory and anticipatory approaches. Exploratory (or ‘what-if’) analysis articulates different plausible future outcomes, and explores their consequences. Prioritising technological choices, technical and economic experts perform the analysis in a relatively closed process, with government actors mostly assuming the role of client (they ‘order’ the analysis). Anticipatory scenarios represent organised attempts at evaluating the feasibility and consequences of achieving certain desired outcomes or avoiding undesirable ones. Finally, **trend** scenarios based on extrapolations of (perceived) dominant trends, differ from **peripheral** scenarios focusing on unexpected developments and genuine ‘surprising’ events. Several choices on the suitable foresight methodology are therefore to be made.

2.3.2 Hybrid backcasting as the SEPIA method of choice

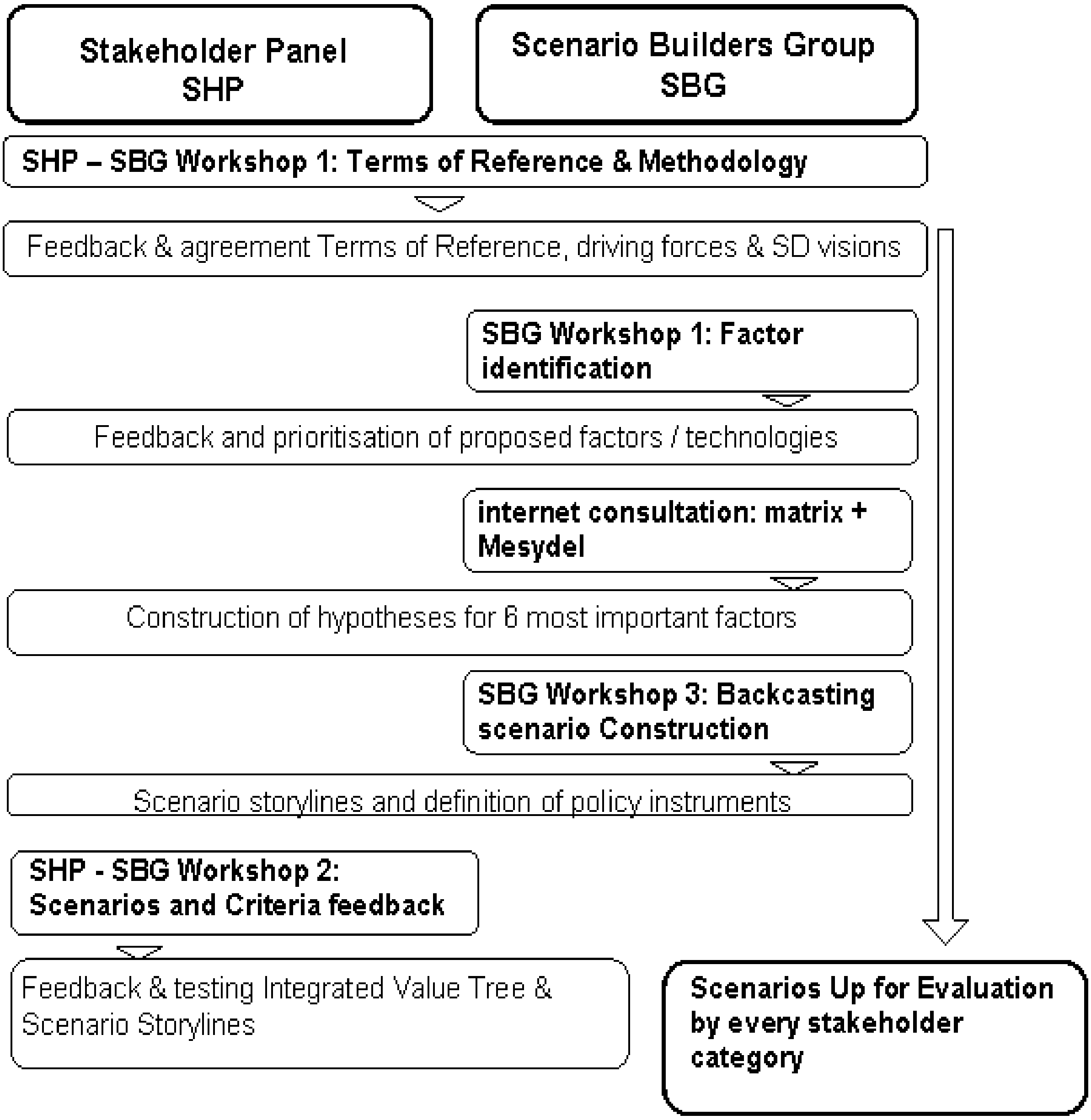
Corresponding to SEPIA’s ‘opening up’ logic, the foresight methodology explicitly acknowledges the possibility of different ‘framings’ of the energy system (the ‘socio-technical object’ under consideration) and of the factors that cause long-term changes in this system. Narrative scenario-building is particularly well-suited for ‘opening up’ the system description to, and for exploration of, fundamental complexities and uncertainties (Bunn and Salo 1993). The construction of scenarios for exploring alternative future developments under a set of assumed ‘driving forces’ has a long tradition in strategic decision making, especially in the context of energy policy (Kowalski et al. 2009). Exploratory scenario-building is however criticised for its propensity to limit the space of the possible to only a few probable ‘storylines’ (Granger Morgan and Keith 2008). The backcasting approach is more suited for long-term and complex problems – such as sustainable development – requiring solutions which shift society away from business-as-usual trends. Backcasting is however often criticised for defining utopian futures with little value for decision makers in the ‘real world’.

For combining the strengths of explorative and (traditional) backcasting methodologies SEPIA developed a ‘hybrid backcasting’ approach. ‘Traditional’ backcasting starts from future visions – i.e. a quantitative and qualitative interpretation of a ‘sustainable energy system’ in 2050. From this, we worked backwards to define the pathway that links the ‘here and now’ (i.e. the energy system in 2009-2010) to the ‘there and then’ (i.e. the energy system in 2050). Pathways were built with rather traditional scenario-building methods. A ‘scenario’ resulted from the combination of a vision and a pathway. Scenario building (following a hybrid backcasting approach) takes place starting from a systematic exploration of futures, by studying many combinations resulting from the breakdown of the energy system. The process of ‘breaking down’ the system implies the definition of a set of factors, which could each influence the development of the energy system into different directions. These possible developments are formulated as ‘hypotheses’ or ‘possible configurations’. The total number of combinations represents a ‘morphological space’, which must then be reduced to a number of coherent sets by formulating transition conditions (‘exclusions’ and ‘compromises’) congruent with reaching the sustainability visions. For this process, we proceeded in a number of separate steps (cf. Fig. 1). These steps are explained in sections 2.3.3.1 – 2.3.3.6. The scenario-building phase relied on qualitative in-depth deliberative workshops with the scenario builders group (SBG), and the SEPIA team acting as ‘scientific secretariat’, delivering input materials for the workshops (e.g. information sheets) and processing the outcomes. Scenarios were reviewed by the stakeholder panel (SHP).

Social mapping was used for composing the SBG and SHP groups respecting the following criteria:

- **Scenario Builders Group (SBG)**: The SBG is responsible for developing the long-term energy scenarios describing the different possible visions on a sustainable energy future (horizon 2050) and the pathways (including policy instruments) needed to realise those visions. We expected from each participant to contribute their expertise and personal experience to the discussions. The Scenario Builders were asked to participate on personal title and not as a representative of the organisation in which they are active. Members of the SBG were contacted by the SEPIA team and submitted for approval to the steering committee.

Fig. 1: Scenario-building steps in the context of the SEPIA project



- **Stakeholder Panel (SHP)**: The SHP was mainly responsible for evaluating the long-term energy scenarios developed by the SBG; though they also were given an important role in setting the general directions for these scenarios and providing feedback on scenario assumptions before the LEAP-modelling will take place. This group aims to be representative of the 'stakes' in the Belgian energy sector. Therefore, it was important to ensure that all the potential social groups with a current or potential interest in the problem had the possibility of being included in the process. When deciding on the composition of groups taking part in participative processes, inclusiveness refers to ideas of *representativeness*, although *not in a statistical sense*.

> Rather, participants should be selected to represent constituencies that are known to have *diverse and, especially, opposing interests*. No stakeholder group should be composed of a preponderance of representatives who are known to have a similar position or who have already formed an alliance for common purpose. In the case of experts – who are presumed not to have constituencies but ideas – they should be chosen to represent whatever *differing theories or paradigms* may exist with regard to a particular task.

2.3.3 Scenario building steps

2.3.3.1 SHP-SBG workshop 1: Terms of Reference & Methodology

It is clear that before starting to formulate sustainable energy strategies, policy makers and/or relevant stakeholder groups will already have some general ideas about the possible alternative solutions. Before entering the multi-criteria assessment phase (in which a decision about the significance of the possible impacts of the alternatives in terms of furthering the sustainable development agenda has to be made), these general ideas will already have to be worked out to a greater level of detail. It is only as a result of the detailed ‘scoping’ of the sustainability assessment that the decision alternatives will take on their definitive shape – that is, the ‘scoping’ provides the necessary consensual ground rules for deciding what counts as a ‘reasonable’ alternative, the range of alternatives to be taken into account, the level of detail needed to explore each alternative, etc. Scoping is therefore an essential part of the sustainability assessment, and should form the basis of a negotiated ‘contract’ between the project team, stakeholders, experts and steering committee involved in the project. This ‘contract’ is called the ‘Terms of Reference’ (TOR). The SEPIA Terms of Reference were thoroughly discussed in a full-day workshop[4]. Since the (hybrid) backcasting approach adopted in the project essentially relies on normative inputs for the development of desirable end points, the first workshop was for a large part devoted to finding a consensus on sustainability principles.

An **integrated value tree** was developed which discusses the sustainability goals specific to the development of energy systems in more detail. A value tree identifies and organises the values of an individual or group with respect to possible decision options. It structures values, criteria, and corresponding attributes in a hierarchy, with general values and concerns at the top, and specific attributes at the bottom. For the purposes of the SEPIA project, the integrated value tree integrates ***fundamental sustainable development (SD) objectives***, ***scenario pathway SD principles***, ***SD (sub-)dimensions*** *and* ***SD indicators***.

[4] The final version of the SEPIA TOR can be downloaded from the project website (<www.ua.ac.be/sepia>).

Table III. Fundamental sustainability objectives used in the context of the SEPIA project

8 ultimate objectives of the FRDO/CFDD	SDG's 4th SDR	International commitments
1 • To provide an effective answer to the challenge of climate change consistent with Article 2 of the UN Framework Convention on Climate Change[5]. During the first SEPIA workshop (17 Nov. 2008), a consensus on an 80% GHG emission reduction target for Belgium by 2050 (reduction by the Belgian economy with the exclusion of offsets) was reached.	SDG 13	UNFCCC Art 2
2 • To provide access for all to basic energy services and by doing so contribute to the improvement of living conditions and the creation of wealth and jobs.	SDG 1, 2, 3	JOPI 9,9a,g 10.b; Rio 92 Principle 5, MDG 1
3 • Pursuing the use of (almost) non-depletable natural resources.	SDG 13,15,16	JOPI 9a, 15. 20c
4 • Pursuing demand side management	SDG 11,14	JOPI 9a
5 • Characterised by an optimal energy-efficiency	SDG 11,14	JOPI 9a, 15
6 • Causing a minimal health impact on mankind and ecosystems	SDG 7,11, 12	JOPI 7.f, 15
7 • Owning a high standard of reliability		JOPI 9.e,f, 20e
8 • Implying an affordable cost		UNFCCC Art 3.3 JOPI 20b,e

JOPI = Johannesburg Plan of Implementation
Rio 92 = Rio Declaration on Environment and Development
SDG = Sustainable Development Goal (defined by Federal Planning Bureau)
SDR = Sustainable Development Report (written by Federal Planning Bureau)
UNFCCC = United Nations Framework Convention on Climate Change

Fundamental SD objectives are objectives which have to be aimed for ultimately in each long-term energy scenario (though not necessarily by 2050). They are considered to be fundamental to the notion of sustainability and of equal standing. However, because of different interpretations of these objectives, different views on priorities, and the inherent uncertainty of long-term societal evolutions, choices will have to be made. These choices are made apparent in the different visions. In order to establish a consensual list in line with the broad political debate, the fundamental SD objectives referred to widely shared objectives (embedded in international treaties and constitutions, e.g. article 2 of the UNFCCC or the Millennium Development Goals). In other words, they are derived as much as possible from international commitments subscribed to by the Belgian state. For the purposes of the SEPIA

[5] The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

project, we used the following list of fundamental sustainability objectives related to energy system development. These were inspired by the objectives defined by the Belgian federal council on sustainable development (FRDO/CFDD), by the federal planning bureaus' 'Sustainable Development Goals'[6] and international commitments (cf. Table III).

Scenario pathway SD principles are five Rio principles most often used by Belgian governments which have to be respected on the pathway towards the SD visions:

- Global responsibility;
- Integration of all dimensions of development (social, institutional, environmental, economic);
- Inter- and intragenerational equity;
- Precaution;
- Participation of civil society in decision making.

However, these principles are formulated in a rather general way and are subject to divergent interpretations in the different long-term energy pathways.

SD (sub-)dimensions are the constituent dimensions of sustainability covering all possible areas of interest related to sustainability assessment of long-term energy scenarios (for some of which fundamental SD objectives are defined). The top-level dimensions relate to the economic, ecological, social and institutional dimensions of SD.

SD indicators are the measurable variables resulting from a decomposition of SD into its (sub-) dimensions. SD indicators will be used to score the different long-term energy scenarios.

[6] Taken from Belgium's fourth federal report on sustainable development.

Fig. 2: The SEPIA integrated value tree

______OBJECTIVE 1: CLIMATE CHANGE

1 GHG reductions.

______OBJECTIVE 2: WEALTH and JOB CREATION

1 Improved access to basic energy services.
2 Improved quality of life.
3 Improved equity.
4 More high quality jobs.

______OBJECTIVE 3: ENERGY RESOURCES and LAND USE

1 Limited use of non-renewable energy resources.
2 Limited land use.

______OBJECTIVE 4: DEMAND SIDE MANAGEMENT

1 High Demand Side Management.

______OBJECTIVE 5: ENERGY EFFICIENCY

1 High energy efficiency improvement.

______OBJECTIVE 6: ENVIRONMENT and HEALTH IMPACT

1 Limited non-nuclear risks and impacts on human health and ecosystems.
2 Limited risks and impacts of CO2-storage
3 Limited nuclear related risks and impacts.

______OBJECTIVE 7: RELIABILITY OF THE ENERGY SYSTEM

1 High continuity of energy service over time.
2 High flexibility and adaptive capacity.

______OBJECTIVE 8: AFFORDABILITY

1 Limited expenditures on energy for households.
2 Limited expenditures on energy for the industry.

As mentioned before, the SEPIA integrated value tree incorporates all the previously mentioned sustainability dimensions (cf. Fig 2). In practice, the value tree supported both the construction of long-term energy scenarios by the ‘scenario builders group’ and the evaluation of these scenarios by the ‘stakeholder panel’.

Different interpretations/prioritisations of fundamental SD objectives and scenario pathway SD principles lied at the basis of different visions on the long-term future of the Belgian energy system and the pathways needed to get there. Using a backcasting approach, the consequences of different long-term sustainability visions (horizon 2050) were explored using foresight methods for the near (e.g. 2012), mid- (e.g. 2020/2030) and long-term (2050) future. The more detailed development of these fundamental objectives into a hierarchy of (sub-)dimensions (attributes) and associated indicators guided the stakeholder multi-criteria evaluation process (cf. Section 2.5).

2.3.2.2 SBG workshop 1: Factor identification

For the first SBG workshop, the SEPIA project team developed brief explanations and ‘fact sheets’ for about 50 major factors (trends, tendencies) / technological developments expected to have an impact on long-term Belgian energy system development. A ‘factor’ was defined as anything that could influence energy system development in the long run. This workshop was meant to explore the possible factors of change without pronouncing an opinion on the desirability of certain evolutions.

Table IV. List of 22 factors selected during SBG-W1

T8 Advances in energy storage technologies
P2 EU internal energy market policy
T1 Competitiveness of energy conservation technologies for stationary end uses
Ex3 Structural changes to the Belgian economy in a globalised environment
Ex13 Location
P1 EU energy vulnerability strategy
P3 EU energy RD&D strategy
P4 Price instruments to internalise externalities
T13 The ‘hydrogen economy’
T6 Advances in renewable energy technologies
T14 The ‘electric economy’
Ex 11 Ecological and health constraints
T10 ICT technology innovations
B5 Active public involvement in environmental issues
Ex 12 Market environment
Ex 9 Energy price dynamics
P9 Land use policies
B6 Risk perception and evaluation
B8 Shifts in demands for housing and living space/comfort
P8 Stranded assets & Lock in
P7 Importance of social policy
T2 Energy efficiency of various transport modes: technological progress

Only in the later process steps possible factor evolutions were connected with desirable visions on the long-term energy future. During the workshop comments, suggestions and remarks on current state, predictability, possible states (hypotheses) and time horizon of change (slow evolution vs. sudden change) of different factors were elicited. The afternoon session of the workshop continued with the identification and selection of about 20 most important factors rated according to their impact on reaching sustainable development objectives in 2050. The results of the individual point allocation (green and red dot stickers) as well as the bailout points (blue dot stickers) resulted in the definition of the guiding factors for the SEPIA exercise. The participants agreed on selecting 22 factors instead of 20 as to avoid wasting valuable time in discussions. The final list of 22 factors was accepted after the question *“Do we all agree on this?”* (cf. Table IV).

2.3.3.3 Internet consultation: Matrix exercise

The list of 22 factors with a likely influence on energy system development was consequently submitted to the SBG in an internet consultation in order to perform a cross-impact analysis of interdependencies between factors. The cross-impact analysis was performed by asking the members of the SBG to fill in a 22 x 22 matrix with the 22 factors represented in the rows and columns of the matrix. Each cell of the matrix represented the impact of the factor in the row on the evolution of the factor in the column (score between 0 and 3; 0 = no impact; 3 = high influence). By adding together the scores of all members of the SBG, factors could be classified into the following groups (cf. Fig. 3):

- ***Determinants***: factors with a high influence on the development of other factors, without being influenced much in return. In other words, these factors act as ‘motors’ or ‘restraints’ for the development of energy systems;
- ***Strategic variables***: factors with both a high influence and dependence on other factors. These factors are likely candidates for the development of broad strategic actions plans, provided they can be ‘steered’ by political interventions;
- ***Regulatory variables***: factors with both a mid- to low influence and dependence on other factors. These factors can be taken into consideration when designing specific policy instruments, provided they can be ‘steered’ by political interventions;
- ***Dependent variables***: factors which are highly dependent on the evolution of other factors. These factors can be likely candidates for monitoring efforts;
- ***Autonomous variables***: factors which evolve largely independently of other factors.

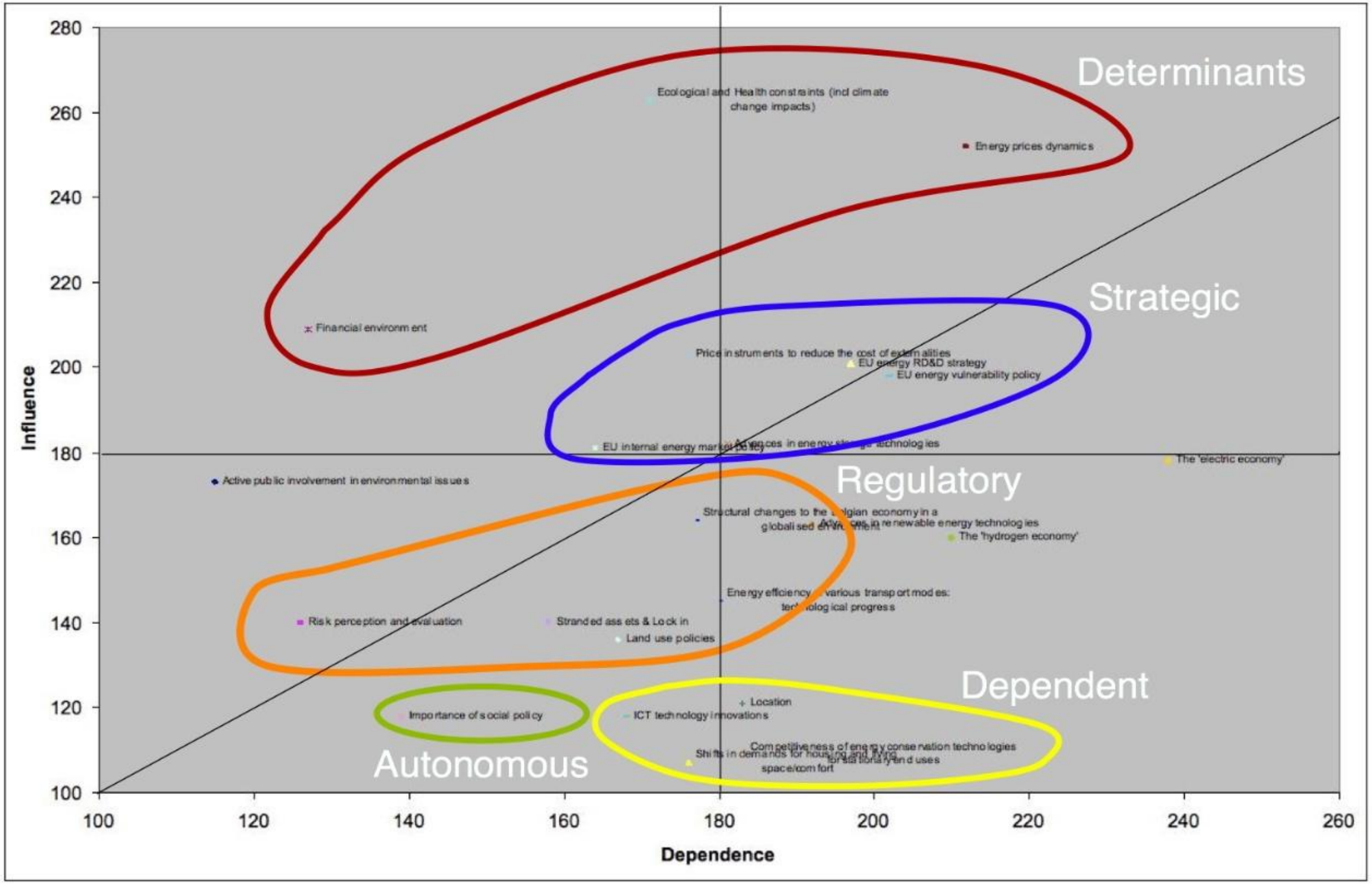


Fig. 3: Classification of factors based on result of SEPIA matrix exercise

Based on this matrix exercise, 6 factors were selected (3 determinants and 3 strategic variables) that would serve as the 'backbone' for the scenario storylines (developed in SBG-W3):

- **Ecological & health constraints**;
- **Energy price dynamics**;
- **Market environment**;
- **Use of price instruments to internalise externalities**;
- **EU energy RD&D strategy**;
- **EU energy vulnerability strategy**.

2.3.3.4 Internet consultation: Mesydel

At the start of the second phase of the internet consultation, the project team developed 2-3 hypotheses with regard to the long-term evolution for each of the 6 most influential factors. These hypotheses were submitted to deliberative feedback by members of the SBG with the aid of the 'Mesydel' tool[7]. With Mesydel, questions are encoded on a central computer and an access to the software is given to each expert. At any time they could come back to the software and amend or augment their answers. The mediator, for his part, has access to a series of answers classification tools: ability to mark the answer's relevance, to note if he will or will not work later on the question, to comment on the answers (these comments are for his exclusive use) and – the most interesting feature – to give "tags" (keywords) to answers. These tags could then be classified according to topics selected by the mediator. These classification tools allow the mediator a huge flexibility in his work and help optimising his results by allowing him finding very quickly all relevant messages on a given topic. The 'Mesydel' round thus resulted in amended versions of the hypotheses developed for each of the factors:

Ecological and health constraints (incl. climate change impacts)

Common basis

- Negative consequences of the production & consumption habits on the environment and health get individuals and policy makers to become increasingly sensitive to environmental and health concerns.
- At the international level, global environmental problems are addressed in a spirit of 'common but differentiated responsibilities and capabilities'. 'Differentiated responsibilities' are recognised by industrial countries on the basis of an acknowledgement of their historic responsibilities in causing environmental problems worldwide.

[7] For more information, see <http://www.mesydel.com/mesydel.php>.

- The EU continues to promote sustainable development and to play a major role at the international level.

Hypothesis 1 **Public focus on local impacts**	**Hypothesis 2** **Think globally, act locally**
Concerns about the environmental and health impacts of energy use compete with concerns about security of supply and affordability. Citizens feel they have little influence on pollution problems beyond the local level: it is a task for policy makers, economists, engineers... Public involvement in environmental decision making is focused on the local level (e.g. decision involving local traffic, construction of ‘risky’ infrastructures). People do not automatically oppose local activities, but demand to be fully informed and (if possible) compensated for any negative consequences.	Increasingly concerned citizens put pressure on policy makers and companies on the local, EU and global levels, either by direct actions or by actively supporting issue-centred NGOs. “Think globally, act locally” becomes the mainstream attitude. The EU provides ‘passports’ for product streams in the entire economy (i.e. information about the impacts of the entire product life cycle), and defines increasingly stringent product and process norms based on sustainability criteria for the entire product life cycle.

Market environment

Common basis

- All private or public companies and/or institutions active in energy system operation have an official recognition of corporate social responsibility (CSR).
- Transfer of funds and/or technology to aid non-Annex 1 countries in mitigation or adaptation to climate change is implemented to support sustainable development on a global level.
- Both hypotheses differ in the degree of government intervention in the market environment.

Hypothesis 1 **Strong government intervention**	**Hypothesis 2** **Heavy government intervention**
The EU focuses on establishing a truly integrated internal energy market and lets the market forces determine the energy balances, within the limits of an overall energy policy framework. Investments decisions are taken within competitive, regulated and open market conditions, creating transparent energy pricing. Government intervention is strong but relies on the use of market-conform instruments (i.e. taxes, emission trading, tradable green certificates, etc.). Governments do not want to pick technology ‘winners’. Interventions may target new participants/technologies, but only for a limited time-span (in order to ‘level the playing field’).	The EU and national governments intervene directly in the market environment if market outcomes are judged to be in contradiction with overall energy policy objectives (e.g. energy security, national interests, etc.). Corrective actions taken by governments could take different forms (e.g. sharpening or relaxing market rules, creating state-owned companies, taking risk-sharing participations in energy companies, etc.). Supportive action for new participants/ technologies is possible over long periods of time.

Oil & gas price dynamics

Common basis

- World demand for commercial primary energy is forecasted to rise substantially over the next decades (by 50% according to the IEA 2008 reference), with a more modest rise in the EU (some 10%).
- Energy balances will continue to be based largely on oil and gas over the 2010-2030 period, with a projected increased import dependency on oil and gas in the EU.
- Common timeline for both hypotheses:
    - Short to mid-long term (2010-2030): the international market produces more in response to pressures from rising oil & gas demands.
    - By 2030: the international climate change agenda really starts to have effects on oil supply and demand. Strong reduction in the economy’s overall energy intensity due to a combination of factors (more efficient end-uses for energy, development of energy conservation and of new sources of primary energy, changes in lifestyles and productive patterns).

- Long-term (2030-2050) : further gains in energy productivity and the extension of the useful lifetime of oil & gas reserves (as demand decreases) give enough economic resources and time to launch new technologies on the demand and supply side.
- By 2050: oil is mostly limited to an expensive source for chemical compounds.

Hypothesis 1 **Gradual evolution**	**Hypothesis 2** **Oil shock(s)**
Short/mid-term (by 2010-2030): Production costs are kept within limits, thanks to a combination of technology, investment and broad political support, though these costs will increase structurally over the period, following a stepwise pattern. Oil and gas price increments and volatility are not perceived as major policy concerns.	Short/Mid-term (2010-2030): the oil (and possibly also the gas) market goes through a series of crises before 2030, caused by physical (peak production capacities are surpassed) or political factors (e.g. crisis in the Middle East), resulting in sudden and unpredictable price increments. Leading powers try to control the remaining resources. The EU is too weak to act as one, member states are left to their own devices.
Over the period 2030-2050, oil prices stabilise at a relatively high level (lower than in Ex7-2).	Over the period 2030-2050: tensions provoked by the oil crisis are eventually alleviated as the international climate change agenda really starts to have effects on oil & gas supply and demand. Prices stabilise at a high level.

Price instruments to reduce (carbon) externalities

Common basis

- Governments increasingly make use of price instruments to reduce the costs of externalities of energy technologies. They agree on the principle of changing price setting for energy carriers in order to reflect external costs of all kinds.
- However, the scope, rhythm, means and extent of internalisation vary according to the hypothesis under consideration.

Hypothesis 1 - Technological fix	Hypothesis 2 - Ecological reform
Governments, mainly backed by business & industry, use price instruments to reduce the (carbon externality) very cautiously, keeping a close eye on overall welfare impacts and the impacts on trade & national interests. The general perception is that immediate action is rather costly; policy makers prefer to wait and undertake more ‘drastic’ reduction efforts in the future.	Governments, backed by business & industry and civil society, set the agenda for rapid and drastic reductions in global GHG emissions.
Short-term (post-2012): • Fragmented climate change regime in which states (and even local governments) have a lot of room for policy approaches. No common global agreement on the priority to be given to the issue of climate change. • EU adheres to the 20/20/20 agenda; cap-and-trade approach is implemented. • Alliances with fast-developing nations with a focus on technology research and partnerships with fast-developing nations.	Short-term (post-2012): • Global climate change regime under the UNFCCC umbrella, due to a combination of political will, technological progress, pressure from public opinion and environmental urgency. • EU accepts to reduce GHG-emissions by more than 20% in 2020. • All major industrial nations participate.
Mid-term (2020-2030): climate-friendly ‘breakthrough’ technologies become competitive, even in the absence of a global climate change agreement.	Mid-term (2020-2030): Synergies are progressively established between UNFCCC and other international environmental and non-environmental institutions. A global environmental regime emerges, applying both “polluter pays” and precautionary principles on a global scale, as well as strict liability to risk-inducing activities.
Long-term (2030-2050): gradual accession of all countries to a global climate change regime, based on ‘cap-and-trade’ principles. No major tax reform is implemented.	Long-term (2030-2050): Tax systems are gradually reformed as the income from carbon/energy taxes and/or emissions trading are used to lower taxes in other areas and for global redistribution.

EU energy RD&D strategy

Common basis

- The overall EU RD&D strategy supports the evolution of the EU towards a strong knowledge-based economy (Lisbon strategy).
- The sustainable development agenda is increasingly integrated in EU RD&D, e.g. by promoting research towards environmentally-friendly production methods (e.g. eco-efficiency) or by creating high-quality job opportunities.

Hypothesis 1 **Business takes the lead**	**Hypothesis 2** **Public/Private partnership**	**Hypothesis 3** **Patchwork**
Attention is focused on supply innovation – i.e. RD&D policy follows a ‘technology-push’ logic.	Attention is focused on supply and infrastructural innovations – i.e. RD&D policy follows a ‘technology-push’ logic.	Attention is focused on the demand side, aiming at solutions for a better indirect ‘steering’ of consumer behaviour.
The innovation agenda is for a large part set by the big multinational firms, which determine the overall strategic research priorities. The EU mainly plays an ‘orchestral role’ – i.e. that of providing a platform where networks of major stakeholders centred on certain technologies can be formed, and where views, ideas and proposals can be discussed and co-ordinated.	An increasing amount of projects are carried out within the context of EC framework programmes or international collaborations (strategic partnerships with e.g. China, U.S.A., India, etc.); public authorities set the agenda.	Energy-related RD&D is undertaken both in the public and private sector, and at all levels (regional/national/EU). However, no policy level or player is dominant, as RD&D is mainly aimed at finding the ‘right’ solution depending on the specific local and/or regional needs and policy objectives.
These discussions form the base of the European Commission’s policy and legislative proposals, intended to create an ‘accommodating’ environment for technological innovations once they are ready to enter the market.	RD&D focuses on technological ‘breakthroughs’ with potentially large implications for the EU economy as a whole (e.g. ICT, large offshore wind parks, smart grids, energy storage technologies, etc.), and which contribute to the achievement of the broader policy goals (climate change, competitiveness, energy security). Those solutions – if successful – mostly require big investments in new technology/ infrastructure	EU countries or regions try out different innovations (social, environmental, economic or institutional), with different degrees of success, and the results of these ‘experiments’ are discussed in specific forums at the European level (and possibly transferred to other contexts).

EU energy vulnerability policy

Common basis

- Energy vulnerability remains a concern for the national and regional (EU) level. Policy makers stay attentive to a number of possible ‘threats’, e.g.:
    - dependence on finite resources (esp. oil and gas),
    - dependence on geographic supply areas,
    - dependence on single technology,
    - dependence on a limited number of delivery lines (esp. gas pipelines),
    - market power of energy-exporting countries, and/or risk of market disruptions due to regulatory failure.
- The hypotheses differ in the way these vulnerability risks are tackled (e.g. indirect effect of policy measures in other areas vs. targeted policy interventions) and the policy level on which they are tackled (national initiatives vs. EU policy intervention).

Hypothesis 1 **Market mechanisms**	**Hypothesis 2** **EU approach**	**Hypothesis 3** **National governments**
Overall: energy vulnerability concerns are addressed mainly through market mechanisms, as Europe further develops its economic agenda for the internal and external markets. Vulnerability and security of supply concerns are seriously alleviated as a ‘by-product’ of the competitive environment. Externally, the EU is able to secure relationships with the most important energy trade partners (e.g. Middle-Eastern countries, Russia, etc.) based on a commercial basis of revenue maximisation. Free transport of persons, goods, services and capital between the countries involved is encouraged. Thanks to good commercial relationships and stable multilateral	Short/mid term (2010-2030): concerns about energy supply security, reliability and vulnerability in general play an active role in shaping EU energy policy. Member states increasingly recognise the role of coordinated EU action on energy vulnerability issues. Externally, with the consent of member states, the EU negotiates bilateral energy arrangements or ‘strategic partnerships’ based on overall ‘deals’ including economic, political and financial aspects (e.g. with Russia, in the case of gas supply).	Short/mid term (2010-2030): concerns about energy supply security, reliability and vulnerability in general play an active role in shaping energy policy, both at the EU and member states level. Externally, the EU as a whole does not speak with ‘one voice’ on energy vulnerability issues: the issue is addressed on the basis of the national interest, as national governments support their energy industries to engage in ‘scramble’ for oil and gas supplies in particular.

interactions, the EU’s increasing import dependency is not seen as a particular concern. Specific EU vulnerability policy interventions are limited to setting up and maintaining crisis response mechanisms dealing with unforeseen supply interruptions in all energy sources, and setting up the necessary regulatory arrangements for securing energy infrastructures (e.g. gas pipelines, electricity transmission lines, etc.).		
Internally, the EU succeeds in setting up an efficient and truly competitive energy market, with market forces and prices as strong drivers. A regulatory framework for securing the necessary interconnections is eventually set up. In addition, the EU succeeds in forcing some of the major energy companies into substantial divestitures, strongly increasing energy diversification all over Europe.	Internally, the EU focuses on inducing competition by further integration of energy markets under strong regulatory oversight, with a particular emphasis on security of supply in gas and electricity.	Internally, larger EU member states are most successful at effectively combining their foreign policies with energy trade policies. Therefore, there is considerable room for ‘national champions’ (large integrated energy giants) to develop into a few European ‘giants’ (with backing of their respective national governments). The EU does not intervene in this evolution. These European ‘giants’ have strong market shares in their home countries, and compete fiercely for market shares in other EU member states.
By 2030, security of supply concerns start to become alleviated (as the need for substantial reductions of GHG emissions also impacts on energy import dependence).	By 2030, security of supply concerns start to become alleviated (as the need for substantial reductions of GHG emissions also impacts on energy import dependence).	By 2030, security of supply concerns start to become alleviated (as the need for substantial reductions of GHG emissions also impacts on energy import dependence).

2.3.3.5 SBG workshop 3: Backcasting and scenario construction

Starting from the processed results of the internet consultation (priority factors, short description of possible alternative hypotheses for their evolution), the members of the SBG developed three scenario ‘skeletons’ composed of factor hypotheses and technological developments congruent with the logic of reaching the 8 sustainability objectives. This can be done by a formal consistency check; however – in view of the highly resource-intensive mathematical character of this procedure (and the need for supporting software) – we chose a more **intuitive** method. Starting from a certain factor, a hypothesis was selected and then connected to other hypotheses (for the other factors) that were deemed to be consistent with the initial hypothesis. This combination of hypotheses could then be regarded as an alternative ‘solution’ to the problem of moving towards the attainment of the 8 sustainability objectives in 2050. These combinations were then taken as a basis for the construction of a scenario, and the procedure was repeated until the SBG felt that they had covered the range of possibilities with their scenarios.

For each of the scenario skeletons (which both enable and constrain certain developments), the SBG group had to explore in which other factors (taken from the original list resulting from SBG-W1) – i.e. technologies, behavioural changes, broad policy choices etc. – ‘critical’ changes had to be achieved (compared to now) in order to achieve a certain vision on a Belgian energy system in 2050 which is supportive of the 8 sustainability objectives. They also had to indicate an approximate timing of the changes needed in the ‘critical’ factors. Finally, in order to complete the pathways, the SBG group had to backcast the necessary policy interventions needed on the Belgian level for reaching the 8 sustainability objectives, given a certain combination of a vision and pathway elements as the policy context. The backcast had to give an answer to the question: “*What is needed at the Belgian (i.e. federal and regional) level in order to realise the changes in the factors within the timeframe indicated by a particular pathway*?”. Although the workshop discussions lead to many interesting suggestions, we did not succeed in constructing policy pathways in sufficient detail. A detailed backcast also proved to be too demanding a task, mainly due to the rather low attendance. As a result, the policy orientations included in the three resulting scenarios (cf. Section 2.4) remained at a more abstract and strategic level. ‘Strategy’ should be understood as referring to i) the framing of the 8 objectives to be reached (e.g. decisions w.r.t. the exact interpretation given to these objective or the relative importance of the objectives over different time horizons); as well as ii) indication on the way these objectives could be reached in the form of general guiding principles (rather than a set of ready-made or concrete policy interventions). Also, in order to serve as a ‘workable’ input to the LEAP energy system model, a lot of decisions on modelling parameters still had to be made. As a consequence, the project team decided to change the format of the final workshop to some extent, dedicating it also to the further elucidation of the scenarios storylines.

2.3.3.6 SHP-SBG workshop 2: Feedback on scenario storylines and criteria

The last workshop, which combined inputs from the SHP and SBG, served a dual purpose: deliberation and feedback on a draft value tree as proposed by the project team (with 'fact sheets' unequivocally explaining each indicator, potential data sources and possible measurements (e.g. quantitative/qualitative), taking into account uncertainties); and feedback and further development of the 'scenario skeletons' developed by the SBG in the previous workshops. The value tree was modified according to the feedback received. Deliberative feedback on the scenario skeletons resulted in more needed specifications on the scenarios to serve as an input into the LEAP modelling exercise; however, a lot of 'room for interpretation' was still left for the project team. In Section 2.4, a qualitative description of the three scenario storylines is given.

2.4 The SEPIA scenarios

This section describes the long-term energy scenarios developed by the 'scenario builders group' (SBG) in the 2nd phase of the SEPIA project: ***global consensus***, ***confidence in RD&D*** and ***oil shock(s)***. Each of the scenarios discusses a possible pathway for the development of the Belgian energy system, and describes how the scenario contributes to reaching **8 fundamental sustainability objectives,** as set out by the Belgian Federal Council for Sustainable Development (FRDO/CFDD) and accepted by the SEPIA stakeholder & scenario builders group in the SHP-SBG workshop 1 (cf. Section 2.3.3.1). These objectives have to be aimed for ultimately in each of the long-term energy scenarios (though not necessarily by 2050). They are considered to be fundamental to the notion of sustainability and of equal importance. However, because of different interpretations of these objectives, different views on priorities, and the inherent uncertainty of long-term societal evolutions and driving forces, choices have been made in the scenarios. Since we chose 2006 as the reference year for all of our scenarios (for reasons of availability of data), we could not include recent events (such as the financial crisis) in our scenario assumptions, even though such events could have an impact on long-term growth expectations. This (inherent) limitation of long-term energy foresight should be acknowledged. For the scenario storylines, the following (global and/or European) scenarios studies were used as sources of inspiration:

- Shell energy scenarios to 2050 (Shell 2008);
- The EU FP6 Eurendel (European Energy Delphi) scenarios (Eurendel 2005);

- The Clingendael Institute's "Europe, the EU and its 2050 Energy Storylines" (de Jong and Weeda 2007);
- Belgian Federal Planning bureau sustainable development scenarios (FPB 2007).

Table V. Summary of SEPIA scenarios

	Global consensus	Confidence in RD&D	Oil shock(s)
GDP growth	**Equal in all scenarios – not explicitly modelled.**	**Equal in all scenarios – not explicitly modelled.**	**Equal in all scenarios – not explicitly modelled.**
Dominant economic growth sectors	**Service sector**	**Growth in all sectors**	**Growth in all sectors (2006-2030); Less growth in energy-intensive sector after 2030**
Number of households	**Equal in all scenarios**	**Equal in all scenarios**	**Equal in all scenarios**
Primary energy consumption (2050)	**-58%**	**-50%**	**-44%**
Transport demand (activity levels) (2050)	**+12% (passenger) -6% (freight)**	**+100% (passenger) +100% (freight)**	**+16% (passenger) +25% (freight)**
Energy use – households (2050)	**-50%**	**-35%**	**-35%**
Energy use – Manufacturing (2050)	**-25%**	**-13%**	**-25%**
Transport fuels	**Biofuels + electric vehicles**	**Electric vehicles take over**	**Biofuels take over; electric vehicles towards end of modelling horizon**
Electricity supply structure (2050)	**Renewables dominant (wind energy, biomass); No coal, no nuclear**	**Offshore wind energy dominant; No coal, no nuclear**	**Diverse mix: wind energy, coal + CCS, nuclear, biomass**
Decarbonisation policy	**Behavioural changes + technological innovation – moderate penetration rate (demand + supply)**	**Technological innovation – high penetration rate (demand + supply)**	**'Crisis response' Slow technological innovation + Behavioural change after 2030**

2.4.1 Global consensus

The 'global consensus' scenario combines the following hypotheses (cf. Section 2.3.3.4):

- Ecological and health constraints: "*Think globally, act locally*";
- Use of price instruments to internalise (carbon) externalities: "*Ecological reform*";
- EU energy RD&D strategy: "*Public-Private partnership*";
- Market environment: "*Strong government intervention*";
- EU energy vulnerability policy: "*EU approach*";
- Oil & gas price dynamics: "*Gradual evolution*"

Global consensus starts from the assumption that climate change policy is the main driver behind energy system development, in the sense that early action is taken with the support of civil society. This evolution is not solely driven by global altruism. Over the next decade, bottom-up initiatives first take root as cities, regions or coalitions of business take the lead. These become progressively linked as national governments are forced to harmonise resulting patchworks of measures and take advantage of the opportunities afforded by these emerging political initiatives. Faced with the prospect of a patchwork of different policies, businesses start to lobby for regulatory clarity. As a result, effective demand-side efficiency measures emerge quickly, and CO_2 management practices spread. The rate of growth of atmospheric CO_2 is constrained at an early stages leading to a more sustainable environmental pathway. Both supply-side (e.g. electric vehicles) as well as demand-side innovations (behavioural change, energy efficiency improvements) are implemented. Energy RD&D spending on the EU level is increased substantially and is geared towards realising a common European vision – a low-carbon energy system with maximum penetration of renewable and distributed energy sources. Technologies that are labelled as 'risky' encounter strong public and political opposition. A combination of low public acceptance and unresolved waste, safety and proliferation issues leads to a rejection of the nuclear option in many countries (including Belgium). Public support for carbon capture & storage (CCS) is also reluctant, though CCS is needed to reach the -80% target in Belgium by 2050. By 2050, energy supply is largely based on renewable energy sources.

2.4.2 Confidence in RD&D

The 'confidence in RD&D' scenario combines the following hypotheses (cf. Section 2.3.3.4):

- Ecological and health constraints: "*Public focus on local impacts*";
- Use of price instruments to internalise (carbon) externalities: "*Technological fix*";

- EU energy RD&D strategy: “*Public-Private partnership*”;
- Market environment: “*Strong government intervention*” or “*Heavy government intervention”* (members of the SBG did not come to an agreement w.r.t. the level of government intervention needed to realise the sustainability objectives);
- EU energy vulnerability policy: “*National governments*”;
- Oil & gas price dynamics: “*Oil shock(s)*”

The “***Confidence in RD&D***” storyline stands for a scenario where (the speed of) technological innovation is the key enabling factor of the transition towards a sustainable energy system. A combination of high oil (and gas) prices, climate policy and competitive energy markets decisively influence the pace of transition to a low-carbon energy future in the OECD countries. In the EU the Lisbon agenda (and possible successors) carries high priority. The EU protects and expands its previous economic achievements, including the internal energy markets. However, governments are still heavily involved in securing their external energy supplies (this goes for ‘government’ as well on the EU as on the national level in Europe), albeit in a more subtle and indirect way than in the “Oil shock(s)” scenario. In general, market forces determine the investments choices made by energy industry between renewables, ‘clean fossil’ or nuclear power, but public and/or political perceptions sometimes lead to targeted interventions. The use of the nuclear option is especially closely associated to national preferences. Independently from the developments in the fields of nuclear, Europe is on its way to a smooth and accelerated transition towards renewable energy. Large off-shore wind farms are the most important renewable source for electricity production and biomass playing a major role in heating or cogeneration. On the demand side, the increase in energy efficiency is also determined by market forces as new energy end-use technologies emerge in electricity use, space heating, ‘smart’ decentralised energy systems and transportation.

2.4.3 Oil shock(s)

The ‘oil shock(s)’ scenario combines the following hypotheses (cf. Section 2.3.3.4):

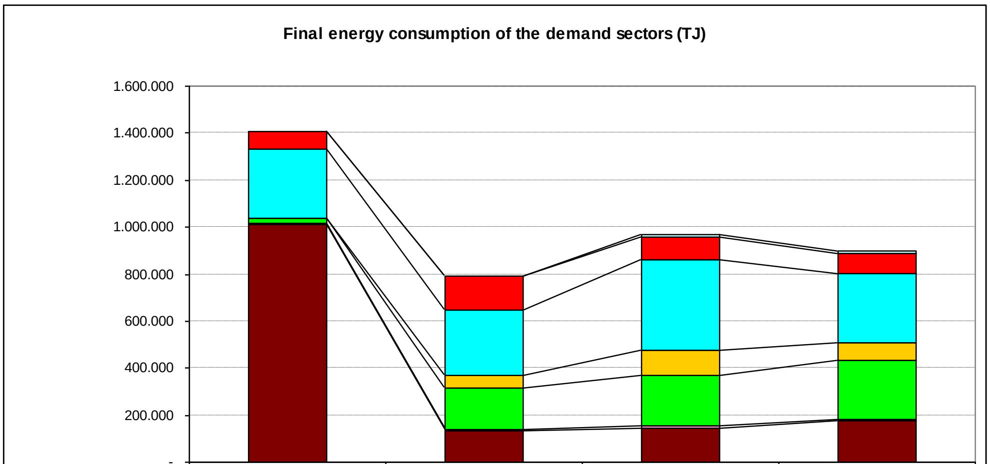
- Ecological and health constraints: “*Public focus on local impacts*”;
- Use of price instruments to internalise (carbon) externalities: “*Technological fix*” (high oil & gas prices act as main drivers);
- EU energy RD&D strategy: “*Patchwork*”;
- Market environment: “*Heavy government intervention*”;
- EU energy vulnerability policy: “*EU approach*”;
- Oil & gas price dynamics: “*Oil shock(s)*”

In the “***Oil shock(s)***” storyline, the oil (and possibly also the gas) market goes through a series of crises in the period 2020-2030, caused by physical (peak production or refinery capacities are surpassed) or political factors (e.g. crisis in the Middle East), resulting in sudden and unpredictable price increments. Governments of the oil-consuming industrial countries typically react following a three-step pattern: first, nations deal with the signs of tightening supply by a flight mainly into coal (later on equipped with carbon capture & storage technology), renewables (mainly wind energy and biofuels) and extending the lifetime of existing nuclear power plants (where applicable); next, when the growth in fossil fuels can no longer be maintained, an overall supply crisis occurs (between 2020-2030); and finally, governments react with rather draconian measures. Over the period between 2010-2030, leading powers try to control the remaining resources by engaging in strategic alliances, as energy policy is to a large extent dictated by foreign policy and security considerations. Demand-side policy is not pursued to its maximum potential until supply limitation become acute. Eventually however, energy security concerns are alleviated over the period 2030-2050, allowing the climate change agenda to take over as a priority issue.

2.4.4 Summary information on results of LEAP modelling

2.4.4.1 Final consumption of demand sectors

Fig. 4: Final energy demand in 2006 and 2050, all scenarios



	2006: Reference	2050: Global consensus	2050: R&D	2050: Oil shock
hydrogen	-	578	12.644	8.197
heat	71.654	140.518	96.309	88.122
electricity	297.083	279.592	384.964	293.345
other renew ables	212	55.717	106.892	75.524
combustible renew ables	17.097	173.987	214.379	248.849
w aste	5.415	4.770	6.251	5.395
fossil fuels	1.013.228	135.666	146.492	178.816

The demand sectors are households (dwellings), commercial sectors / services, industry, transportation, and ‘agriculture, forestry and fishing’. Fossil fuels include coal, oil products (gasoline, diesel, residual fuel oil but also kerosene or petroleum cokes) and natural gas. Waste comprises waste fuels in the chemical sectors, and other combustible industrial wastes (e.g. for the production of cement). Combustible renewables consist of (primary solid) biomass as well as bio-fuels (bio-ethanol, biodiesel, and bio-gas). “Heat” refers to heat produced by combined heat and power (CHP) plants and distributed via local heat grids. Hydrogen is used in fuel cells, mainly for transportation.

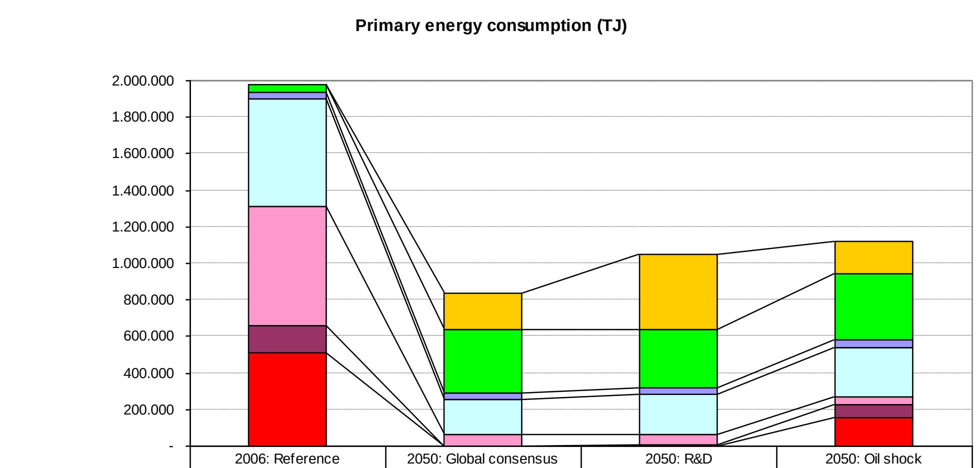
Table VI: Share of energy carriers in final energy demand, all scenarios

	fossil fuels	waste	combustible renewables	other renewables	electricity	heat	hydrogen
2006: Reference year	72%	0%	1%	0%	21%	5%	0%
2050: Global consensus	17%	1%	22%	7%	35%	18%	0%
2050: R&D	15%	1%	22%	11%	40%	10%	1%
2050: Oil shock	20%	1%	28%	8%	33%	10%	1%

Total final energy consumption (demand sectors) in the global consensus scenario is 44% lower in 2050 compared to the reference year 2006, compared to -31% in the R&D scenario and -36% in “oil shock”.

2.4.4.2 Primary energy consumption

Fig. 5: Primary demand in 2006 and 2050, all scenarios



	2006: Reference	2050: Global consensus	2050: R&D	2050: Oil shock
flow renewables	2.829	198.061	408.197	177.251
combustible renewables	45.914	346.768	323.275	363.587
waste	32.883	32.558	33.088	38.361
natural gas	590.171	194.579	223.032	272.603
oil derivatives	649.316	63.347	51.888	38.728
coal derivatives	151.329	111	8.597	71.326
nuclear	508.946	-	-	157.016

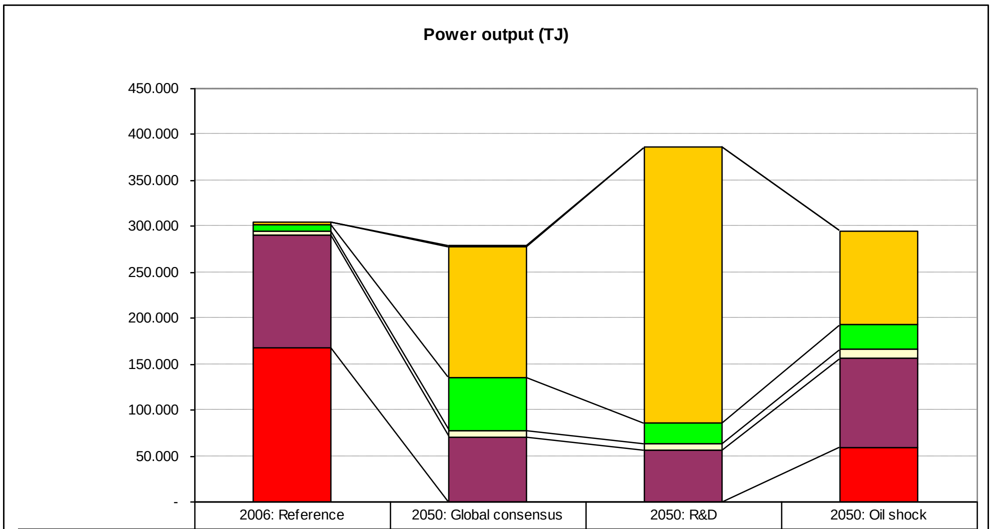
Table VII: Shares of energy carriers in primary energy demand, all scenarios

	waste	coal derivatives	oil derivatives	natural gas	combustible renewables	flow renewables	nuclear
2006: Reference year	2%	8%	33%	30%	2%	0%	26%
2050: Global consensus	4%	0%	8%	23%	42%	24%	0%
2050: R&D	3%	1%	5%	21%	31%	39%	0%
2050: Oil shock	3%	6%	3%	24%	32%	16%	14%

Primary energy consumption in the global consensus scenario is 58% lower in 2050 compared to the reference year 2006, compared to -47% in the R&D scenario and -44% in “oil shock”.

2.4.4.3 Electricity output

Fig. 6: Electricity output, all scenarios



	2006: Reference	2050: Global consensus	2050: R&D	2050: Oil shock
hydrogen	-	1.426	265	270
flow renew ables	2.618	142.344	301.305	101.727
combustible renew ables	6.680	57.278	22.184	26.957
w aste	4.446	7.454	7.231	8.869
fossil fuels	123.116	70.574	55.974	97.386
nuclear	167.922	-	-	59.666

Table VIII: Shares of energy carriers in electricity output, all scenarios

	nuclear	fossil fuels	waste	combustible renewables	flow renewables	hydrogen
2006: Reference	55%	40%	1%	2%	1%	0%
2050: Global consensus	0%	25%	3%	21%	51%	1%
2050: R&D	0%	14%	2%	6%	78%	0%
2050: Oil shock	20%	33%	3%	9%	34%	0%

Electricity output in the global consensus scenario is -8% lower in 2050 compared to the reference year 2006, compared to an *increase* of +27% in the R&D scenario and a *decrease* of -3% in "oil shock".

2.4.4.4 Energy-related CO_2 emissions

Fig. 7: Energy-related CO_2 emissions in Belgium in 2006 en 2050, all scenarios

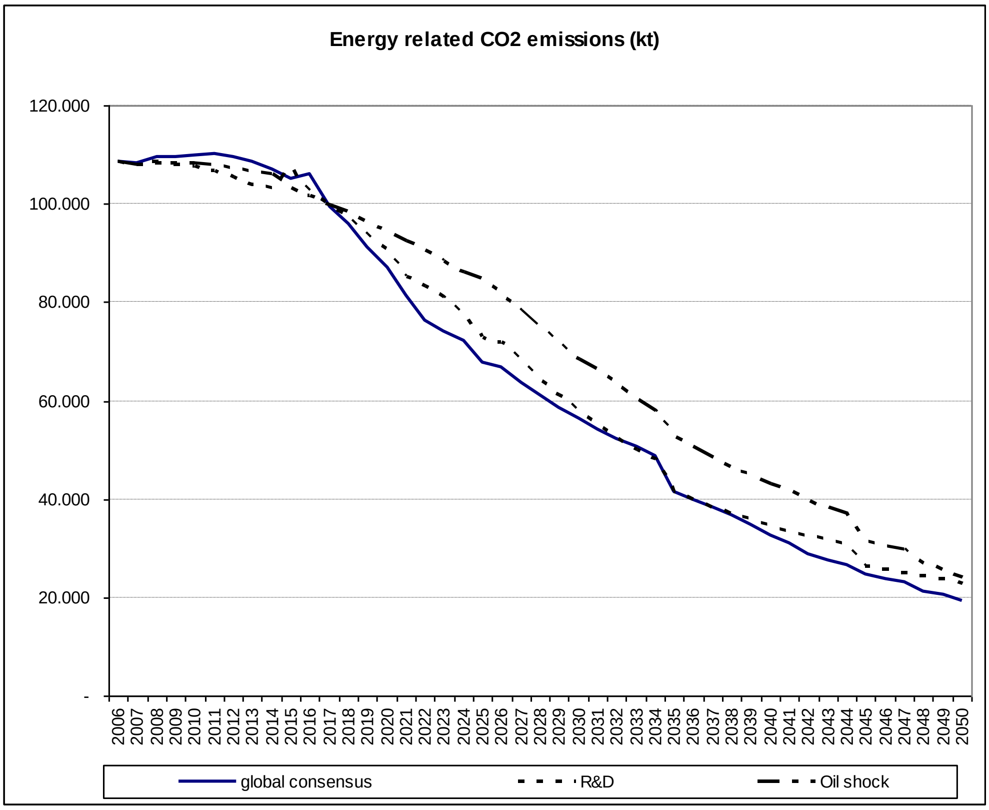
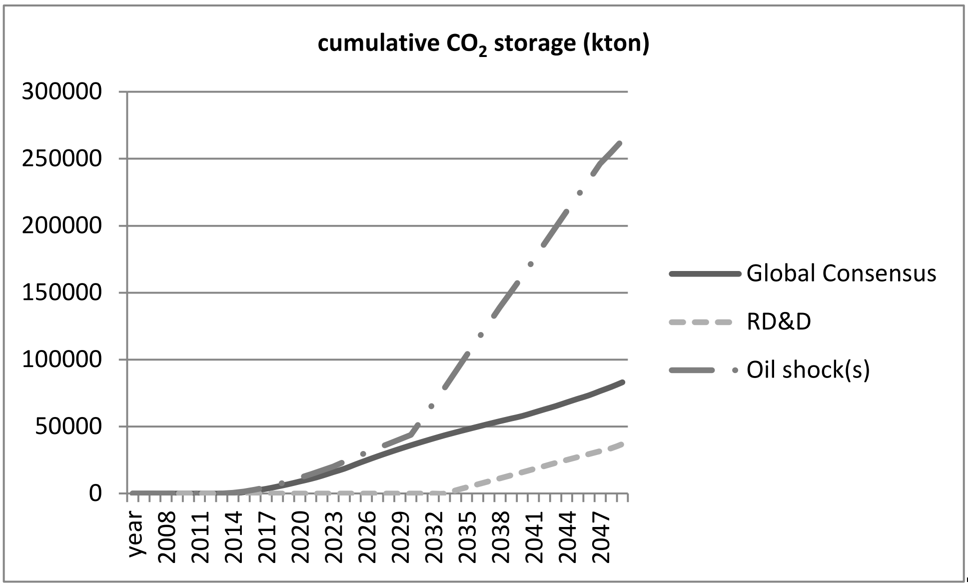


Fig. 8: Cumulative CO_2 storage in 2006 and 2050, all scenarios



A -80% reduction target compared to 1990 levels would mean roughly 22000 kt allowed CO_2 emissions in 2050. Figure 9 shows the cumulative level of CO_2 storage, which is highest for the Oil shock(s) scenario, where approximately 265.000 kton of CO_2 have to be stored over the entire scenario horizon.

2.4.5 Main scenario trends

Here we summarise the main trends as evident in the three scenarios developed in the course of the SEPIA project.

Global consensus

In terms of energy consumption per energy carrier, the overall trends in the global consensus scenario are as follows. Nuclear is gradually phased out, as planned (i.e. a first step after 2015 and than completely from 2023 to 2025). For fossil fuels there is a slow downward trend all the way to 2050, although they do retain a share of around 31% in 2050. The share of coal derivatives slowly decreases until 2020. In the period 2021 to 2034 the coal derivatives' share remains fairly stable (with perhaps a very slight increase), but from 2035 onward coals almost disappears, and after 2040 completely. Oil derivatives show a monotonous decreasing trend all the way to 2050. For natural gas the evolution is a little bit more complicated. There is an overall increase in the use of natural gas until 2015. Between 2016 and 2025 its share is a bit more erratic although it remains within the 35% to 40% interval, mainly because combined cycle plants help to compensate for the loss of nuclear. From 2026 onward the share of natural gas monotonously decreases, very similar to the evolution of oil derivatives. The share of combustible renewables enjoys a spectacular growth from 2015 to 2025, mainly driven by its burgeoning use in transport and industry. After 2026 its share keeps growing, albeit at a much slower rate. Both flow renewables and heat experience a monotonous growth during the whole time horizon. Heat, that already has a much larger share than flow renewables in 2006, grows at a slower pace than flow renewables. It really takes off after 2025; mainly the effect of sustainable ‘collective’ lifestyles (local CHP plants and micro-CHP), but starts to top off near 2050 and never reaches the heights of flow renewables. The real success story in the global consensus scenario is the share of flow renewables. Its steady increase even accelerates after 2035, as it becomes more and more the primary energy source for the generation of electricity. The share of electricity, being fairly stable until 2015 gradually increases from 2025 onward and accelerates after 2035 (partial ‘electrification’ of society), although near 2050 the pace of increase does start to slow down. In summary, as trends of energy carriers are concerned, in the global consensus scenario combustible renewables, flow renewables, electricity and to a lesser extent heat are the undisputed winners.

Confidence in RD&D

In the RD&D scenario the trend for the share of nuclear is the same as in the global consensus scenario. For the share of coal derivatives, we can distinguish four periods: first a slow decrease and stabilisation until 2020, at that point a stepwise decrease (closing down coal power plants) but again a slight increase until 2035, once more in that year a stepwise decrease and stabilisation, and finally from 2045 a tiny (less than 1%) but stable share until 2050. For oil derivatives there is a rather sharp decrease until 2035, but from then on their share bottoms out at approximately 5%. The share of natural gas follows a similar pattern as in the global consensus scenario, an overall increase until 2025, albeit with some erratic behaviour between 2015 and 2025 (nuclear phase out), followed by a rather sharp decrease until 2035. Contrary to oil derivatives, the share of natural gas keeps decreasing after 2035, but at a slower rate than before. The share of combustible renewables shows a very steep growth until 2025, then slowly levels off until 2035; and for the remaining period even starts to decrease slowly, as flow renewables take over the lead. After an accelerated start until 2025, flow renewables and their share in primary production demonstrate a monotonous but fast growth at least until 2045, mainly as a result of technological breakthroughs. After 2045, the pace starts to slow down somewhat. As is the case in the global consensus scenario, electricity’s share is fairly stable until 2015, rapidly increases until 2025 and keeps increasing from then on albeit not as rapidly as before. The share of heat on the other hand shows a monotonous but rather slow increase until 2045 (collective living is not encouraged in the R&D scenario), only to stabilize from then on. In the R&D scenario, flow renewables and electricity are the clear winners as far as trends in the evolution of energy carriers are concerned. Fossil fuels, esp. natural gas, are able ‘to limit their losses’ after 2025, following a rather steep decline from 2015 to 2024, during which time mainly combustible renewables temporarily take over their role, in attendance of the breakthrough of flow renewables.

Oil shock(s)

In the oil shock scenario the trend evolutions of the shares of nuclear and coal derivatives differ markedly from the other two scenarios. The share of nuclear little by little decreases until 2024 (but still enjoys a share of more than 21% in that year), then decreases stepwise until 2035 (postponed phase out of existent nuclear plants), next stabilizes at a share of around 5% on average, only to increase again to 14% near the end of 2050 (commissioning of next generation nuclear plants). Coal derivatives decreases its share until 2015, then stabilizes at around 3.5 % until 2030-2031, to increase sharply again at a level of 10% (to compensate for the aftermath of the ‘oil shocks’). Coal derivatives maintain their 10% share until 2045, after which their share decreases step by step, as new nuclear plants and flow renewables take over base load electricity generation. The share of oil derivatives decreases slowly but surely until 2025, after which – as a result of several oil shocks – its decline accelerates until 2035, only to keep decreasing at a slower rate all the way to 2050, where it reaches a share of 3.5%. The evolution of combustible renewables is somewhat similar to the one in the R&D scenario, where its share grows rapidly until 2015, sharply increases to more than 35% in the early 2040s (mainly because bio-fuels take over from fossil transportation fuels), only to stabilize and even decline near the end of 2050 (as a result of next generation nuclear replacing biomass power plants and particularly electric vehicles making their entrance)). The share of flow renewables grows steadily until 2045, after which it accelerates. This acceleration appears rather late in the time horizon as compared to the R&D and to a lesser extent the global consensus scenario, since large amounts of R&D money into these technologies only begin to pour in after the initial oil shocks (‘late awakening’). The share of electricity remains fairly stable until 2025, increases slowly until 2035, and accelerates from then on until 2050 and beyond. Thus, as compared to the two other scenarios, electrification of society starts noticeably later, and is unable to catch up by 2050. Heat shows a monotonous albeit slow and unremarkable growth toward 2050.

2.4.6 A reflection on the SEPIA scenarios based on a study of Belgium’s nuclear energy policy (past, present and future)

Nuclear energy is a thoroughly divisive issue in Belgian energy policy. Notwithstanding different opinions on the future of nuclear energy in Belgium, one cannot deny the fact that nuclear energy has dominated energy system development in the past, and that energy systems in general show a great inertia towards changes. Therefore, in a separate SEPIA work package a critical assessment was made of past, present and future nuclear energy policy options in Belgium taking into account the international development context. The results of this work package can serve as an input in the scientific debate on societal transformation towards sustainable energy supply systems, highlighting the role of assessment exercises in transition management[8]. The conclusions of this report are summarized here.

The nuclear controversy only started after demonstration of **global pollution** due to fall out of atomic bomb tests. **Military misuse** and threats had a negative influence on public perception. Not enough coherent attention was given by Belgian nuclear actors to these ethical concerns. It could be addressed in future by a more reticent attitude in new business alliances. Examples are new rich countries having poor democratic standards or leading nations which continue to develop atomic bombs.

When new reactor **sites** were looked for locally in the past, nuclear opposition became organised. This should be considered now in due time for life time extension strategies of Gen II NPPs and other old nuclear facilities and certainly for Gen III proposals in order to organise dialogue before, instead of waiting for reaction on policy making by “fait accompli”. The lack of **siting policy** illustrates a **lack of coherence** as important indicator of integration, required by sustainability. Opposition was first successful in Belgium at the coast where the Zeebrugge site was abandoned. This opposition gradually gained a broader (political) base and finally led to the majority of political parties being in favour of a nuclear phase-out policy. The **phase-out** law of 2003, strongly opposed now by industry, can be considered in this whole context as a logic oscillation movement. It illustrates the risk of poor integration of complex (nuclear) technology in society. Moreover we need to question simple reasoning pro or contra nuclear but to challenge policy makers if they are capable to learn from history in present decision making about phase out and regarding proposals for generation III and IV. A new pendulum movement in public opinion could be disastrous for the so-called “nuclear renaissance” as the period put forward by proposed investments concerns a an entire century.

The **accidental hazard** of NPP’s was not recognised as such in the scientific discourses demonstrated to the public at the time of the **Harrisburg (TMI)** accident**.**

[8] These conclusions are the sole responsibility of the author (prof. Gilbert Eggermont) based on his long experience and involvement in the nuclear sector over the last decades. The views reflected here do not necessarily reflect those of other members of the SEPIA research group. Considering the limited scope of this task in SEPIA and due to the limited human resources capacity available this work has not the ambition to reflect a complete picture of the subject. Mistakes or misinterpretations are the author’s responsibility.

Human error was blamed too much but the strength of safety in depth concepts was demonstrated as well. The destructed NPP remained under control for external environmental releases. Notwithstanding this fact the accident had a disastrous impact on nuclear investments for over 25y. Accidents with large societal impact such as in case of reactor vessel rupture are possible also in Belgium, even with our high safety standards. The probability is very low, more preventive technology is available for new Gen III plants but insurance provisions are still insufficient. The **Chernobyl accident** occurred 25 years ago in the middle of a controversy on fuel cycle transitions (FBR, MOx) and waste. It demonstrated the on-site destructive power together with a need for evacuation of a large region for a long period and illustrated (as atomic bomb tests had already done) the global pollution capacity of nuclear power. Accidents of global impact were considered before as almost impossible by leading nucler experts. The causes were complex and not only related to Russian technological concepts (not criticised before at the international level), but also to political causes, management reliability and lack of criticism in engineering education. It mobilised less biased emergency management worldwide and improved the capacity to measure radioactivity and the modelling of its global dispersion. It was disastrous for the Soviet political system but also for the demonstration of incapacity of western authorities to manage environmental crises and crisis communication.

Nuclear regulatory approaches and the organisation of the State in the face of nuclear risks was delayed for decennia. The state had to take up responsibilities private companies cannot share for long periods (e.g. nuclear waste). The crisis of the nuclear regulatory agency in Belgium, the delay at European level to realise a minimum safety and waste policy harmonisation, as well as the persisting ambiguity of proliferation policies worldwide, has revealed **contradictions in nuclear policy**. Regulatory organisation has been given particular attention in the last three years considering its high importance for public confidence in managing risk complexity. A number of corrections have been made through management optimisation but strategic corrections are limited and still constrained by political manipulation steered more subtle than before by interest groups.

The public refusal of **sea dumping of nuclear waste** was for a long time underestimated but had to stop in the early eighties. A purely anthropocentric expert approach, guaranteeing marginal impact on human health due to the large ocean dilution capacity, had neglected effects on local ecosystems and was no longer tolerated. Incidents had not been communicated to the public. In the Belgian context, this led to waste treatment problems for the Belgian nuclear research centre (SCK) which was at the responsible for nuclear waste management. Technology was not mature as told. An international nuclear waste scandal occurred in Mol

(TRANSNUKLEAR) from 1986 to 1992. The parliamentary enquiries and recommendations had a very negative impact on public opinion. But it allowed also to restructure nuclear R&D independently from waste management. NIRAS became fully operational and NWM started really. Crisis management transformed nuclear culture and had to abandon or decrease industrial financing and in particular to stop the exhausting European fast breeder collaboration (Kalkar, Superphenix). New priorities were set (safety, waste, integration of human & social sciences, medical applications and safety). The management of **nuclear waste** is nowadays presented systematically as technically feasible. Considerable integrated progress was made by the new management of NIRAS, being the first nuclear actor opening its decision-making processes for sustainability assessment structured in transparent risk governance initiatives. But the high-level waste problem is not yet technologically solved. Residual problems were demonstrated by the fundamental move in concept for geological disposal of HL nuclear waste in Boom clay at Mol. Moreover quality control remains the Achilles heel in nuclear waste management. Characterised as it is by a very long time scale a solution not only requires a regulation based on trans-generational values but also transboundary financial arrangements adapted to the globalised European market context of energy liberalisation. This was highlighted during the nuclear waste consensus forum of NIRAS organised by the King Baudouin Foundation.

Generally speaking, the nuclear debate has evolved from a simple pro or con debate into a debate on social distribution and justice. As put forward in the last MIRA report and as came up during the Public Forum on the Waste Plan of NIRAS, the financing of nuclear waste management is not yet solved in this international context as long as the **EC** has not created common rules for international companies to **guarantee funding** over the borders and over long periods. The **transgenerational impact** of nuclear waste disposal is now considered as a major challenge for acceptance, needing policy firmness and communication priority. However, in strong contrast to this message, the drivers of new research strategies create the paradoxical image that new fuel cycle technology no longer requires long time management of nuclear waste. **Coherence** of all these arguments should be assessed independently with new methodologies. Similar participatory efforts as for waste disposal plans should be deployed for siting large scale GenIV R&D projects.

Such **paradoxes** illustrate that a number of historical lessons could remain valid for prospective work. In such an evolutionary context of interests, new approaches of sustainability assessment of transitions can lead to a **coherency check of arguments** over the borders of the nuclear island (see also the contribution of J.Hugé to the SEPIA project). Other demand/supply scenarios made in transition exercises of the Federal Planning Bureau and in EC Delphi Eurendel can broaden the scope beyond the so-called nuclear renaissance.

The **perception**, as an impression of risk reality, and the loss of public confidence as noticed in the late eighties and nineties have to be considered not simply as the result of a lack of information as the Nuclear Forum (cf. *infra*) seems to assume. It is part of a social construct, historically grown and shaped by societal errors or culture defects of the nuclear industry and developers in the past (e.g. lack of coherent messages, low transparency, paradoxes) leading to loss of confidence. There is a serious risk now that the nuclear industry will again commit the same errors, as nuclear development plans gain momentum again within the hope and faith in a nuclear renaissance. Nuclear industry could mobilise public institutions and political representatives to support a recent **communication** or **promotion campaign** (organised by the Nuclear Forum, a platform of companies active in the Belgian nuclear sector) in order to change or delay the phase out law. This occurs without installing the necessary research based process mechanisms (RISCOM) to organise transparency claiming control as well on the truth, the authenticity as the legitimacy of the message.

The international dynamics has added the new dimension of **globalisation** to the nuclear debate. At the **European** nuclear level we still **lack sufficient regulation** (e.g. harmonised nuclear reactor safety criteria and control) and we lack policy coherence on environmental concepts between EURATOM and decision making based on other treaties. A transboundary solution for nuclear waste is made almost impossible but will be a condition sine qua non for residual nuclear waste management in GenIV, if realised. The globalisation of main actors and the European liberalisation of electricity production, was unsuccessful in its market results. Oligopolies in the electricity sector remain capable of paralysing national political forces (citing the late EC Commissioner K.Van Miert in his last interview) Fundamental contradictions are illustrated in French nuclear policy with the the refusal to accept nuclear waste from activities of French utilities abroad. The EPR crisis on the contrary confronts the largest nuclear actors in the world strategically with their inherent weaknesses regarding large scale new investments.

Overall, the application of present SD principles to the nuclear sector shows a poor balance.

The nuclear discourse has strategically taken up sustainability elements related to climate issues. The demand for more proactive assessment and precaution and for comparative **sustainability assessment** has shown to be a difficult task for the sector. Experts and institutions in the nuclear sector in particular face cultural difficulties with the transition towards sustainability. There is an absolute lack of independent expertise which is not particular for the nuclear sector.

The nuclear experience illustrates **lack of integration** of a technological sector in society. Paradoxically this contrasts with the robustness of the sector supported by international networks and still strongly financed by the government.
Precaution is almost not belonging to the culture of the nuclear sector notwithstanding important precursors such as ALARA in radiation protection and safety culture.
Equity is handicapped more than ever and requires international measures for nuclear waste and liability (insurances) recognising the transgenerational and transboundary nature of the challenges.
Stakeholder participation is on a turning point and should not be limited to blocked regional nuclear waste problem solving. They should be organised proactively as dialogue on future options conditioned by lessons learned from the past.
The **global responsibility**, once characterised by the strength and pro-activity of European nuclear policy (EURATOM treaty) is reduced to a conglomerate of national initiatives without global ambitions for common safety criteria and guaranteed waste funding and quality control at EC level.

The international fora on alternative nuclear fuel cycles (GenIV) present new generations of nuclear technology as sustainable contributions to climate challenge based on optimised resource use, long term waste reduction, proliferation resistance and safety improvements. But ecosystem approaches as for the atmosphere are paradoxically not yet applied within the nuclear sector. While mobilising huge innovation budgets for financing these future “sustainable” R&D strategies the EU was **unable to harmonise** waste and nuclear safety management and could not agree on a nuclear weapon-free zone in the Middle East, a *conditio sine qua non* for solving the proliferation challenge.

It can no longer been excluded that, considering the required huge budgets and time scales of development, internal competition and even **controversy between the nuclear renaissance generations** will come up. A fine-tuning around plutonium availability between Gen II/III and IV is inherent in coming decennia. Controversy started on the relevance of Gen V (fusion) after doubling of project costs of ITER in Cadarache.
To conclude the considerations on all nuclear nuclear reactor generations (Gen I-V), we remark that the financial crisis has shown that intragenerational transboundary ethics are still lacking within the overall dynamics of globalisation, while **conflicts of**

interests still confuse politics at national level. The nuclear sector is technologically at least as complex and vulnerable as the financial sector and lack of transparency with bubble arguments were common to both. Nuclear also faces a transgenerational ethical challenge in nuclear waste management which also has transboundary characteristics. Locally, inefficient national solutions (from an economic point of view) are still to be set up institutionally. New participative initiatives are not yet formalised as demonstrated by the FANC approach for NIRAS proposals.

Setting and controlling conditions for acceptance of new technological developments seems a never ending discovery where few lessons are learned.

2.5 Multi-criteria decision support

The multi-dimensional nature of sustainability imposes that public plans or strategic decisions are evaluated with procedures explicitly integrating a broad set of (possibly conflicting) points of view. Hence, multi-criteria evaluation is a most appropriate decision framework (Kowalski et al. 2009). A variety of multi-criteria decision support tools can be used in sustainability assessments under both the 'policy as discourse' and the 'policy as calculus' philosophy. Each analysis method is based on specific assumptions and supports only a certain type of analysis. The preference for one particular tool must follow from its fitness for the problem characteristics and the desired scope/features of analysis. A promising start for reflection on the application of multi-criteria decision support in sustainability assessment is provided by Munda (2004) and Granat and Makowski (2006). For complex decision-making problems Munda (2004) developed the 'social multi-criteria evaluation' (SMCE) technique, applied to wind farm location problems by Gamboa and Munda (2007). Granat and Makowski (2006) find as required properties of a multi-criteria decision analysis tool for a stakeholder evaluation of energy technologies and scenarios at the European level:

- The multi-criteria method can handle criterion scores of a different nature ('crisp' scores, stochastic scores, 'fuzzy' scores, etc.);
- In general, simplicity is a very desirable characteristic of the multi-criteria decision process – i.e. the number of *ad hoc* parameters used should be limited (preferably only information on weights and on scores should be used as exogenous inputs);
- Criterion weights should be seen as 'importance coefficients' (and not as numerical values allowing for full compensability between criteria or as indicators of a 'trade-off' between different criteria);
- Information on all possible rankings for each actor should be given (and not only on the 'optimal' one, since taking into account second-best or third-best

options can reveal a space for compromise solutions compared with other actors’ rankings);

- The multi-criteria appraisal should include a ‘conflict analysis’ (i.e. an analysis of the ‘distance’ between the different actor perspectives, revealing possible groupings into major ‘world-views’). As win-win situations are not always achievable, some trade-offs will have to be made. These trade-offs will then appear in the discussions on values stimulated by the use of the multi-criteria appraisal and will give normative input to consequences of selecting one alternative over another. Mathematical models can then be of assistance in the selection of the most consensual alternative, regroup alternatives according to the results of the conflict analysis, etc.

2.5.1 Brief introduction to fuzzy-set multi-criteria analysis

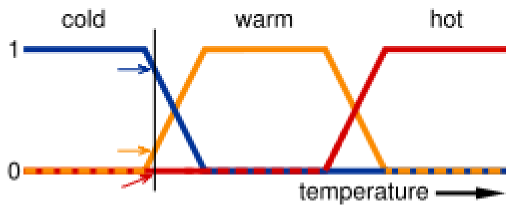
To claim the motivation of the use of fuzzy-set multi-criteria analysis, we briefly introduce the reader to the principles of fuzzy logic and the particular advantages of using a fuzzy-logic multi-criteria group decision support tool named DECIDER, which was chosen for the evaluation of the energy scenarios by the stakeholder panel in the context of the SEPIA project based on earlier experiences (Ruan et al. 2010).

2.5.1.1 Fuzzy logic

Fuzzy logic deals with reasoning that is approximate rather than precise. In fuzzy logic the truth degree of a statement can range between 0 and 1 and is not constrained to the two truth values {true, false} or {yes, no} as in classic binary logic. And when *linguistic variables* (Zadeh, 1975) are used (as is the case in the DECIDER tool), these degrees are modelled by specific mathematical functions (e.g. membership functions in fuzzy logic as shown in Fig. 4). The difference between ‘classic’ and ‘fuzzy’ logic can be illustrated by the example of a 100-ml glass containing 30 ml of water. We may consider two concepts: ‘Empty’ and ‘Full’. In classic logic, the phrase “*the glass is empty*” can only have one ‘truth value’ (i.e. true or false). In fuzzy logic, the meaning of ‘empty’ or ‘full’ can be represented by a certain fuzzy set. One might define the glass as being 0.7 empty and 0.3 full. Clearly, the concept of ‘emptiness’ is subjective and would depend on the observer or designer. Another observer might equally well consider the glass to be ‘full’ for all values down to 50 ml. It is essential to realise that fuzzy logic uses truth degrees as a mathematical model of the vagueness of human judgement which is quite simply prevalent in all kinds of decision situations.

To illustrate the use of *linguistic variables*, consider the example of the temperature of the liquid contained in the glass. Each function maps the same temperature value to a truth value in the 0 to 1 range. These truth values can then be used to determine e.g. whether the liquid is too hot or too cold to drink.

Fig. 9. Illustration of membership functions



In Fig. 9, the meaning of the expressions cold, warm, and hot is represented by functions mapping a temperature scale. A point on that scale has three ‘truth values‘ – one for each of the three functions. The vertical line in the image represents a particular temperature that the three arrows (truth values) gauge. Since the red arrow points to zero, this temperature may be interpreted as “not hot”. The orange arrow (pointing at 0.2) may describe it as “slightly warm” and the blue arrow (pointing at 0.8) “fairly cold”.

2.5.1.2 Application of fuzzy logic to sustainability assessment

It is fair to say that some clear measures or, at least, indicators of sustainability exist, but the overall effectiveness of policies towards a goal of sustainability cannot be assessed. Attempts have been made to measure sustainability using the economical, the ecological, or a combined ecological–economic approach, but the results still lack universal acceptance (Laes 2006). For the sake of analysis, researchers have broken down sustainability into a large number of individual components or indices whose synthesis into one measure appears to be next to impossible. As pointed out in the literature, it is not so much that environmental and socio-economical information is lacking but the fragmentary, often qualitative, and very detailed nature of this information hampers its direct usefulness in policy making. Not only are there no common units of measurement for the indicators of sustainability, but quantitative criteria for certain values are lacking. A systemic method based on a reliable scientific methodology, which combines multidimensional components and assesses uncertainty, is needed. In reality, the border between sustainability and unsustainability is most of the time not sharp but rather fuzzy. This means that it is not possible to determine exact reference values for sustainability, and a scientific evaluation of uncertainty must always be considered in the procedure of sustainability assessment. For this reason, the use of natural language and linguistic values based on the fuzzy logic methodology (Munda et al. 1994) seems more suitable to assess sustainability.

2.5.2 Fuzzy-set multi-criteria decision support in the SEPIA context

Multi-criteria analysis (MCA) with linguistic variables, commonly known as fuzzy-set multi-criteria decision support, has been one of the fastest growing areas in decision making and operations research during the last three decades. The motivation for such a development is 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. 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 (scenarios), and judgments (weights) for criteria (indicators). Moreover, MCA aims at supporting decision makers who are faced with making numerous and conflicting evaluations. It highlights these conflicts and derives a way to come to a compromise or to illustrate irreducible value conflicts in a transparent process. First, as decision aiding tools, such methods do not replace decision makers with a pure mathematical model, but support them to construct their solution by describing and evaluating their options. Second, instead of using a unique criterion capturing all aspects of the problem, in the multi-criteria decision aid methods one seeks to build multiple criteria, representing several points of view. In particular, fuzzy-set multi-criteria decision support respects the principles of the ‘policy as discourse’ approach. This will be illustrated in the next section by the application of the DECIDER decision support tool to the SEPIA project.

There are many ways to evaluate these scenarios. Due to the complexity of this study, different experts will have different views under various uncertain information for different scenarios. Experts’ views are often expressed in certain linguistic variables and some undetermined values during the evaluation procedure. In some original multi-criteria exercise for instance the PhD thesis described in Laes (2006), only crisp values for weights and criterion scores were used. In a later application, we have softened those crisp values into certain fuzzy numbers that better reflect perception based views from experts (Ruan et al. 2010). Hence the integration of multi-criteria decision making, group decision making and fuzzy logic systems is recommended to carry out for this study. Based on the development of a rational-political group decision model (Lu et al. 2007; Marimin et al. 1998), three uncertain factors involved in a group decision-making process are identified: decision makers’ roles (weights), preferences (scores) for alternatives (scenarios), and judgments (weights) for criteria. Hence, the DECIDER decision support software has been constructed and applied to the SEPIA project. The mathematical details of the designed stages and steps and the algorithm of the tool are outlined in Annex 4 & 5.

2.6 Results of the multi-criteria evaluation

The scenarios were then to be evaluated by the stakeholder panel on the basis of the sustainability value tree. To this purpose, the stakeholders were first contacted on 14 April 2010 (by e-mail) with a detailed description of the scenarios and an (extended) questionnaire. We received only one response within the foreseen deadline. A greatly simplified questionnaire (regrouping the very detailed sub-criteria into larger overarching criteria) was subsequently sent on 4 May 2010. We individually contacted each of the stakeholders in order to stimulate participation or elicit reasons for not participating. Because of the low response rate, the deadline was further extended through another e-mail on 24 June 2010**.** Finally, 7 questionnaires were returned; 1 of these questionnaires was only partly completed making it unsuitable for further analysis. Results in this section are based on the six stakeholders' surveys. To avoid all real information of the six stakeholders, we have renamed the real names of them as Expert 1 (e1), Expert 2 (e2), …, Expert 6 (e6).

There were eight objectives to be evaluated by each expert against each of the three scenarios. Each objective has a variable number of criteria (cf. Fig. 2). For the simplicity of the calculated results, we name all of them as the form of *a.b*, where *a* (as a number from 1 to 8) refers to one of the eight objectives, *b* (as a number from 1 to 4) refers to one of the criteria under each objective, i.e.,
1.1;
2.1, 2.2, 2.3, 2.4;
3.1, 3.2;
4.1;
5.1;
6.1, 6.2, 6.3;
7.1, 7.2;
8.1, 8.2.
For each separate objective, each expert assigns the importance of that objective in terms of reaching a sustainable energy system in Belgium in 2050. Scoring of importance is based on a linear scale of "*very high*," "*fairly high*," "*medium*," "*rather low*," and "*very low*," in addition to "no answer" or "blank tick". By common sense, on a scale of 0-100

- "*very high*" means over 90%
- "*fairly high*" means around 70 to 80%
- "*medium*" means about 50%
- "*rather low*" means around 20 to 30%
- "*very low*" means below 10%.

Scores in terms of linguistic variables (see Zadeh, 1975) are also called fuzzy numbers. For each separate criterion, each expert was asked to express his opinion on the likelihood of fulfilling that particular criterion for each of the different scenario storylines. Scoring is again based on a linear scale of "*almost certain*," "*very likely*," "*likely*," "*unlikely*," and "*highly unlikely*," in addition to "no answer." For those terminologies (also known as fuzzy numbers)

- "*almost certain*" means just that
- "*very likely*" means more than a 9 out of 10 chance
- "*likely*" means more than a 2 out of 3 chance
- "*unlikely*" means less than a 1 out of 3 chance
- "*very unlikely*" means less than a 1 out of 10 chance.

Notes: the above explanations might have been useful in communicating to the public and to policy makers. It is only for some understanding, but not for any further calculating as standard statistics or probability theory will not be adequate for this kind of calculations. Annex 4 records the inputs of the six stakeholders.

2.6.1 An illustrative example for a crisp case of multi-criteria decision making applications

Before given the detailed results to be calculated by a fuzzy-logic multi-criteria group decision support tool named DECIDER (Ruan et al. 2010), we have a simple numerical example to show the working principle for a multi-criteria decision making application. The following steps are illustrated in the form of the DECIDER algorithm when only real numbers are involved only. The illustration is to show how calculations are actually done when fuzzy numbers are replaced by crisp numbers.

<u>Step 1</u>: identify experts, criteria, and sub-criteria (if any)

For example, the evaluation model (without any sub-criteria) is identified as:

- 2 criteria (c1, c2)
- 3 scenarios (S1, S2, S3)
- 3 experts (e1, e2, e3)

<u>Step 2</u>: identify weights for experts

The weights for three experts are all 1/3 (one may change their weights in any values).

<u>Step 3</u>: identify weights for criteria.

The weights for all criteria {c1, c2} are ½ (one may change them as well if desired)

Step 4: set up the relevance degree (score, overall assessment) on leaf criterion
In the given example, the two leaf criteria are c1 and c2. For c1, the relevance is computed as below. Here, we take scenarios S1 as an example. For scenario S1, the assessments from three experts are

	e1	e2	e3
c1	0.2	0.1	0.8
c2	0.6	0.9	0.6

Therefore, the relevance degree (score, overall assessment) Ass^1 C1 of the expert group ({e1, e2, e3}) in terms of c1 is

Ass^1 c1 = 1/3*0.2 + 1/3*0.1 + 1/3*0.8
= 0.367
Similarly, the overall assessment Ass^1 c2 of the expert group in terms of c2 is
$Ass^{1\ c}$2 = 1/3*0.6 + 1/3*0.9 + 1/3*0.6
= 0.7

Step 5: compute the relevance degree (score, overall assessment) for all criteria
In the given example, the overall assessment Ass^1 of the expert group in terms of {c1, c2} is

Ass^1 = 0.5*0.367 + 0.5*0.7
= 0.5335

For scenarios S2 and S3, the similar process is shown as follows.
For scenario S2, the assessments from three experts are

	e1	e2	e3
c1	0.3	0.3	0.6
c2	0.5	0.5	0.4

Therefore, the overall assessment Ass^2 c1 of the expert group in terms of c1 is
Ass^2 c1 = 1/3*0.3 + 1/3*0.3 + 1/3*0.6
= 0.4

The overall assessment Ass^2 c2 of the expert group in terms of c2 is
Ass^2 c2 = 1/3*0.5 + 1/3*0.5 + 1/3*0.4
= 0.467

Hence, the overall assessment Ass^2 of the expert group in terms of {c1, c2} is

Ass^2 = 0.5*0.4 + 0.5*0.467

= 0.434

For scenario S3, the assessments from three experts are

e1	e2	e3	
c1	0.4	0.5	0.4
c2	0.4	0.1	0.2

Therefore, the overall assessment Ass^3 c1 of the expert group in terms of c1 is

Ass^3 c1 = 1/3*0.4 + 1/3*0.5 + 1/3*0.4

= 0.433

The overall assessment Ass^3 c2 of the expert group in terms of c2 is

Ass^3 c2 = 1/3*0.4 + 1/3*0.1 + 1/3*0.2

= 0.233

Hence, the overall assessment Ass^3 of the expert group in terms of {c1, c2} is

Ass^3 = 0.5*0.433 + 0.5*0.233

= 0.333

Step 6: rank all scenarios

The rank of all scenarios in terms of {c1, c2} is S1>S2>S3 because the overall assessments of them are 0.5335, 0.434, and 0.333, respectively.

2.6.2 Results for the ranking of the SEPIA scenarios

Here we have two tasks:

(1) Experts' individual and aggregated assessments on the three scenarios.

(2) Experts' order for three scenarios.

In the DECIDER software tool, both tasks are conducted simultaneously. The implementation includes three steps as follows.

Step 1: Obtain expert’s individual assessment on three scenarios.

Input: each expert’s assessments on three scenarios and eight objectives.

Output: each expert’s aggregated assessments on each scenario and an order of the three scenarios based on the aggregated assessments. (Cf. Annex 4 for details of the used aggregation method in the DECIDER tool.).

The report takes “Expert 1” as an example to illustrate the implementation.

Table IX: Assessment from Expert 1

Name	Objective		Criterion	global consensus	Confidence R&D	Oil Shock
	#	Importance	#			
Expert 1	1	very high	1.1	unlikely	likely	almost certain
	2	fairly high	2.1	likely	likely	almost certain
			2.2	unlikely	likely	very likely
			2.3	highly unlikely	very likely	almost certain
			2.4	likely	likely	very likely
	3	fairly high	3.1	almost certain	very likely	almost certain
			3.2	likely	unlikely	very likely
	4	Medium	4.1	very likely	likely	very likely
	5	very high	5.1	almost certain	very likely	likely
	6	fairly high	6.1	likely	unlikely	likely
			6.2	unlikely	unlikely	?
			6.3	highly unlikely	unlikely	likely
	7	Medium	7.1			
			7.2	very likely	very likely	very likely
	8	Medium	8.1	unlikely	highly unlikely	very likely
			8.2	unlikely	unlikely	likely

Step 1.1: Process for missing data and clarify data semantics.

Assessments of Expert 1 are given in Table IX. This table is pre-processed to amend missing and unclear semantics.

There are three pre-processing issues, i.e.

(a) “**importance” of criteria**: Let importance of each sub-criterion inherent from that of its objective. For example, importance of criterion 2.1 is set to be “fairly high”.
(b) “**no answer” response**: Any “no answer” criterion will be removed from aggregating. For example, Expert 1 gave no answers for three scenarios with respect to criterion 7.1. Hence, aggregating will not consider criterion 7.1.
(c) **“question mark” response**: A question mark indicates that an expert may have different opinion or confuse with a criterion. Any criterion with a question mark will be removed from aggregating.

Step 1.2: Represent assessments.

To apply the DECIDER tool to the SEPIA project, the used linguistic terms in DECIDER (right column in Table X) have been mapping to those in the given response to the three scenarios (left column in Table X).

Table X: Mapping between the real used and DECIDER provided terms (for scenario assessments)

Terms used in responses	**Terms used in DECIDER**
almost certain	very high
very likely	high
likely	medium
unlikely	low
highly unlikely	very low
no answer	

Similarly, the used terms for importance in DECIDER (right column in Table XI) have been also mapping to those for impotence of objectives in the SEPIA project.

Table XI: Mapping between the real used and DECIDER provided terms (for objective importance)

Terms used in response	**Terms used in DECIDER**
very high	very high
fairly high	high
medium	medium
rather low	low
very low	very low
no answer	

<u>Step 1.3</u>: Input assessments into DECIDER

The assessment information includes four forms.
Structure of objectives
Structure of experts
Expert 1's assessment on three scenarios
Expert 1's assessment on listed objectives
Below screenshots are used to illustrate above four kinds input information.

Fig. 10: Structure of objectives

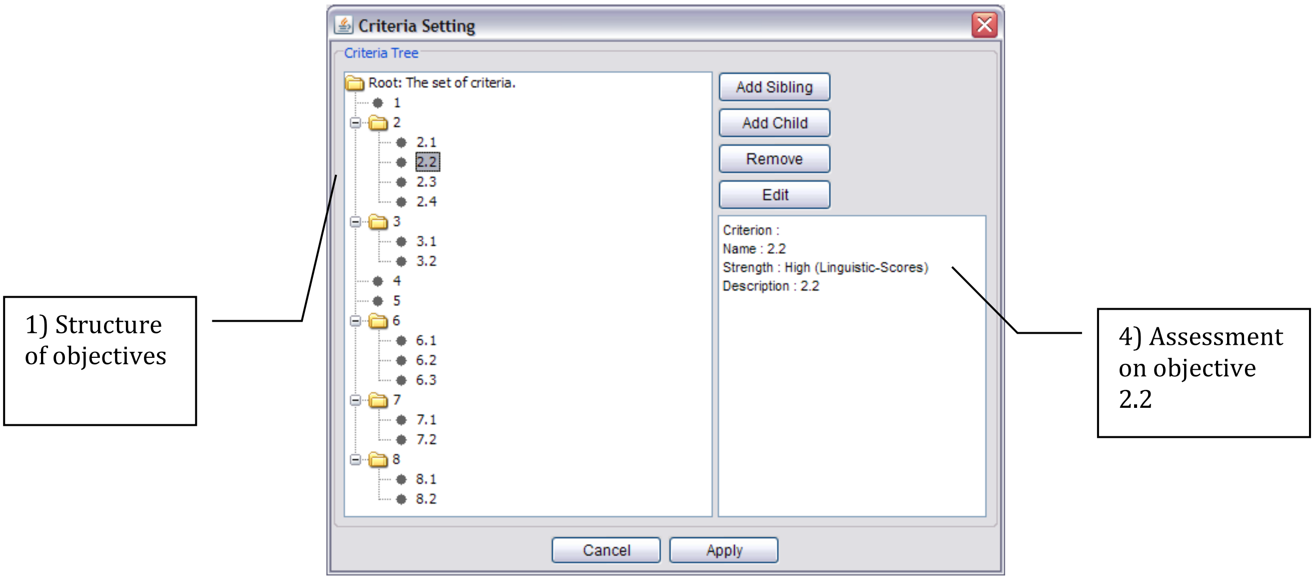


Figure 10 illustrates the structure of the listed objectives and expert 1’s assessment on the given objectives. The listed objectives are organized in a tree-like structure with a virtual root node “Root” to the left in this figure. The expert 1’s assessment on objective 2.2 is shown to the right.

Figure 11 illustrates the assessments of Expert 1 on three scenarios. For instance, the highlighted item indicates that Expert 1’s assessment on *Global-Consensus* (inner label in DECIDER is <u>Alternative 1</u>) in terms of *objective 2.2* (inner label in DECIDER is <u>Information Source 5</u>) is a linguistic term “*low*” (corresponding to the given term “*unlikely*”).

Fig. 11: Assessment of scenarios

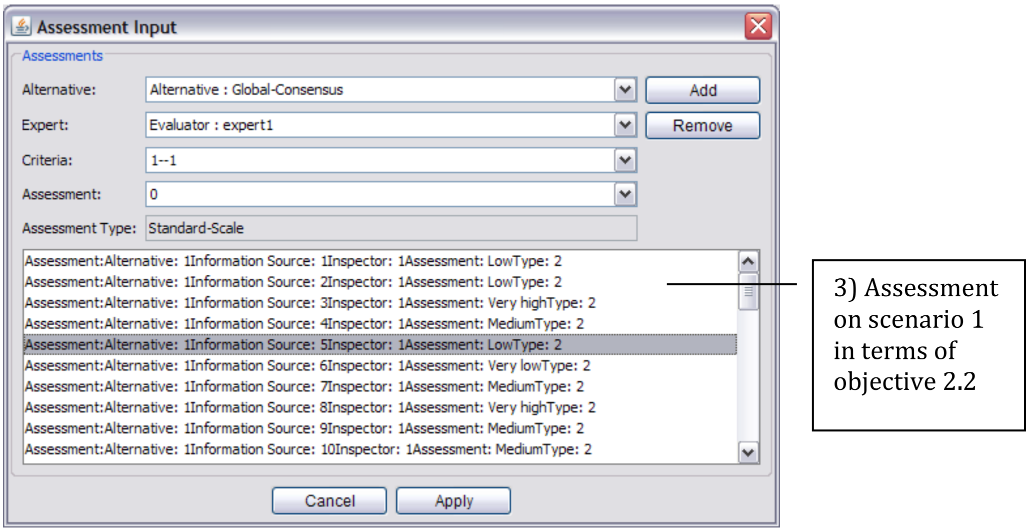
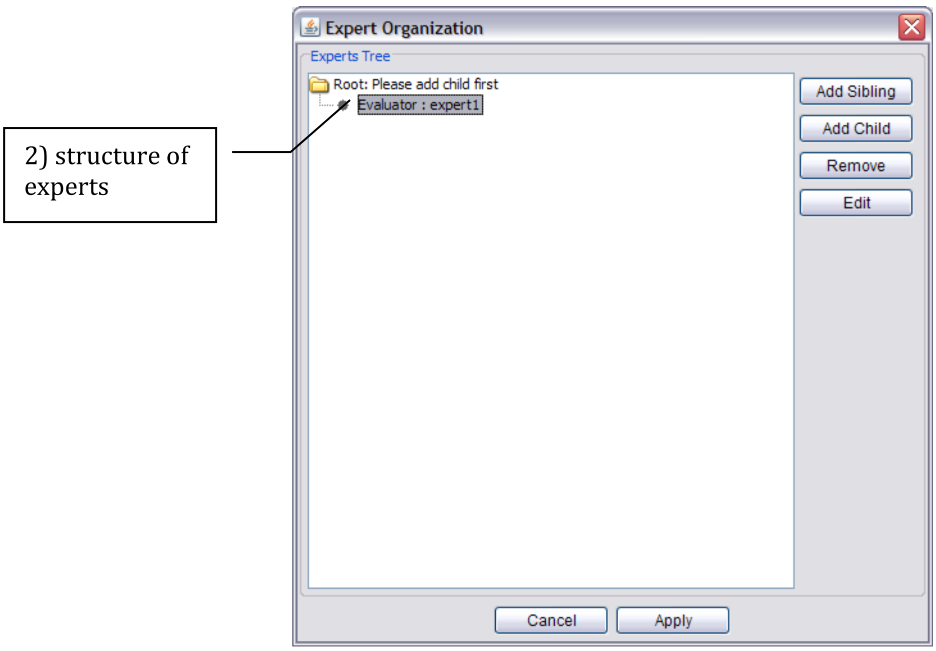


Fig. 12: Structure of experts

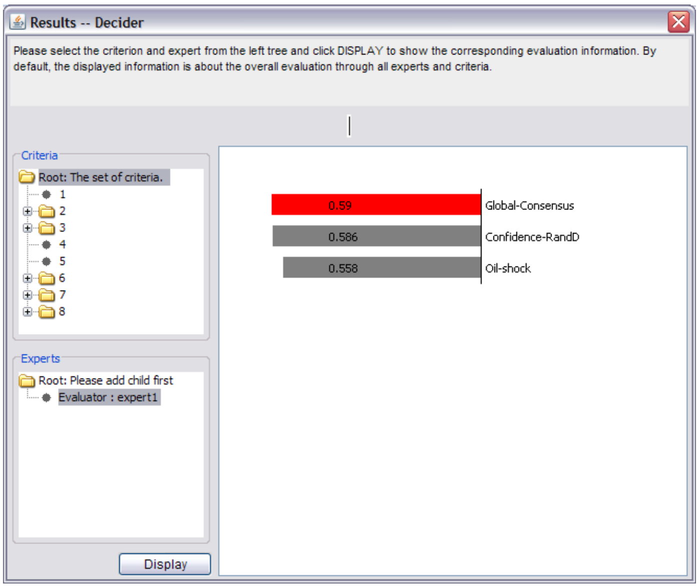


This screenshot illustrates the structure of experts. Because this case focuses on Expert 1 only, the tree-like structure of experts just includes Expert 1 and a virtual root “Root”.

Step 1.4: Select evaluation model and conduct evaluation.

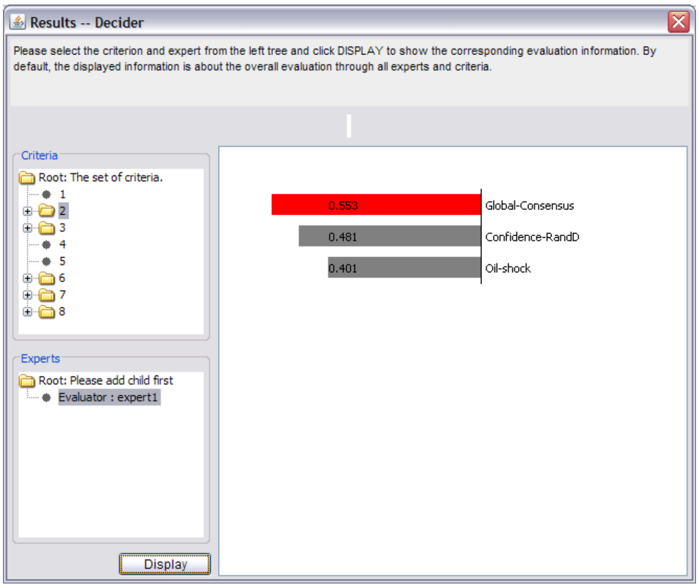
Step 1.5: Display evaluation result.
This case selects the Fuzzy Multi-criteria group decision making (MCGDM) evaluation model [Lu, et al., 2007] to conduct evaluation. Below are some screenshots of evaluation results.

Fig. 13: Evaluation result on Objective 1



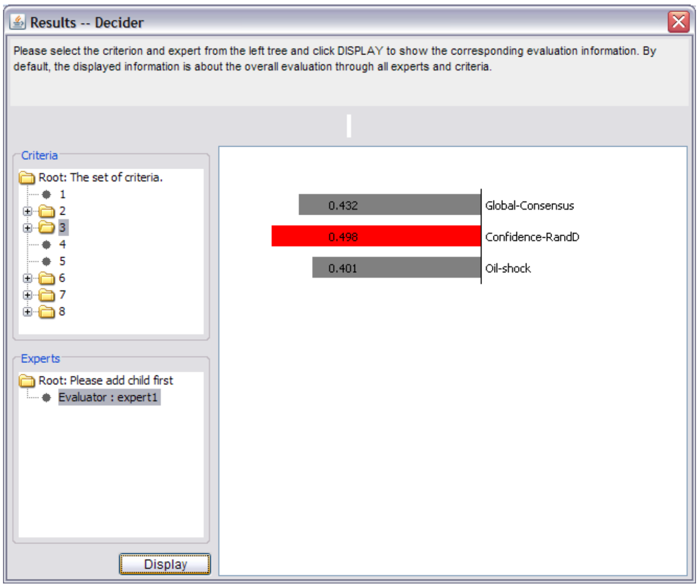
The overall evaluation result from expert 1 with respect to all listed objectives, where the order of the three scenarios is Global-Consensus > Confidence-R&D > Oil-Shock (G>C>O)

Fig. 14: Evaluation result on Objective 2



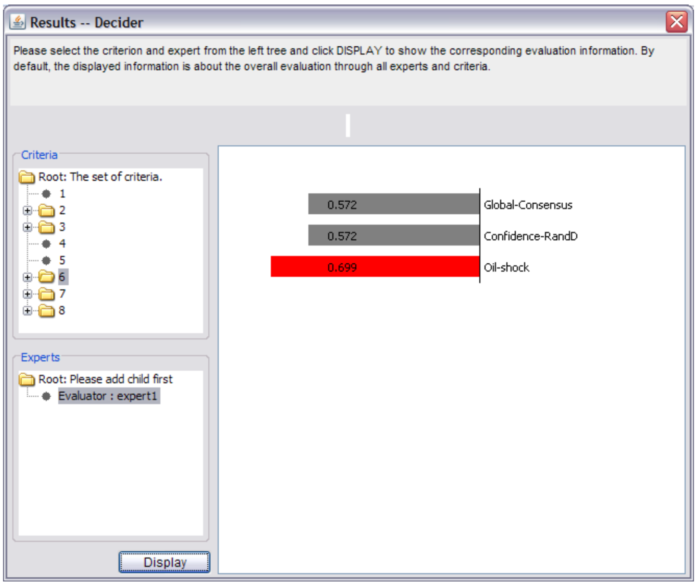
The evaluation result from expert 1 with respect to Objective 2, which indicates that the order of the three scenarios is the same.

Fig. 15: Evaluation result on Objective 3



The evaluation result from Expert 1 with respect to Objective 3, which indicates that the order of the three scenarios is Confidence-R&D > Global-Consensus > Oil-Shock (C>G>O).

Fig. 16: Evaluation result on Objective 6



The evaluation result from Expert 1 with respect to Objective 6, which indicates that the order of the three scenarios is Oil-Shock > Global-Consensus (= Confidence-R&D) (O>G=C).

Similarly, the evaluation results for other experts can be obtained. Table 4 summaries the evaluation results of the six experts. The table is read as:

- Objective "1-8" is the evaluation result based on all eight objectives
- Objective "X" is the evaluation result based on objective X
- symbol ">" indicates the "better than" relation
- symbol "=" indicates the "equal to" relation

Table XII: Individual evaluation results on the given objectives.

objective	expert 1	expert 2	expert 3	expert 4	expert 5	expert 6
1-8	G>C>O	C>G>O	G>O>C	O>C>G	O>C>G	O>C>G
1	O>C>G	G=C>O	O>C>G	G>C>O	G>C>O	G>C>O
2	G>C>O	G>C>O	G>C>O	O>C>G	O>C>G	O>C>G
3	C>G>O	C=O>G	O>G>C	G>C>O	O>C>G	O>C>G
4	G=O>C	G=C=O	C=O>G	G>C>O	G>C>O	G=C=O
5	G>C>O	G=C=O	O>C>G	C>G>O	G>C>O	G=C=O
6	O>G=C	C>G>O	O>G=C	C>G>O	O=C>G	O>C>G
7	G=C=O	G=C=O	G>O>C	O>C>G	O>C>G	O=C>G
8	G=C>O	G=C>O	G>C>O	G=C>O	O>C>G	O>C>G

Remark *Expert 5 did not given any assessments on importance of objectives. This case treats all objective with same importance “**medium**” for two reasons: 1) the importance setting will not influence the evaluation results if we just focus on the single Expert 5, i.e., changing “medium” to other importance description will not change the evaluation result of Expert 5; and. 2) the importance description given by Expert 5 will affect the evaluation result of the whole group experts, the setting may reduce this influence. Generally speaking, setting the importance to “medium” is a rational trade-off between without information and reducing influence.*

Step 2: Aggregate six experts’ assessments as a whole

<u>Step 2.1</u>: Reset objective importance.
Five out of the six experts have presented their assessments on objective importance. The objective importance in this case is reset based on the following simple-majority principle:

The most occurred term for an objective will be used as its importance.

For instance, three out of five provided assessments on importance of Objective 1 are “very high”; therefore, the importance of Objective 1 is “very high.” Below is the resetting of importance of all eight objectives.

Table XIII: Reset importance of objectives.

Objective	**Reset importance**
1	very high
2	fairly high
3	fairly high
4	very high
5	fairly high
6	fairly high
7	very high
8	fairly high

<u>Step 2.2</u>: Assign impacts of experts.
Because no impact of experts is presented, this case assumes that all experts are with the same impact; and sets it to “*high*.”

Step 2.3: Aggregate six experts’ assessments.
Using the similar processing steps, six experts’ assessments are aggregated in Table XIV.

Table XIV: Group evaluation results on the listed objectives.

Objective	**Expert group**
1-8	G>C>O
1	G>C>O
2	G>C>O
2.1	G=C>O
2.2	G>C>O
2.3	G>C>O
2.4	G=C>O
3	C>G>O
3.1	C>G=O
3.2	C>G>O
4	G=O>C
5	O>C>G
6	O>G=C
6.1	C>G=O
6.2	O>G=C
6.3	G>C>O
7	G=C=O
7.1	G=C=O
7.2	G=C=O
8	C>G>O
8.1	C>G>O
8.2	G=C>O

From Table XIV, we conclude for all six experts by taking into account all eight objectives the order of the three scenarios are Global Consensus (G)> Confidence R&D (C) > Oil Shock (O). For each of the eight objectives, the orders of the three scenarios by the six experts are also indicated in Table XIV as well.

2.6.3 Clustering of experts’ opinions

Munda’s (2009) idea on a conflict analysis approach for illuminating distributional issues in sustainability policy is interesting. By calculating the ‘distance’ between the revealed preferences of the different experts, one can obtain the similarities between two experts, their evaluations on some objectives. However, the way of the Munda’ calculation is rather complicated and needs a specific software tool from his mathematical algorithm (See B. Matarazzoa, G. Mundab). Here we will present an alternative way of clustering of experts’ opinions.

Refer to Table XII on the six experts’ evaluations based on the selected objectives as follows:

objective	expert 1	expert 2	expert 3	expert 4	expert 5	expert 6
1-8	G>C>O	C>G>O	G>O>C	O>C>G	O>C>G	O>C>G
1	O>C>G	G=C>O	O>C>G	G>C>O	G>C>O	G>C>O
2	G>C>O	G>C>O	G>C>O	O>C>G	O>C>G	O>C>G
3	C>G>O	C=O>G	O>G>C	G>C>O	O>C>G	O>C>G
4	G=O>C	G=C=O	C=O>G	G>C>O	G>C>O	G=C=O
5	G>C>O	G=C=O	O>C>G	C>G>O	G>C>O	G=C=O
6	O>G=C	C>G>O	O>G=C	C>G>O	O=C>G	O>C>G
7	G=C=O	G=C=O	G>O>C	O>C>G	O>C>G	O=C>G
8	G=C>O	G=C>O	G>C>O	G=C>O	O>C>G	O>C>G

In this case, the similarity S between expert X and expert Y is defined by the total reward points assigned according to their evaluations. The reward point is assigned based on the following simple rules:

Rule 1. If two experts gave the same order of the three scenarios on the group objectives “1-8”, a reward value 3 will be assigned; otherwise, 0.

Rule 2. If two experts gave the same order of the three scenarios on an individual objective, a reward 1 will be assigned; otherwise, 0.

<u>Example 1</u>: The similarity points for Expert 4 and Expert 5.
Because Expert 4 and Expert 5 gave the same order on the individual objectives 1, 2, 4, and 7, the reward points for individual objective are 4 (=1+1+1+1) by Rule 2.

Because Expert 4 and expert 5 gave the same order on the eight objectives as a whole, the reward points for the group objectives are 3 by Rule 1. Therefore, the total reward points are 7(=4+3).

<u>Example 2</u>: The similarity points for Expert 4 and Expert 3.
Because Expert 4 and Expert 3 did not give the same order of the three scenarios on any individual or group objectives, the reward point is 0. Hence, the total reward point between these two experts is 0.

The total reward points between pair wise experts are as represented in Table XIV.

Table XIV: Total reward points by pair-wise comparison between experts

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
Expert 1	=	**3**	**3**	1	2	0
Expert 2		=	1	2	0	2
Expert 3			=	0	1	1
Expert 4				=	**7**	5
Expert 5					=	**7**
Expert 6						=

From the above table, the six experts can roughly be divided into two groups, i.e., the first group is composed of Experts 1, 2, 3 and the second group includes Experts 4, 5, 6. In particular, Experts 4, 5, and 6 gave the same order for the three scenarios on the eight objectives as a whole; and they also had the same assessments on Objective 1 and Objective 2.

Remarks: The above clustering way of experts’ opinions is rather rough and simple. It won’t give a systematic manner for any further analysis, especially, when the number of experts increases. Therefore, during the SEPIA project, we have also researched other approaches to Munda’s idea. One of the newly developed approaches is to use Belief Degree Distributed Fuzzy Cognitive Maps (BDD-FCMs) (see Kabak and Ruan, 2010; Mkrtchyan and Ruan, 2010) for the SEPIA project.

In BDD-FCMs we use belief structures to represent the general belief of experts about the given relationship between one criterion and one scenario for instance in the SEPIA project. With the given linear scale of "*almost certain*," "*very likely*," "*likely*," "*unlikely*," and "*highly unlikely*," an expert may express his/her opinion by the following statement: he/she has 60 % about "*likely*," 20 % about "*unlikely*," 10% about "*highly unlikely*," and 10% on "unknown" (not sure). Here the percentages are referred to as the belief degrees that indicate the extents that the corresponding grades are assessed. The belief structure in this case is {(0, *almost certain*), (0, *very likely*), (0,6, *likely*), (0,2, *unlikely*), (0,1, *highly unlikely*) } . Note the sum of all percentages is 0, 9, which is less than 1. This means there is some 10% "unknown" info. By this belief structure, we can easily convert all scores (one of the five items from Appendix 1) as for instance, Expert 1 for the item 6.2 for the three scenarios scored as "*unlikely*," *unlikely*," and with a "?" mark , respectively, could be converted as {(0, *almost certain*), (0, *very likely*), (0, *likely*), (1, *unlikely*), (0, *highly unlikely*) }, {(0, *almost certain*), (0, *very likely*), (0, *likely*), (1, *unlikely*), (0, *highly unlikely*) }, and {(0,2, *almost certain*), (0,2, *very likely*), (0,2, *likely*), (0,2, *unlikely*), (0,2, *highly unlikely*) }, respectively, in the belief degree structures. The"?" mark could mean everything as a kind of possibility distribution within this framework of BDD-FCMs, which allows us to calculate the 'distance' between the revealed preferences of the different experts.

Fig. 17: Dendrogram of the cluster formation process

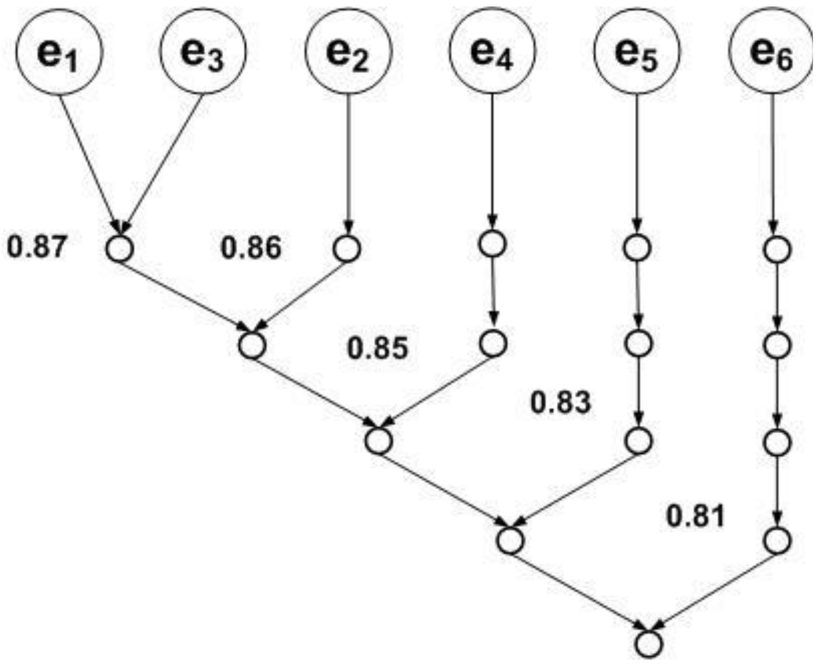


Figure 17 gives us the following information:

- The opinions of e1 and e3 are closest to each other (as expressed by the similarity degree of 0,87). Therefore, they are the most likely candidates for a 'coalition'. Therefore, if we want to simplify the decision process and work with just five opinions instead of the original six, e1 and e3 are the most likely candidates to be taken together without major conflicts (i.e., represented by an 'average opinion');
- The opinions of e2 is closer to those of e1 and e3 with the similarity degree of 0,86. And so on for the rest of e4, e5, and e6 as clearly shown.
- Indeed, we could also see roughly two groups such as (e1, e2, e3) and (e4, e5, e6) as the DECIDER tool gave above.

2.6.4 Conclusions

The DECIDER tool is a very flexible tool for decision support in political contexts. It respects the requirements for multi-criteria decision aiding in this context as set out in Section 2.2.3. The main results in the context of the SEPIA project are the individual expert evaluation results on the given objectives, the six-expert group evaluation results, and the similarities among the six experts’ opinions. Especially this ‘clustering process’ can be an important tool for policy makers. Instead of just relying on the average result for the whole group (which hides important value conflicts), or individual opinions (which gives no information on a collectively preferred scenario), clustering can be used to investigate different possible rankings of scenarios based on different decision principles, such as:

- What happens if we give different weights to the different individuals or coalitions (i.e., policy makers might attach more importance to the opinion of some experts over others)?
- What happens if we respect the majority principle?
- What happens if we give veto power to minority opinions (e.g., they can veto the scenario they prefer least)?
- Which scenarios provoke the strongest conflicts of opinion?

2.7 Some remarks concerning participation in the SEPIA project

The SEPIA project, as often stressed in this and other documents, needed to rely heavily on a free willing participation of experts and stakeholders, chosen to represent the range of value sets existing among the citizens. The complexity of a long-term forecasting of energy scenarios needed to gather a wide range of expertises, and to have them working together on a very wide set of factors including many uncertainties. The energy issues imply to some extent almost every aspect of societal development. The project was ambitious not only for this complexity, but also for the aim of integrating the participative exercise with the econometric modelling and the assessment tools. It implied thus a large variety of tasks which, if we consider participation in a full sense, should have been produced by the participants with only a role of secretarial work and facilitation from the scientific team.

SEPIA, as many former similar exercises, faced the limits of what can be expected from the voluntary participation of experts, maybe in some more extents right because it was more demanding on them according to the ambition of the task. As a methodological research, it was aimed at testing such a design. The level of attendance of the last workshop and for the final assessment can only be described as deceptive despite the efforts invested into the participation. However, the deception is possibly the result of the high expectation, which seemed to be met up to the Mesydel phase, and suddenly dropped. The amount of work injected by the scientific team in complement to the room for interpretation left by the workshop production was also an aspect we had been warned about by experienced leaders of such projects. Therefore, SEPIA certainly did not fare worse than most of the similar exercises we are aware of, considering its nature as discussed above, and it produced the expected scenarios in a way that fits exactly the planned program, if it weren't for the low attendance at the last sessions. Since the scenarios have been produced as expected, we can just reflect on what may lack in them following this lost of participants: the question is relevant for a methodological research, yet it is only based on a few hypotheses on what could have happened. The hindsight on some process steps might raise the following questions:

- The amount of work during the first SBG workshop on one hand proved the participants that SEPIA was a serious undertaking, but also that much was asked from them. It somehow may have raised the bar: participants needed to invest pretty much energy during the sessions they were to attend.
- Yet, we proposed an initial set of factors to start from. As far as the construction of the scenarios relied on the initial set of factors (discussed, revised and completed by the participants), it's only when looking at the result at the end of the day that they realized that they had collectively produced a set biased toward technological factors, and asked to rescue some social ones. An effect of framing is possible there, which might have affected the following steps. On the other hand, refraining ourselves from proposing a starting point would have meant an impossible workload, or needed an extra workshop, worsening thus the vulnerability to the dropout.
- Since the participants come and bring their expertise on a limited basis (i.e. agreeing to attend a certain number of meetings and answering some consultations, no matter how deeply involved they feel), it seems unavoidable that the scientific team has to fill the gaps left by the experts when they leave the workshop. It can thus not be expected that all decisions are univocally taken by the participants. The production will always be the product of interaction between the scientific team and the experts, with the balance leaning more or less on one or the other side. Since no trace of discomfort was heard at any time, SEPIA has certainly managed to hold its place on that aspect.
- Moreover, the reaction of the experts to their own production, at the end of the two workshops (of the bias in factor selection and on what they had actually drawn as scenarios rationales) proves that they were implicated enough into the task as not to see their production from a meta level (i.e. "playing the game" instead of following some agenda) and as to feel themselves real authors of the production.
- Yet, working with only a fraction of the expertise selected as relevant when designing the scenario builders group means that many hypotheses have to be decided upon by persons whose expertise is not sharp on those specific

topics. It could always be argued that possibly, if another expert had been present, he would have decided differently about some topics of his own field.

- There are possibly conflicting hypotheses about the way to reduce the drop out. On one hand, too tight a schedule make it impossible for the team to properly compute the results between two sessions, and it puts much weight on high level experts' agendas, risking to cause more absenteeism. On the other hand, if the process is spread over a longer time span, there is the symmetric risk that the participative project drops among the everyday priorities.
- The assessment phase by the stakeholder had been presented to them as only marginally affected by representation principles. It meant that no proportional representation did matter, and a single opinion could, by the design of the assessment tool, weight as much as several. Yet the condition was that every relevant value set had to be represented. This was aimed at when selecting the stakes to be represented, but could not be guaranteed when only a minority of them actually responded.

In conclusion, the participative construction of energy scenarios for 2050 did produce the scenarios expected in a way that fits the initial intentions, with all the necessary adjustments to the process it needed. The importance of building such scenarios should however be reflected into future similar projects by at least two commitments of the decider who calls for such an exercise, and which could help obtaining an actual stronger commitment, on the long term implied by the complexity of the task, from participants. As far as experts are concerned as scenario builders, a proper retribution of their work would, beyond the financial interest, mean a contractual commitment in the process, and therefore play as an internal reminder of the commitment. As for the stakeholder, the awareness that the opinion expressed may have an impact on future policies would raise the value of participation. A more direct commitment of political bodies should thus help in that way. Under such conditions, a long an complex process such as SEPIA could be implemented in the real decision making world without being excessively constrained over simplifying the scenario development stages or planning over too long a time span for keeping participation.

2.8 Conclusions

Sustainability assessment of energy policy strategies is performed at the interface between scientific theory-building and political practice. Therefore, practical sustainability assessments are judged by criteria like scientific soundness, political legitimacy and practicability (in a real political setting). In this section, we offered a reflection on how such criteria could be met by a discursive approach using a combination of decision support tools. However, the 'burden of proof' for such a discursive approach is heavy. Indeed, we hereby presume that deciding on an appropriate (i.e. sustainable) long-term energy strategy is at least a suitable ‘test case’ for a more deliberative (discursive) governance arrangement, *ergo* that it is not *a priori* better handled by alternatives such as (a combination) of free market competition, lobbying and/or direct government regulation (top-down ‘government’ as opposed to bottom-up ‘governance’). Further in-built presuppositions include that some particular composition of actors is thought to be capable of making decisions according to (voluntarily accepted and consensually deliberated) rules, that will resolve conflicts to a maximum extent possible and (ideally) provide the resources necessary for dealing with the issue at hand. Moreover – next presupposition – that the decisions once implemented will be accepted as legitimate by those who did not participate and who have suffered or enjoyed their consequences. All together, substantiating the quality of the SEPIA approach is challenging, in theory and in practice, as documented by the following observations.

On a theoretical level, the SEPIA methodology aligns with insights derived from ecological economics, decision analysis, and science and technology studies, favouring the combination of analytical and participatory research methods in the field of ‘science for sustainability’. This view is motivated by sustainability problems being multi-dimensional (thus limiting the use of only monetary cost-benefit analysis), of a long-term nature (thus involving significant uncertainties) and applying to complex socio-economic and biophysical systems (thus limiting the use of mono-disciplinary approaches). SEPIA shows the advantages of combining a (hybrid backcasting) scenario approach with a (fuzzy logic) multi-criteria decision aiding tool. Scenario exploration allows taking into account the (socio-economic and biophysical) complexities of energy system development so that uncertainties on the long term can be explored. Multi-criteria methods, and especially those based on fuzzy-set theory, are very useful in their ability to address problems that are characterised by conflicting assessments and have to deal with imprecise information, uncertainty and incommensurable values. Both methods are supported by a large body of scientific literature, ensuring that an effective check of ‘scientific soundness’ can be made through the peer review process. However, the application of these methods, and especially their participatory nature, are challenging in practice. For instance, the combination of narrative scenario building and quantitative modelling in theory necessitates the need for a deliberative consensus on all parameters used in the model, which in practice turns out to be impossible to organise (the LEAP model requires hundreds of inputs). The scenario development phase as it was already turned out to be time intensive for stakeholder participants. We struggled with non-participation and dropouts of stakeholders; without proper investigation we cannot explain why participation fluctuated as it did. However, at least part of the explanation can probably be found in the general impression that the potential players in the Belgian energy system transition landscape – how limited their number may be – are rather scattered. In Belgium (as in many other countries), energy problems cross a varied set of policy domains and agendas, such as guarding the correct functioning of liberalised energy markets, promoting renewables, environmental protection, climate policy etc. These are dealt with by different administrative 'silos' and analysed by separate groups of experts and policymakers. As a result of this fragmentation, a lot of the key players struggle with overloaded agendas, organisation specific expectations and performance criteria and hence find no time for explicit reflective/exchange moments in the context of a scientific project not directly connected to any actual decision-making process. There may be many contacts on the occasion of events and by communication means, but there is not a structured exchange of experiences, knowledge and mutual feedback ('structured' in the sense of embedded in a culture of working methods). This impression of fragmentation sharply contrasts with the high priority assigned to institutionalised networks and collaboration as advocated in the above-mentioned theoretical strands of literature. Perhaps the best way to sum up the findings so far is: assessing scenarios in the form of transition pathways towards a sustainable energy future with the aid of a participatory fuzzy-logic multi-criteria decision aiding tool certainly has the potential to support a more robust and democratic decision-making process, which is able to address socio-technical complexities and acknowledges multiple legitimate perspectives. However, these methods are time- and resource intensive and require the support of adequate institutional settings for a proper functioning in real political settings. Participation in integrated energy policy assessment should therefore not be taken for granted. We hope that the experience gained so far in the context of the SEPIA project will allow future initiators of similar participatory projects to level the project objectives, the participants' expectations and the political backing with each other, a prerequisite for successful participation in foresight exercises.

3. POLICY SUPPORT

The usefulness of any scenario development process of course ultimately lies with its ability to actually inform and influence current decisions. While this seems like a commonplace statement, it points out the relevance of the following questions: What do we do with scenarios once we have developed them? How do we translate what we learn from them into action? This section gives some indications regarding the possible policy uses of the SEPIA scenarios. **Of course, given the incompleteness of the present exercise (since the backcasting envisaged in the project could not be carried out in full) and the limitations experienced w.r.t. the actual participation in the process, substantive conclusions w.r.t. the actual energy transition pathways to be supported by government cannot be drawn from the project alone. However, it remains possible to obtain more or less conclusive results with regard to the proposed methodology, which was actually the main objective of the SEPIA project.**

3.1 Integrated sustainability assessment as a practice informing policy making

Decision makers face many challenges when designing new energy policies aimed at furthering the cause of a sustainable energy future. A first key challenge concerns the complexity of the issues at hand. Secondly, the institutional complexity arising from the new realities of multilevel governance networks blurs the boundaries between the responsibilities and competences of ‘classical’ jurisdictional entities such as the nation state, and new players such as regions, stakeholder groups and multilateral organisations. These new challenges create a need for instruments to *structure* both the increasing intrinsic complexity and the institutional complexity of current decision-making. Impact assessment provides a systematic approach that allows policy-makers to deal with complexity and to structure the input of various actor categories. The SEPIA project emphasises precisely this ‘structuring power’ of integrated sustainability assessment. When integrated into decision-making, impact assessment becomes part of the process of developing new policy. The appeal of impact assessment lies in its easily understood basic steps and in its contribution to generate order out of the chaos by identifying linkages in complex policy-making environments. **SEPIA has operationalised sustainable development in the field of energy policy in overarching fundamental objectives and principles that should be respected when considering pathways toward a sustainable energy future.** However, one should always keep in mind that impact assessments are based on a large number of choices; the results of such impact assessment procedures will therefore always leave a considerable room for interpretation.

Careful deliberation about and structuring of sustainability objectives and principles can limit this room for interpretation but cannot exclude it altogether, nor should this be the aim of a well-designed ISA.

3.2 Policy support through scenario development

Regardless of the particular nature of the SEPIA scenarios developed in the course of the project, many relevant lessons were learnt on methodological choices for scenario development. Firstly, **one of the strong points of the SEPIA methodology was to draw up a detailed ‘Terms of Reference’ (TOR)**, constituting the basis for mutual understanding between all partners involved in the project (stakeholders, scenario builders and the project team). It is also vital that such TOR is developed on the basis of an intensive ‘negotiation’ with all partners involved. Secondly, **developing scenarios from a detailed breakdown of a wide range of possible factors influencing energy system developing on the long run is also generally considered to be a good practice** in view of giving analysts, policy planners and decision makers an (to a maximum possible extent) unbiased assessment of future possibilities. Here, the SEPIA approach could be improved provided that more resources are dedicated to this phase of scenario development. For example, one could ask several recognised energy system experts to each independently think about influencing factors before bringing them together in a joint workshop. In this way an even broader array of factors could be brought to the table for consideration, with the added advantage that in this case the factors are developed by the scenario builders themselves, which will likely lead to a greater legitimacy of the factor selection process. Careful attention should also be given to the involvement of a wide range of expertise w.r.t. the issue at hand (in our case, a ‘framing effect’ w.r.t. a prioritisation of technological factors was evident). Thirdly, concerning the combination of factor hypotheses into coherent scenario storylines, it is evident that other storylines than the ones developed in SEPIA could be envisaged. However, we are relatively confident that the **particular ‘driving forces’ identified in the course of the project** – the timing and stringency of regulatory constraints on GHG emissions, the level of concern that develops about supply reliability and security, oil & gas price dynamics, European RD&D strategy, and public attitudes w.r.t technology pathways – **will likely play an important role in any long-term energy scenario**. Lastly, once the scenarios are built, different uses of these scenarios in an actual decision-making context can be envisaged. In our case, **we invited stakeholders to give a ‘holistic’ assessment** of the different scenarios based on their view of the relative importance of the different sustainability objectives and criteria, and their assessment of the likelihood that the sustainability objectives are met given a particular scenario storyline. **Policy makers could use this approach to select one scenario as the ‘reference’ scenario, serving as a**

reference for energy strategy development (cf. Section 3.3). However, another possibility is that **the full range of energy scenarios are taken at face value** (hence, no judgement is pronounced as to the relative likelihood of reaching the sustainability objectives in each of the scenarios), and that **separate energy strategies are developed for each of the scenarios under consideration** (cf. Section 3.3). Without doubt, this option represents the most sophisticated – and demanding – approach, one that makes optimal use of scenario planning methods in strategy development. It provides policy makers with the maximum feasible range of choice, and forces careful evaluation of these options against differing assumptions about the future. It does, however, demand effort, patience and sophistication, and works best when the decision makers participate directly throughout the process.

A final cautionary remark on the use of energy models as a support in scenario development seems to be in place here. The use of energy models in support of long-term energy scenario development presents a clear trade-off. On the one hand, models allow for a systematic, consistent and coherent inclusion of many different factors (e.g. demographics, energy demand, energy system costs etc.). But on the other hand, energy system models inevitably also include (many) subjective judgements made by the modellers, e.g. regarding model structure or parameter values. As is evident from our experience, because of the sheer number of choices involved they can never be the subject of a full stakeholder review. On the time scale spanned by the SEPIA scenarios, formal models are probably best used as inputs to a broader process that weighs multiple sources of evidence. This may include – but is not limited to – traditional sensitivity analysis of the value of uncertain parameters, as well as using models with different structural energy systems representations[9].

3.3 Developing transition pathways

The SEPIA scenarios (or similar scenarios developed by the methods discussed here) can furthermore be used to develop a number of possible transition pathways for the Belgian energy system and explore the (policy) consequences of each of these pathways. Indeed, since because of the limitations discussed above we were unable to carry out the full scope of the backcasting envisaged for the SEPIA project (i.e. discussing in detail the policy measures which would be needed in the context of a specific scenario logic) the reader might get the mistaken impression that the (ambitious !) sustainability objectives set out at the beginning of the project will be realised regardless of government action. On the contrary: **each of the SEPIA scenarios embodies more or less ‘radical’ assumptions on in specific energy**

[9] The use of different models in support of long-term energy strategy development is at present investigated in the BELSPO cluster project “FORUM” (http://www.ua.ac.be/main.aspx?c=.BELSPO-FORUM&n=85902).

system pathways: e.g. on the use of biomass for transport and heating in all of the scenarios, on the use of nuclear energy and coal power (equipped with CCS) in the 'oil shock(s)' scenario, on the use of decentralised energy technologies and the possibilities of energy demand reduction through behavioural changes in the 'global consensus' scenario, and on the use of electric vehicle technologies and technological advances in renewable electricity production and storage (offshore wind energy in particular) in the confidence in RD&D scenario. For each of the scenarios, the following line of questioning should be used to reveal policy implications:

- Identify critical factors (i.e. a level of change in technologies, values, behaviours, infrastructure, or other physical or social variables, excluding policy instruments, necessary to bring about the specific end point (2050) in each of the scenarios for the intermediate years (e.g. 2020, 2030);
- Relate these critical factors to the changes in energy and transport technologies, behaviour, social patterns, industries and services etc., required to ensure the critical factors are realized;
- Discuss the policy, social, value, technological and economic changes needed to underpin these changes.

Finally, once the concrete changes needed to realise certain pathways are charted, stakeholder consultations can be organised to reveal opinions on the desirability as well as the feasibility of the proposed changes. Stakeholder consultations can also reveal the 'boundary conditions' to be respected in case certain pathways are to be realised, e.g. regarding the sustainability of biomass[10].

3.4 Testing the robustness of transition pathways

In general, the objective of scenario planning is the development of a resilient or robust energy strategy. Now, it should be obvious that robustness is not the only quality to be sought in a strategy; and, taken to an extreme, robustness could mean little more than the lowest common denominator of scenario-specific strategies. At a time that calls for bold, even radical, action (in view of the urgent and drastic action needed to mitigate the effects of climate change), such an interpretation would be a prescription for mediocrity at best, and catastrophic consequences at worst. The

[10] The sustainability of biomass issue has risen high on the policy agenda in the course of the SEPIA project, and is for instance addressed in the IST report "Biobrandstoffen van de eerste, tweede en derde generatie" (2009) (http://www.samenlevingentechnologie.be/ists/nl/publicaties/rapporten/biobrandstoffen.html) resulting in concrete policy recommendations (derived from a policy Delphi exercise) addressed at the European, federal and regional level ("Biobrandstoffen – Aanbevelingen; http://www.samenlevingentechnologie.be/ists/nl/publicaties/aanbevelingen/biobrandstoffen.html). At the Belgian federal level a report on the impact of the EU biofuel policy on the non-EU countries was commissioned and published very recently (Nov. 2010) ("Evaluation de l'impact de l'expansion des cultures pour biocarburants dans les pays extracommunautaires" – CITRE).

point is, rather, that, before taking ‘bold’ steps, **the energy strategy should be tested against a variety of scenarios so that policy makers are forewarned of potential vulnerabilities**. Robustness can then be built into the strategy, *not* by reducing its force or boldness, but rather by “hedging” or contingency planning. The SEPIA scenario storylines (or similar scenarios developed by the methods discussed here) could be used as a ‘test bed’ for the robustness of the pathway elements developed along the lines discussed under Section 3.3.

4. DISSEMINATION AND VALORISATION

Project (intermediate) results have been presented in various conferences:

- “Managing Radioactive Waste Problems and Challenges in a Globalizing World” conference, Center for Public Sector Research (CEFOS), University of Gothenburg, Sweden, 15-17 Dec. 2009.
- “Participatory Energy Foresight at the European level” workshop, EFONET project, Athens, Greece, 30 April 2009.
- WCCI 2010 IEEE World Congress on Computational Intelligence, Barcelona, Spain, 18-23 July 2010.

Dissemination and valorisation activities will continue in further publications and contributions to (international) conferences.

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ANNEX 1 – COPY OF PUBLICATIONS

Copies of all publications related to the SEPIA project are available upon request.

http://www.ua.ac.be/main.aspx?c=.SEPIA

ANNEX 2 – MINUTES OF FOLLOW-UP COMMITTEE MEETINGS

Minutes of all follow-up committee meetings are available upon request.

ANNEX 3 – COLLECTED MULTI-CRITERIA EVALUATIONS

Name	Objective #	Importance	Criterion #	Global consensus	Confidence R&D	Oil Shock
Expert 1	1	very high	1.1	unlikely	likely	almost certain
	2	fairly high	2.1	likely	likely	almost certain
			2.2	unlikely	likely	very likely
			2.3	highly unlikely	very likely	almost certain
			2.4	likely	likely	very likely
	3	fairly high	3.1	almost certain	very likely	almost certain
			3.2	likely	unlikely	very likely
	4	Medium	4.1	very likely	likely	very likely
	5	very high	5.1	almost certain	very likely	likely
	6	fairly high	6.1	likely	unlikely	likely
			6.2	unlikely	unlikely	?
			6.3	highly unlikely	unlikely	likely
	7	Medium	7.1			
			7.2	very likely	very likely	very likely
	8	Medium	8.1	unlikely	highly unlikely	very likely
			8.2	unlikely	unlikely	likely
Expert 2	1	fairly high	1.1	very likely	very likely	likely
	2	fairly high	2.1	unlikely	likely	likely
			2.2	unlikely	highly unlikely	likely
			2.3	unlikely	unlikely	likely
			2.4	likely	very likely	likely
	3	fairly high	3.1	very likely	very likely	unlikely
			3.2	unlikely	highly unlikely	likely
	4	fairly high	4.1	almost certain	almost certain	almost certain
	5	fairly high	5.1	almost certain	almost certain	almost certain
	6	fairly high	6.1	very likely	likely	likely
			6.2	likely	likely	very likely
			6.3	highly unlikely	highly unlikely	very likely
	7	very high	7.1			
			7.2	very likely	very likely	very likely
	8	fairly high	8.1	highly unlikely	highly unlikely	unlikely
			8.2	highly unlikely	highly unlikely	likely
Expert 3	1	fairly high	1.1	highly unlikely	likely	very likely
	2	fairly high	2.1	unlikely	unlikely	likely
			2.2	highly unlikely	likely	very likely
			2.3	highly unlikely	unlikely	highly unlikely
			2.4	unlikely	very likely	very likely
	3	very high	2.1	likely	very likely	almost certain

			2.2	highly unlikely	likely	
	4	fairly high	4.1	unlikely	very likely	very likely
	5	fairly high	5.1	unlikely	very likely	almost certain
	6	fairly high	6.1	very likely	very likely	unlikely
			6.2	very likely	very likely	highly unlikely
			6.3	almost certain	almost certain	likely
	7	very high	7.1	unlikely	very likely	unlikely
			7.2		very likely	unlikely
	8		8.1	likely	highly unlikely	highly unlikely
			8.2	likely	very likely	likely
Expert 4	1	very high	1.1	very likely	likely	unlikely
	2	very high	2.1	very likely	likely	very likely
			2.2	almost certain	unlikely	
			2.3	likely	likely	highly unlikely
			2.4	almost certain	likely	unlikely
	3		3.1	unlikely	unlikely	highly unlikely
			3.2	unlikely	highly unlikely	highly unlikely
	4	very high	4.1	almost certain	very likely	likely
	5	fairly high	5.1	very likely	almost certain	likely
	6	very high	6.1	very likely	likely	almost certain
			6.2	highly unlikely	highly unlikely	likely
			6.3	almost certain	almost certain	very likely
	7	fairly high	7.1	very likely	likely	unlikely
			7.2	very likely	very likely	unlikely
	8	very high	8.1			unlikely
			8.2	unlikely	unlikely	highly unlikely
Expert 5	1		1.1	very likely	unlikely	highly unlikely
	2		2.1	very likely	unlikely	highly unlikely
			2.2	very likely	unlikely	highly unlikely
			2.3	likely	highly unlikely	highly unlikely
			2.4	almost certain	likely	highly unlikely
	3		3.1	almost certain	unlikely	highly unlikely
			3.2	unlikely	likely	highly unlikely
	4		4.1	almost certain	unlikely	highly unlikely
	5		5.1	almost certain	unlikely	highly unlikely
	6		6.1	very likely	unlikely	highly unlikely
			6.2	likely	unlikely	highly unlikely
			6.3	very likely	unlikely	highly unlikely
	7		7.1	almost certain	likely	unlikely
			7.2	very likely	likely	unlikely
	8		8.1	very likely	unlikely	highly unlikely
			8.2	very likely	likely	unlikely
Expert 6	1	very high	1.1	likely	unlikely	highly unlikely
	2	fairly high	2.1	very likely	likely	unlikely
			2.2	likely	highly unlikely	highly unlikely

		2.3	unlikely	unlikely	highly unlikely
		2.4	very likely	very likely	likely
3	fairly high	3.1	likely	unlikely	highly unlikely
		3.2	highly unlikely	highly unlikely	highly unlikely
4	very high	4.1	almost certain	almost certain	almost certain
5	very high	5.1	almost certain	almost certain	almost certain
6	fairly high	6.1	highly unlikely	highly unlikely	highly unlikely
		6.2			
		6.3	likely	unlikely	highly unlikely
7	very high	7.1	likely	highly unlikely	highly unlikely
		7.2			
8	fairly high	8.1	very likely	unlikely	highly unlikely
		8.2	likely	unlikely	highly unlikely

ANNEX 4 – AGGREGATION IN DECIDER

The used aggregation algorithm and ranking algorithm for generating the overall evaluations and order of scenarios are presented in Lu et al. (2007). They are used in two purposes, i.e., one for evaluation by individual expert and the other for evaluation by group experts.

First, consider the usage for individual expert. For convenience, suppose O is one of the given objectives, $c_1, c_2, \cdots, c_n$ are the criteria related to the objectives, $wc_1, wc_2, \cdots, wc_n$ are the importance evaluations on these criteria[11]. Also suppose the evaluations on the three scenarios in terms of these criteria are $v_{j1}, v_{j2}, \cdots, v_{jn}, j = 1,2,3$. Then the overall evaluation v_j on scenario j is calculated by

$$v_j = \sum_{i=1}^{n} wc'_{ji} \times v'_{ji} \qquad \text{(A1)}$$

where v'_{jk} and wc'_{jk} are normalized evaluations and weights by

$$v'_{jk} = \frac{v_{jk}}{\sum_{k=1}^{n} v_{jk} \; {}^{R}_{0}} \qquad \text{(A2)}$$

and

$$wc'_{jk} = \frac{wc_{jk}}{\sum_{k=1}^{n} wc_{jk} \; {}^{R}_{0}} \qquad \text{(A3)}$$

Note that the evaluation problem with eights objectives can also be treated as an objective. Under this assumption, the given eights objectives can be treated as criteria.

Second, consider the usage for group experts. Let $we_1, we_2, \cdots, we_m$ be the weights of experts[12] and $v_{j1}, v_{j2}, \cdots, v_{jm}$ ($j = 1,2,3$) the overall evaluations on the three scenarios about an objective O. Then the overall evaluation v_j of the group on scenario j about objective O is calculated by

$$v_j = \sum_{i=1}^{m} we'_{ji} \times v'_{ji} \qquad \text{(A4)}$$

where v'_{ji} and we'_{ji} are normalized evaluations and weights by

$$v'_{ji} = \frac{v_{ji}}{\sum_{k=1}^{m} v_{jk} \; {}^{R}_{0}} \qquad \text{(A5)}$$

and

[11] In the SEPIA case, the importance of criteria related to one objective take the same value, i.e., $wc_1 = wc_2 = \cdots = wc_n$.

[12] In the SEPIA case, the weights of experts are treated as the same because those weights are not presented, i.e., $we_1 = we_2 = \cdots = we_m$.

$$we'_{ji} = \frac{we_{ji}}{{}_{k=1}^{m} we_{jk} \; {}_{0}^{R}} \tag{A6}$$

Below is an example to illustrate the aggregation algorithm.

Consider Objective 6 in Expert 1’s assessments (shown in Table 1).

This objective has three criteria; and each of them with the weight (importance) “fairly high”. By Eq. (A3),

$$wc_i' = \frac{\frac{2}{3},\frac{5}{6},1}{1+1+1} = \frac{2}{9},\frac{5}{18},\frac{1}{3} \;, \quad i = 1,2,3$$

For Scenario 1 (Global consensus), the normalized evaluation on the first criterion is

$$v_1' = \frac{\frac{1}{3},\frac{1}{2},\frac{2}{3}}{\frac{1}{3}+\frac{1}{2}+\frac{2}{3}} = \frac{2}{9},\frac{1}{3},\frac{4}{9}$$

Similarly, the normalized evaluations of Scenario 1 on the other two criteria are

$$v_2' = \frac{1}{18},\frac{2}{9},\frac{1}{3} \;, \qquad v_3' = 0,\frac{1}{9},\frac{2}{9} \;.$$

By Eq. (A1), the overall evaluation on Scenario 1 is

$$v_1 = \frac{2}{9},\frac{5}{18},\frac{1}{3} \times \frac{2}{9},\frac{1}{3},\frac{4}{9} + \frac{2}{9},\frac{5}{18},\frac{1}{3} \times \frac{1}{18},\frac{2}{9},\frac{1}{3} + \frac{2}{9},\frac{5}{18},\frac{1}{3} \times 0,\frac{1}{9},\frac{2}{9}$$

Obviously, v_1 is not a triangle fuzzy number any more; however, it is a normal fuzzy number. For simplifying computation, we only analyse the end points at 0 and 1 cut-set in the above result. The value is (5/81, 5/27, 1/3). For Scenario 2, the value is (2/81, 5/81, 1/9); and the value for Scenario 3 is (1/12, 5/32, 1/4).

Ranking algorithms for individual expert and for group experts are the same. Below is an illustration of the used ranking algorithm.

Suppose v_1, v_2, v_3 are the overall evaluations on the three scenarios about an objective O. Then the ranking of v_1, v_2, v_3 is obtained by three steps:

1. Predefine two evaluations represent the worst and the best evaluations by two fuzzy points r^- and r^+,

$$r^+ \; x = \begin{matrix} 0, & x \neq 1; \\ 1, & x = 1. \end{matrix} \tag{A7}$$

$$r^- \; x = \begin{matrix} 0, & x \neq 0; \\ 1, & x = 0. \end{matrix} \tag{A8}$$

where r^- indicates the worst evaluation, and r^+ indicates the best one.

2. Calculate the distance between each evaluation v_j and the above two predefined evaluations by

$$d_j = \frac{1}{2}\left(1 - d\left(v_j, r^+\right) + d\left(v_j, r^-\right)\right) \tag{A9}$$

where d is a quasi-distance measure of two fuzzy numbers given by

$$d(a,b) = \left(\int_0^1 \frac{1}{2}\left[\left(a_\lambda^L - b_\lambda^L\right)^2 + \left(a_\lambda^R - b_\lambda^R\right)^2\right] d\lambda\right)^{\frac{1}{2}} \tag{A10}$$

3. Rank v_1, v_2, v_3 by the obtainedd_1, d_2, d_3. The bigger d_j is, the better v_j is.

Continue the illustrative example for aggregation algorithm.

By Eqs. (A9) and (A10) and replacing v_j by (5/81, 5/27, 1/3), (2/81, 5/81, 1/9); and (1/12, 5/32, 1/4), respectively, the d_j is obtained and used to ranking the three scenarios.

ANNEX 5 – FUZZY SETS FOR THE LINGUISTIC TERMS USED IN SEPIA

In DECIDER, there are three categories of linguistic terms. Each linguistic term category contains seven terms. Figure A1 is a basic distribution of the used linguistic terms in each category (.In DECIDER, the used distribution of linguistic terms is slightly different from the basic form here on the consideration of user-freely setting, and programming accuracy and efficiency). For instance, the term "Very High" is represented by a triangular fuzzy number and is read "a triangle fuzzy number (2/3, 5/6, 1)."