Design, implementation and testing of the Sustainability Choice Space concept in SIAT

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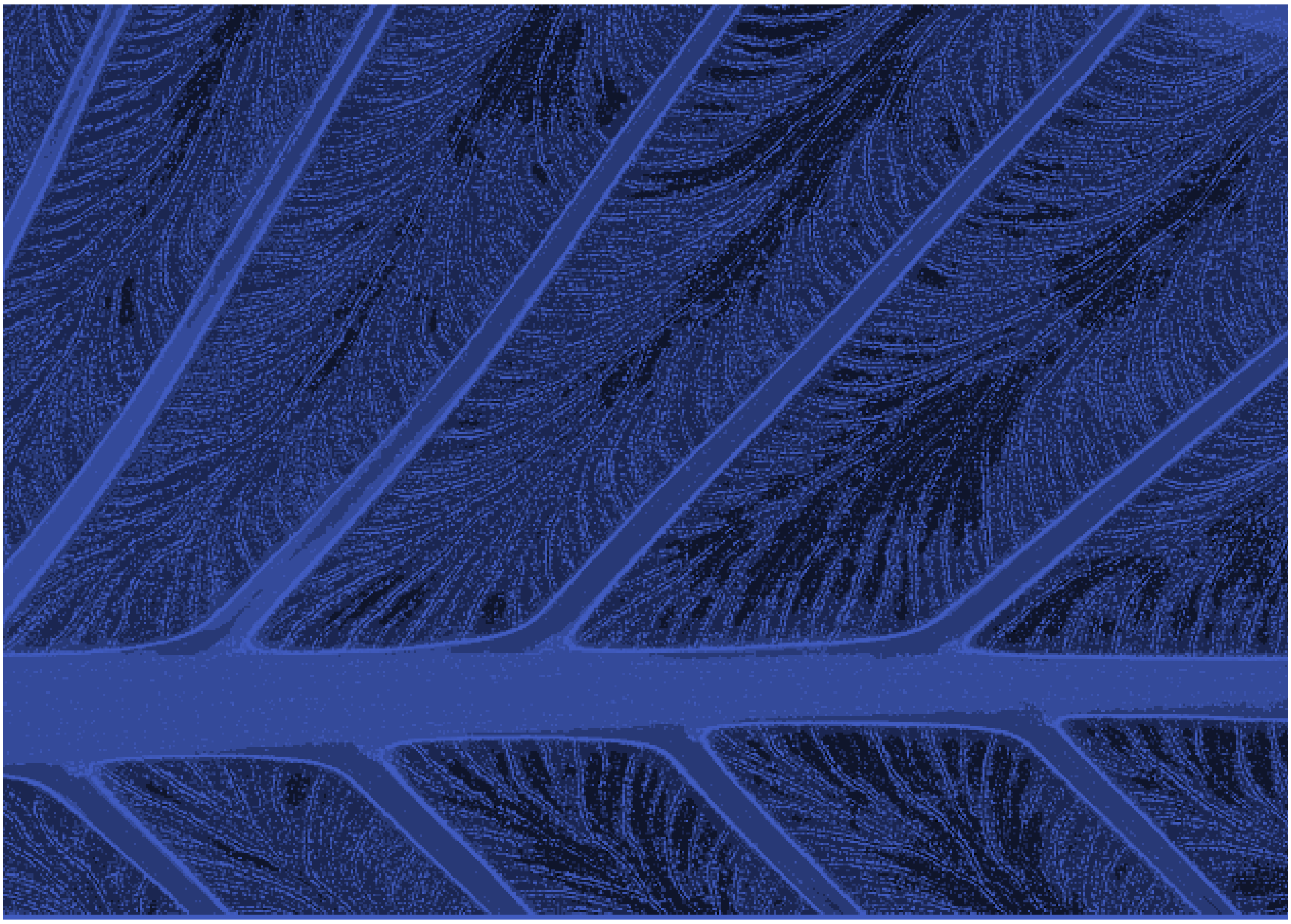

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The University of Nottingham

CEM Report No 16

Centre for Environmental Management

Notes:

This document reflects the views of the authors and not those of Project Coordinator/Partners or the European Commission.

This study was funded by EU 6th Framework Programme (SENSOR, 003874 GOCE).

If you use this document please quote as:

Potschin, M.; Haines-Young, R. and M. DiBonito (2009): Design, implementation and testing of the Sustainability Choice Space concept in SIAT. CEM Report No 16, 77 pp. (SENSOR, 003874 GOCE)

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Acknowledgements:

The UNOT team is very grateful to the following people/partners for fruitful discussion, feedback on earlier versions and general support:

- Peter Verweij and Johnny te Roller (Alterra, NL) for their extensive discussion on the SCS-SIAT implementation;
- Jake Morris (FR), for always being available to update us on M7 development, clarifying issues regarding the FoPIA model and providing all data from the Malta stakeholder workshops, which found their entry in our Bayesian Believe Networks;
- Dolf de Groot, Katrine Soma and former Valentina Tassone (University of Wageningen) for discussion and input in the SCS-valuation linkage, Dolf de Groot also provided feedback on an the draft of this deliverable and Donato Romano (DEART-UNIFI) for providing information and material on the Internet Survey;
- The stakeholders' Case Study representatives, Stefano Moncada (MEPA - Malta), Pavol Kenderessy (SAS - High Tatras) and Grzegorz Siebielec (ISPC - Silesia), for making their databases available;
- Marta Perez-Soba (Alterra), Cesare Pacini (DEART-UNIFI) and Laurence Jones (CEH) for updating us on the indicators; and
- All participants at the SCS-Policy-stakeholder workshop in Nottingham/UK in February 2009.

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ABBREVIATIONS	
B&B	Tourism Demand Model
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regional Impact Analysis Model
CLUE	Conversion of Land Use and its Effects Model
DPSIR	Driver, Pressure, State, Impact, Response
EC	European Commission
EEA	European Environmental Agency
EFISCEN	European Forest Information Scenario Model
EUROSTAT	Statistical Office of the European Communities
FoPIA	Framework for Participatory Impact Assessment
GDP	Gross Domestic Product
IA	Impact Assessment
LUF	Land Use Function
NEMESIS	New Econometric Model for Environment and Strategies Implementation for Sustainable Development
NUTS	Nomenclature of Territorial Units for Statistics
OECD	Organisation for Economic Cooperation and Development
R&D	Research and Development
SACS	Sensitive Area Case Studies
SCS	Sustainability Choice Space
SIAT	Sustainability Impact Assessment Tools
SICK	Urban Land Use Model
TIM	Transport Infrastructure model

Executive Summary

Background and Context

The SENSOR project aims to provide integrated *ex-ante* Sustainability Impact Assessments (SIA) across the 'three pillars' of economy, society and environment through the lens of land use change. Land is considered as multifunctional and the analytical approach adopted traces the potential impact of policy interventions on a range of key economic, social and environmental indicators. The significance of change upon these indicators and a more general set of nine Land use Functions (LUFs) is judged in terms of a set of sustainability limits or thresholds.

The geographical differences in policy impacts across Europe are considered using the Spatial Regional Reference Framework (SRRF). This framework was built by aggregating NUTS-X units into 30 larger areas (Cluster Regions). The Cluster Regions were characterised in terms of the sustainability issues commonly affected. Regional sustainability limits or thresholds for the key indicators and LUFS were also defined for them.

Two main types of tools have been developed through SENSOR. First, a model-base approach that has led to the SIA-tools (SIATs) to be delivered via an internet platform for the analysis of change at Pan-European scales. Second, a set of participatory tools called FoPIA (Framework for Participatory Impact Assessment) that enables stakeholder views and values to be examined at more local scales. In each case the tools employ a common approach, based on indicators and then aggregated LUFs that cover the three pillars of sustainability.

The **Sustainability Choice Space** (**SCS**) concepts and framework are therefore introduced and discussed in this deliverable to help framing aspects of the SIA analysis, in particular to highlight the 'room for manoeuvre' that policy makers and advisors have in shaping a new policy. The framework includes a number of tools and aims to benefit from both the model-based and the participatory approaches to explore the implications of a particular policy case or option. The goal of the SCS is not to identify an optimal outcome but to explore the range of options potentially available, helping users identify what the different choices are and more especially the consequences and trade-offs that are associated with them.

The Sustainability Choice Space approach

The SCS framework recognises that SIAs deal with extremely complex systems that include a large number of factors and dimensions. For this reason analyses are characterised by a very high level of uncertainty, arising from both the underlying data and models and the political nature of decisions themselves. In this deliverable, it is argued that although SENSOR has not explored the question of uncertainty in detail, uncertainties have to be taken into account, and start can be made by using the idea of a Sustainability Choice Space to explore outcomes from the application of the SIAT and FoPIA tools.

The SCS framework is built on the proposition that the consequences of land use change have to be considered from a multidimensional perspective, and that analytical outcomes cannot be evaluated by trying to identify which of them is, in some sense, optimal. Rather, it is suggested that policy advisors have to recognise that in the context of making assessments a number of policy options might be sufficient or adequate in terms of delivering sustainability goals. The SCS concept has been developed to help policy advisors and other stakeholders explore the trade-offs between assessment criteria that arise when different policy options are considered, and hence explore this potential solution space more effectively.

Integrating Perspectives: Bayesian Belief Networks and SCS Tools

Although the model-based SIAT approach and the stakeholder analysis of FoPIA have always been considered as complementary within SENSOR, the nature of their integration has been problematic. The model-based approach aims to explore patterns at broad geographical scales, while FoPIA seeks to investigate issues at more local scales. The extent to which insights that these very different spatial scales can be used to inform each other is sometimes unclear. However, the work undertaken for this deliverable has shown that the SCS concept can be used to demonstrate the common methodological characteristics of both approaches and how their outputs might in the future be more closely linked and used more effectively.

In particular, both the FoPIA and the model-based SIAT can be represented conceptually and operationally as a Bayesian Belief Network (BBN), which can be used to map out the underlying analytical logic and communicate some of the key uncertainties involved in the assessment. Most importantly in the context of this deliverable, it is argued that such networks can be used to implement the idea of a sustainability choice space and that they may form a template for the future integrated development of SIAT and FoPIA.

Achievements and Recommendations

SCS and FoPIA

The work leading to this deliverable has involved piloting a prototype BBN-FoPIA tool, using the results from the case studies undertaken with stakeholders in the Sensitive Area Case Studies (SACS). It was found that the BBN methodology could represent the underlying approach in a systematic and formalised way, and be used to capture and replay results rapidly and effectively so that users could visualise the consequences of the decisions they made. BBNs were also found to be capable of handling the uncertainty arising from the diversity of opinions amongst stakeholders, and had the potential for showing how the different monetary values that they might assign might affect assessment outcomes. The prototype FoPIA-BBN tool encapsulates the main ideas expressed in the SCS framework and represents, in essence, the first operationalization of the concept.

On the basis of the work undertaken with the stakeholder generated data from Module 7 "Stakeholder Participation and Institutional Analysis", it is recommended that the FoPIA approach could be developed and supported via SENSOR through the provision of a down-loadable, BBN-FoPIA tool. The results captured using such a tool could be fed back into the SENSOR database, and replayed using a similar BBN formalism to other users interested in exploring stakeholder views.

SCS and SIAT

The work leading to this deliverable has involved considerable interaction with the other members of Module 3 "Regional Sustainability Problems, risks and thresholds", and has informed the development of the SRRF, the definition of sustainability limits and thresholds and the construction of the nine LUFs used to summarise the outcomes of SIAT runs. The focus of our input has been on developing ways of comparing outcomes so that the consequences of different policy choices might be more easily understood. As a result of this work we have helped shape the design of the various SENSOR prototypes, and the final version to be delivered at the end of the Project (Prototype III).

The recommendations we have made from our earlier input have led to the inclusion of the SCS concepts in SIAT Prototype III, consisting of a SCS League Table that allows the results of different simulations to be listed and reported in a matrix, where LUFs and various spatial scales can be visualised. Users can select the cell(s) in the League Table of interest and drill down to understand assumptions, rules, indicators affecting the results, as well as the geographical patterns underlying the analysis.

The analytical approach adopted in SIAT Prototype III, and potential extensions of it were explored though a workshop with policy advisors from UK organisations operating at local and national scales. Their responses were compared with experts who were asked to take a more EU perspective.

Although clear differences in the requirements of these groups emerged, on the basis of this work it is recommended that in any further development of SIAT, the following design issues should be considered:

- ***That the logic of the knowledge chain leading to particular outcomes should be more transparent, so that users can examine underlying assumptions and plausibility of outcomes.***
- ***That the uncertainties surrounding the modelled outcomes be expressed more clearly, so that the magnitude or likelihood of real differences between outcomes could be better understood;***
- ***That more geographically specific or relevant indicators might be needed for users at local scales - this would be particularly relevant if SIAT is used as the basis of future work with stakeholders;***
- ***That access to stakeholder views and values would be useful in helping shape assessments at national or pan-European scales; and,***
- ***That tools to enable the analysis of trade-offs and make comparisons between different modelled runs, as envisaged by the SCS Concept, were essential.***

Although the workshop focused exclusively on the model-based SIAT approach the participants emphasised that given the uncertainties surrounding the tools, they would have to be used in a deliberative way. The value of these models seems to reside in the process of debate and discussion that is generated and stimulated rather than the individual model results.

On the basis of the findings from our work, we have considered how these recommendations might be carried forward into the design of the next generation of SIA tools, and recommend that an approach based on a Bayesian Belief Networks (BBN) might be of value. A BBN modelling approach would allow the logic of the current SIAT framework to be represented more clearly, and the idea of an SCS to be represented more completely in terms of the uncertainties involved.

Conclusion and Prospect

The assessment of sustainability impacts is an inherently complex undertaking, because ultimately those carrying out such a task have to make policy choices under conditions of considerable uncertainty. Thus the design of SIA decision support tools have to ensure that the implications of alternative strategies are communicated clearly and that comparisons can be made using the widest range of information available. The concept of a sustainability choice space presented here has been developed as one way of ensuring that the new generation of assessment tools, such as SIAT, can meet the challenges that decision makers now face. Although we have shown how these ideas can be implemented using techniques such as Bayesian Belief Networks, the implications of the SCS concept are much wider. In the context of sustainable development, the choice between policy choices is more to do with identifying those strategies that are sufficient or adequate in terms of future needs rather than searching for some optimal solution to current problems. Uncertainties, trade-offs and multiple objectives will always mean that the outcomes of policy debates are compromises. In framing those dialogues society needs to understand better the factors that constrain those choices.

1. Introduction

1.1. Sustainability Impact Assessment and the SENSOR project

Impact Assessments have become an increasingly high priority on the political agenda since its introduction in the European Commission (EC) in 2002, particularly after the publication of the Guidelines for Impact Assessment (e.g., 2005). Sustainability Impact Assessments (SIA) seek to identify possible economic, environmental and social effects of proposed policies and their consequences with respect to sustainable development. For this reason, SIA are inherently difficult to make because they require policy advisors to compare variables that are not easily comparable, i.e. policy proposals or options across the 'three pillars'[1] of economy, society and environment. The assessments become even more complex in the context of landscape which is inherently 'multifunctional', as described by Helming and Wiggering (2003) and Ling et al. (2007).

The SENSOR Integrated Project[2] follows this European agenda for SIA and is part of the Sixth Framework Research Programme. The project aims to provide a set of tools that can be used to predict impacts of policies and policy decisions as they are expressed through changes in land use (Fig.1).

These instruments, called Sustainability Impact Assessment Tools (SIAT) should enable the end user to quickly and easily determine what the impact of a policy on sustainability will be (Tabbush et al., 2008). The policy considered by SENSOR is the Financial reform of the Common Agricultural Policy (CAP) (see deliverable report 2.1.2 - Kuhlman et al., 2007 - for a comprehensive description of the policy cases and the reasoning behind their selection). The SIAT tools aim to provide an integrated assessment, that includes a number of different analyses and appraisals, by establishing a link between drivers and impacts (Scrase and Sheate, 2003). Crucially, these instruments are to be constructed in such a way that end users will not need specialist knowledge of the models powering the tools, nor should need to wait for the various models to run and produce accessible results but provide answers quickly and reliably.

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[1] We use the term 'three pillars of sustainability' although we agree with Kemp et al. (2005, p.3) that "the pillar-focused approaches have suffered from insufficient attention to overlaps and interdependencies and a tendency to facilitate continued separation of social, economic and ecological analyses." … and …that the overlapping circle idea comes closer to the integration of the three parts of Sustainability.

[2] SENSOR - Sustainability Impact Assessment: Tools for Environmental, Social and Economic Effects of Multifunctional Land Use in European Regions; see also http://sensor-ip.org/

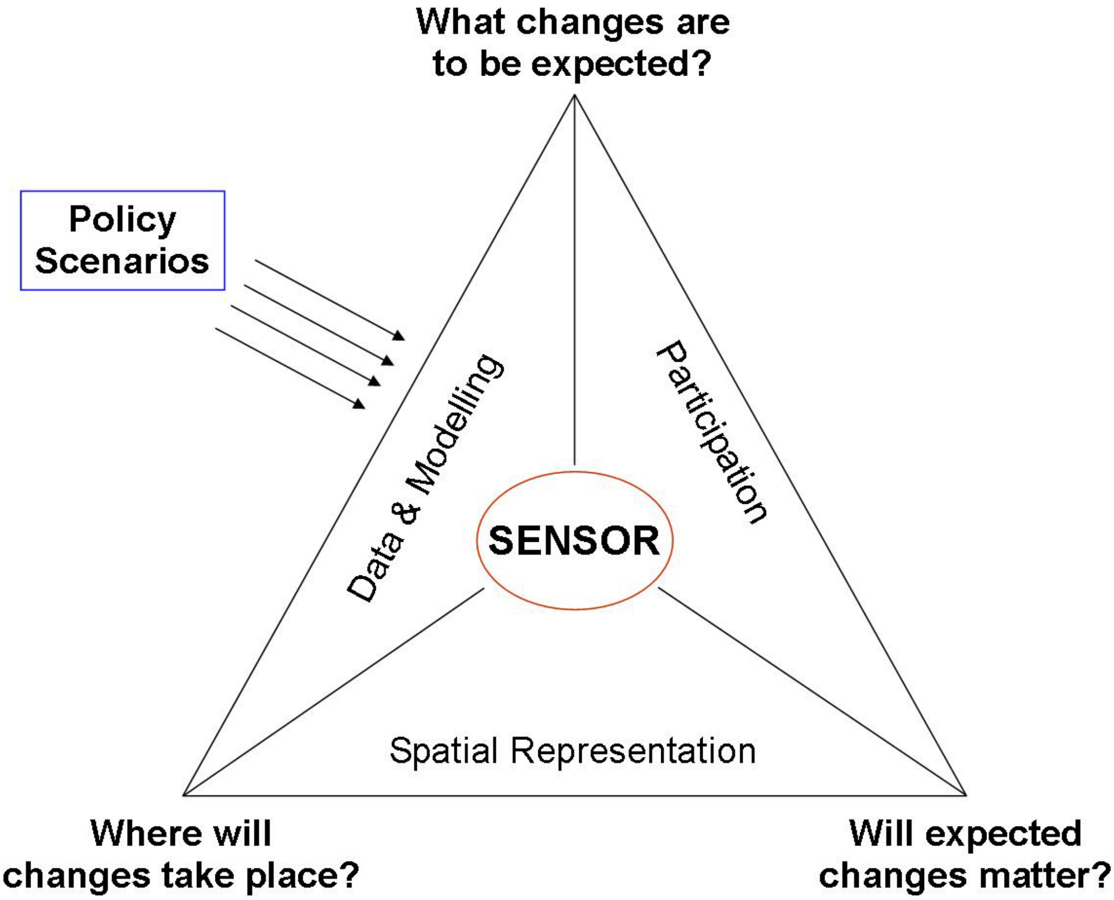


Figure 1. General framework of SENSOR: what are the main questions to be answered with the Impact Assessment (from Helming et al., 2008, modified).

1.2. The SENSOR SIA tools: meta-model and participation

The approach to SIAs adopted in SENSOR involves identifying a set of economic, social and environmental indicators linked to land use change, which allow us to trace the consequences of different EU policy options. The fundamental assumption is that **land use change** is the key driver. For each of the 24 indicators[3] used within SENSOR, critical **limits** (or thresholds) of acceptable change have been defined. Then, to allow for a full sustainability impact assessment *via* a more integrated perspective, indicators that link the effects of land use change to policy have been grouped into a set of nine more general '**Land Use Functions**' (**LUF**), divided broadly into three categories: environmental, social and economic, but with some degree of overlap (Pérez-Soba et al., 2008). LUFs are built by weighting the different indicators that influence the specific functions and will allow the evaluation of the changes in individual indicators that might impact on the wider aspects of human well-being

[3] Of the total number of indicators, 9 are of Environmental type, 8 of Economical and 7 of Social type.

and the environment in a more integrated way (see Paracchini et al., 2009; deliverable report 3.2.2 - Pérez-Soba et al., 2009 - for a more comprehensive description of the LUF methodology).

The geographical pattern of outcomes existing within Europe is also taken into account, by allowing the appraisal to vary across different spatial levels. A set of 30 '**Cluster Regions**' – **CR -** (Renetzeder et al., 2008; Renetzeder et al., 2005) were identified within a **Spatial Regional Reference Framework** (**SRRF**) in SENSOR, where NUTS-X[4] regions were combined to form homogeneous clusters with common economic, social and environmental conditions. Sustainability limits were identified for each region using expert-based knowledge both for the individual indicators and the aggregated LUFs for the **CR** across Europe to construct profiles describing the sustainability issues that are important within each region (Petit et al., 2008).

Within these indicator/LUFs and spatial (SRRF) frameworks, the SENSOR project developed two distinct paths for its tools, a technical-rational and a deliberative-participatory approaches (Tabbush et al., 2008). In detail those are:

i) **The technical-rational approach**. The indicators developed within the technical-rational approach have been chosen and discussed by 'topic experts' and then implemented into a knowledge-based meta-model - **SIAT**[5] - (see deliverables 4.2.1 and 4.2.3 - Haraldsson et al., 2008; Haraldsson et al., 2005), which constitute the principal focus of the project. The planned SIA meta-modelling tool is designed to achieve multiple scenario simulations derived from a series of models (NEMESIS[6], CAPRI[7], EFISCEN[8] and CLUE-S[9], see section 3), where the results would create a solution space within which future policy option can be analysed (Sieber et al., 2008). Time and spatial dimensions and the extent of analysis are further characteristics of scenario design that SIAT had to deal with. The projection year of 2025 was selected to meet decision maker's requirements for medium perspectives (Helming et al., 2008). The driving forces identified to affect the economic situations in Europe for this time scale were:

    1. Demographic changes (in Europe);
    2. Participation rate in the labour force (in Europe);
    3. Growth of world demand;
    4. Oil prices (global market); and

[4] NUTS-X regions were introduced in SENSOR and are a trade-off between administrative European NUTS2 and NUTS3 regions (Renetzeder et a., 2008). See also http://ec.europa.eu/eurostat/ramon/nuts/home_regions_en.html

[5] It is our belief that in reality SENSOR developed several tools for Sustainability Impact Assessments (SIA), therefore in some cases we will refer to them as SIATs.

[6] http://www.nemesis-model.net/

[7] http://www.capri-model.org/

[8] http://www.efi.int/portal/virtual_library/databases/efiscen/

[9] http://www.cluemodel.nl/

5. Expenditure on research and development to stimulate technological advance

Based on these driving forces, three scenario storylines were then constructed (Kuhlman, 2008):

- business as usual,
- high growth and
- low growth

against which policy scenarios could be analysed.

It is planned that SIAT will give access to modelled trajectories for a range of individual and aggregated social, economic and environmental indicators at various scales, from NUTS-X to EU level. In addition to providing metadata for each indicator or LUF, the system will be designed to inform users about any limits that are associated with particular indicators, and thus begin to provide them with the types of information that can help them explore the implications of a particular policy case or option. The scores associated with each LUF and their differences from the assigned limits are then used to perform a SIA for each scenario or simulation run by the meta-model. The results can be used to start exploring the implications of different policy assumptions across the social, economic and environmental dimensions of land use change. The analysis can be enhanced by a number of graphical aids , such as spider diagrams, bar charts, maps, tables, etc. (- see deliverables 4.4.1, 4.4.2 and 4.3 for a more comprehensive description of the model-based SIAT tools - Acevedo et al., 2008).

However, the user who interrogates the meta-model will probably find it difficult to obtain a solution or an answer to the initial query unless an appropriate tool is created to compare different results of different scenarios and for different geographical areas and under different policy options. It is crucial that, within SIAT, a set of tools and functionalities are made available to the user to accurately evaluate the area(s) in which the land use functions are within acceptable limits for the people who are affected by the changes (regional and local stakeholders) and what trade-offs between different outcomes can be considered. The boundaries of these areas will represent the thresholds beyond which unsustainable outcomes for some or all of the land use functions appear to occur with the set of policy assumptions being considered. As it will be described later, this is what the **Sustainability Choice Space** (**SCS**) framework or concepts intend to cover, and it constitutes the focus of this deliverable.

ii) **The deliberative-participatory approach**. Using the same logical framework that defines the design parameters of the model-based SIAT, a stand-alone participation-based framework of sequenced methods for involving national, regional and local stakeholders in assessments of land use policy impacts (**Framework for Participatory Impact Assessment** - **FoPIA**) was also developed (Morris et al., 2008). The indicators developed within the deliberative-participatory approach, were chosen through a participatory process with local stakeholders in sensitive areas (**Sensitive Areas Case Studies – SACS**), developed into the FoPIA and then included in a SIA discourse following the same general principles, based around the OECD's **Driver-Pressure-State-Impact-Response – DPSIR** – framework (OECD, 1998; OECD, 2000; OECD, 2001a; OECD, 2001b).

FoPIA represents a participation-based methodology that can be used as a complementary tool to the model-based SIAT. It encompasses four analytical phases which are structured as follows:

1. examination of national and regional interpretation and implementations of policy, including the perceived sustainability issues behind them;
2. assessment of the impacts, in terms of land use changes;
3. analysis of **sustainability criteria** and assessment of impacts on social, economic and environmental indicators; and
4. assessment of the sustainability of these impacts in terms of **acceptability**.

This structure is built to take into consideration what is sensitive to national and regional sustainability priorities. The whole logic flow is continuously informed by stakeholders and their knowledge of the local/regional and national economic, social and environmental status. For this reason, analytical components are not predefined, but become the subject of discursive analysis during each phase of stakeholder engagement (Morris et al., 2009).

The FoPIA framework recognises that the relationships between the elements of the analytical chain is conditioned by a number of socio-economic, environmental and cultural factors that are often specific to individual geographical contexts. As a result, the FoPIA was developed as a protocol and implemented in a series of workshops with local stakeholders in some of the project's SACS. Different European regions are obviously facing sustainability issues and problems that differ in both type and intensity. The FoPIA methodology is therefore intended to add a further dimension to the SIATs, as these are expected to be capable to capture regional heterogeneities, scaling from pan-European or country level down to regional or local level. The scheme starts from the definition of sustainability limits for key areas in each SACS, with a subsequent translation and comparison with the model-based results, in order to validate and judge the accuracy the outcomes for sustainable and less sustainable policy impacts. With FoPIA, SENSOR aimed to expand the *Impact* component into several consecutive impact steps, seen as a bottom-up approach (Helming et al., 2008). These should include monetary and non-monetary valuation of indicator changes at regional and national scale, assessment of the changes in relation to regional and national standard and threshold values, and finally a multifunctionality approach with the Sustainability Choice Space integrated assessment, which should be partly normative and partly participatory-based.

In essence, the FoPIA structure advocates a fully interdisciplinary, stakeholder-inclusive *modus operandi* that can play an important part in the analysis of policy impact. The social, environmental and economic responses dictated by the changes in policy cannot be anticipated as a consequence of a simple modelling process. In fact, the involvement of stakeholders in this process not only can dispute the very primary assumptions of the modelled predictions, but can indeed introduce another layer of information and complexity (here meaning completeness) for the achievement of more truthful assessments of policy impacts. This in turn can generate a better lead to more informed decisions and highlight where are the trade-offs, where there can be compromises or whether win-win situations are at all likely.

It has been suggested that the modelling (SIAT) and the participatory (FoPIA) approaches should work synergistically (Tabbush et al., 2008) where the rich contextual knowledge characteristic of the various FoPIA workshops could be used to validate and complement the outcomes from the model-based SIAT. The Sustainability Choice Space concepts, with the incorporation of the stakeholder's view and the uncertainty of the outcomes, can facilitate the amalgamation of these two methodologies, shaping the direction and the development of future models. As represented schematically in Fig. 2, the SCS aims to bring together the strengths of the various elements that characterise SENSOR - the modelling approach, the stakeholder engagement and the use of indicators and limits - in a coherently and unifying framework.

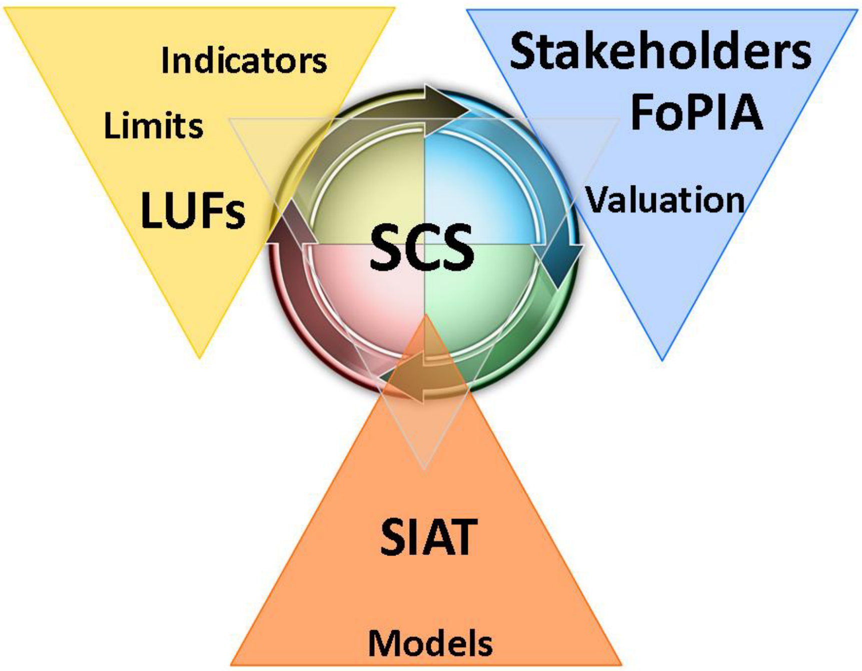


Figure 2. Graphical representation of the Sustainability Impact Assessment elements, and their links through the Sustainability Choice Space (Helming, 2007, modified).

1.3. Objectives of this deliverable

This report examines the issues related to the visualization and the interpretation of results from the tools provided with the SENSOR project (SIAT, FoPIA, etc.), as this is deemed to be the key stage that precedes and supports a decision by a policy-maker. The discussion will touch on both the analytical model-based SIAT and the participatory approaches and in particular reflect upon the problem of integrating information from both expert and stakeholder sources in order to frame decisions across the 'three pillars' of sustainability.

Although such a combination has been widely advocated, exactly how to design a mechanism to achieve this is yet to be described and "there remain very few examples of effective sustainability assessment processes implemented anywhere in the world" (Pope et al., 2004). The same authors emphasise how the interactions between social, economic and environmental impacts are indeed producing combined effects that are unlikely to equal the sum of the parts, where it becomes particularly important that social sciences methodologies are involved at the right level. The process of arriving to a possible solution is therefore essentially political and needs to benefit from local knowledge of the likely impacts (Morris et al., 2008).

As anticipated earlier, the concept of a **Sustainability Choice Space** (**SCS**) is therefore introduced as a framework in which these complex types of judgements can be made in an integrated way (Potschin and Haines-Young, 2008), a solution or decision space where policy advisors might visualise and explore what 'room for manoeuvre' they might have in the design of a specific policy.

As a result, the report will examine:

- How the general framework for the SCS might be used to describe the acceptability of alternative policy outcomes for stakeholders and policy-makers across a range of criteria defined by the suite of indicators that are driven by land use change;
- How the SCS framework and ideas are applicable to the two approaches embedded in SENSOR, the technical-rational and the deliberative-participatory, and the tools developed following those approaches (respectively, the **Sustainability Impact Assessment Tool** – **SIAT** – and the **Framework for Participatory Impact Assessment** – **FoPIA**);
- How the SCS should be assembled using information derived from models **and** stakeholders to identify the dimensions of sustainability, which are important in the context of a specific policy and the limits and thresholds associated with them; and
- How the SCS can enhance the evaluation of the various dimensions and the scales' diversity (geographical and non) that exists within Europe, by allowing the limits to vary across the various regional scales (EU, Country, Cluster Regions, NUTS-X) and economic, social and environmental indicators to be more scale-specific.

All these aspects will be addressed in the following sections, where we will explore how the concept of a SCS can play an important part in the sustainability impact assessment toolkit being developed through SENSOR. In particular, in section 2 the deliverable focuses on issues of decisions and choices in sustainability impact assessments. We will argue that matters of uncertainty need to be taken into consideration, even more so where the complexity of the systems is large. We will begin to build the framework for the SCS, reasoning on the belief that the quest for '*THE*' optimal solutions does not represent the best way to address these issues, whereas 'adequate' or 'sufficient' solutions can. We will start exploring the multitude of dimensions that need to be included in such decision space where decisions can be supported and fostered.

In section 3 the deliverable turns to the tools provided and developed with SENSOR, analysing the two approaches used to tackle sustainability impact assessments in details and trying to build a critical assessment of the positive and negative aspects of top-down and bottom-up methodologies. These are currently proposed as two distinct paths, but in section 4 we suggest that they should complement one another, and form an integrated tool that users may actually benefit from to support decisions on policies at various levels. Although it is recognised that the achievement of such integration is very complex, it is nevertheless viewed as the critical step towards a truly integrated assessment of issues of sustainability across both different geographical and regional levels as well as sectoral. In this section we will discuss the importance of including uncertainty and how this may perhaps only be achieved by a shift towards more probabilistic systems of analysis, where we can take stock of the different sources of data and their accuracy. The additional step of adding weights and monetary or non-monetary values is also discussed and added into the framework (as a result of a workshop carried out with SENSOR colleagues).

In section 5 the deliverable focuses on the practical issues of design and application of the SCS into the current SIAT framework, with recommendations and suggestions for future versions of the tool. Finally, the deliverable reports in section 6 the results of a second workshop, where the tools were explored and critically analysed from a user's point of view.

This deliverable shows how the SCS concepts can enhance the integration of the different approaches described, particularly by the involvement of stakeholders in the definition of sustainability limits and the kinds of trade-offs that need to be considered in a multifunctional landscape. The SCS tool can be used to explore how the effect of different stakeholder values may change the types of judgement made using the model-based SIAT, and hence highlighting the importance of a more inclusive and adaptive approach to sustainability impact assessment.

Box 1.1: Key messages from section 1

- Sustainability Impact Assessments are difficult to achieve because they require comparing variables that are not easily comparable.
- The SENSOR project aims to provide integrated *ex-ante* SIA across the 'three pillars' of economy, society and environment.
- The land is considered as multifunctional and the approach is to consider impacts of land use changes on key indicators.
- The main tools developed by the SENSOR project are based on modelling (SIAT) and participatory (FoPIA) approaches.
- The tools are based on indicators, chosen and assessed by experts and then aggregated into nine broad Land Use Functions (LUFs) that cover the three pillars. Indicators and LUFs are chosen and assessed by stakeholders in the FoPIA approach.
- The geographical differences existing across Europe are accounted for via the Spatial Regional Reference Framework (SRRF), where smaller regions (NUTS-X) have been clustered into 30 bigger regions (Cluster Regions). Variability of limits for the indicators is considered across Cluster Regions.
- The SIATs aim to provide users with the types of information that can help explore the implications of a particular policy case or option, which will be enhanced by a number of graphical aids.
- However, for the user who interrogates the meta-model to obtain a solution or an answer, appropriate tools need to be made available to compare different results of different scenarios and for different geographical areas, where land use functions are within acceptable limits and what trade-offs between different outcomes can be considered. It is suggested that the concept of a Sustainability Choice Space can help framing these aspects of the analysis, highlighting the 'room for manoeuvre' that policy makers and advisors have in shaping a new policy.

2. Choices and decisions

Ex-ante sustainability impact assessments of future policies are based on the comparison of different results and scenarios. To understand whether the introduction or changing of policy options and frameworks can have an impact, it is therefore essential to understand what exactly the policy choices are and what can inform a decision to shape it. Thus we need to consider the various dimensions of sustainability, as the choices will need to cover all the aspects of this complex system, including the uncertainty that is accompanying them.

2.1 Uncertainty and complexity

Normally, a decision making process involves selecting between alternatives, requires an understanding of the choice available, the criteria by which to evaluate those choices and the act of judging. The role of the tools provided by SENSOR should therefore be that of supporting the making of a decision, by providing a view of alternative choices and the background needed to judge them. However, as described in part by Goodwin and Wright (1991), the difficulty arises where:

1. there are multiple and possibly conflicting objectives;
2. there are multiple and possibly equally conflicting impacts;
3. the uncertainty about the choices available and/or the criteria for judgment is high or unknown;
4. there are multiple parties (or stakeholders) 'supporting' the decision, with different attitudes and interests; and
5. the complexity of the system is high and the problems linked to it is even higher.

All these factors are unquestionably present and play an important role when, as in the SENSOR project, the landscape and land use are considered as 'multifunctional'.

The complexity of the problems under scrutiny in SENSOR is clearly extremely high: indicators are used to simplify the system's representation and are at the same time used to describe and monitor the system to be assessed. Following the indicator approach, specific targets need to be defined for the indicators by the principles of sustainability, where coherent policy objectives are therefore essential for the impact assessment to be effective. The central issue is then to define sustainability goals, which can be seen in terms of constraints that identify the operational space or "room for manoeuvre" in policy design. In this context, the users need to accept and be prepared to consider that not only a single, optimal, solution is possible, but several adequate solutions can be more or less equal in the way they shape the future.

In general, complex systems have been called "wicked" by some authors (Rittel and Webber, 1973) and "messy" by others (Acknoff, 1974). This is because they are characterised by a high level of uncertainty which should be recognised and explained, especially in the case of model-based approaches (Fig. 3). Uncertainty can stem from a variety of different sources. These can be generally categorised under the following headings[10]:

- Natural Variability, which refers to the randomness observed in nature;
- Knowledge Uncertainty, which refers to the state of knowledge of a physical system and our ability to measure and model it; and
- Decision Uncertainty, which expresses the complexity of our social/organisational values and objectives.

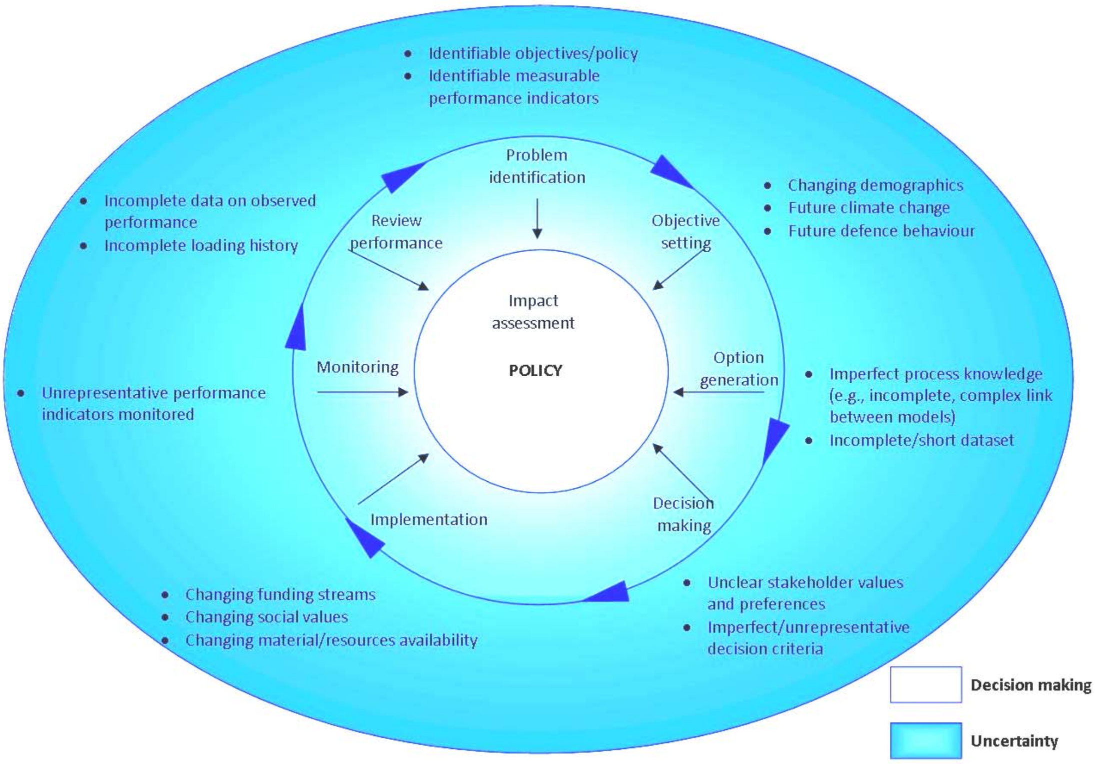


Figure 3. Uncertainties surrounding the process of decision-making (source: see footnote, modified).

It is to deal with these issues that, for example, Post-Normal Science (PNS) (Funtowicz and Ravetz, 1994) appeared on the horizon as a new conception of the management of complex science and policy- related issues, focusing on aspects of problem-solving such as: **uncertainty**, **value loading**, and **a plurality of legitimate perspectives**. PNS considers these elements as integral to science and by including them in the framing of complex issues, is

[10] document of unknown source found on Delft university website, modified www.citg.tudelft.nl/live/pagina.jsp?id=a4751543-3c3e-4787-b3c2-ae34f717f351&lang=en&binary=/doc/citatie26.pdf

able to provide a coherent framework for an extended participation in decision-making, based on the new tasks of quality assurance.

The problem is that, when these issues are included in a model such as that at the centre of the SENSOR project, the ways to deal with sensitivity analysis and uncertainty can be very different. As described by Hisschemöller et al. (2001), some modelling teams try to capture the underlying system as accurately as they can, resulting in very detailed models (the 'kitchen sink' style). In this way, the goal is to try to avoid uncertainty by putting as much knowledge into the model as possible. The problem with this methodology is that the resulting model is not necessarily as accurate as needed, particularly not for complex environmental issues on large spatial and temporal scales. Adding detail to a model implies an increase in computer time to run it, the same time increasing the number of judicious choices and parameters to be analysed in a sensitivity analysis. Other modelling teams place uncertainty in the core of their endeavour, trying to capture the range of possible directions in which the underlying system may develop. All parameters are described by a probability density function rather than a single value, variants of the model are used to analyse uncertainty about functional relationships between variables, and alternative models are used to analyse uncertainty about model and problem structure.

In the case of the SENSOR technical-rational approach, as already described in section 1.2, the choice adopted by the developers of the prototype versions of the model-based SIAT was to deal with these issues by using a style more similar to the 'kitchen sink', therefore by trying to capture the system with as much knowledge as possible, but without quantifying explicitly the uncertainty surrounding the sources and the processes. The other SENSOR approach – the deliberative-participatory - which involves instead the deliberative framework of the FoPIA, is by nature more a conceptual model. Here the participatory process is used as an intellectual device and can only deal with uncertainty to a certain extent. Participatory frameworks are in fact normally less formalised than numerical models, and only very recently have there been attempts to design frameworks to support effective and target-oriented modelling to deal with data uncertainties and results sensitivity (Gottschick, 2008).

In dealing with integrated sustainability impact assessment there is clearly no single-best approach, but multiple approaches may be required. However, the common underlying position to adopt should be the one to recognise that it has been, and always will be, necessary to make decisions in the absence of perfect information. In the past, uncertainty in decisions has been implicit rather than explicitly accounted for. Recognising uncertainty does not however prevent decisions being made. In fact, understanding uncertainty is a key requirement for any decision-making. By quantifying and acknowledging uncertainty we are better placed to decide how to best manage it. The shift to a more inclusive way of managing these complex social and biophysical systems is therefore necessary for developing new problem-solving strategies in which science may help to understand the full context of the complexity and uncertainty of natural systems and the relevance of human commitments and values. However, in absence of proper quantifiable uncertainty measurements, the alternative is to create a space where solutions can be visualised and compared, to discard those outside the scope of sustainability, and cross-compare the ones with sufficient capacity. For this reason it is here suggested that the definition of a Choice Space of potential solutions can effectively work as a way of coping with uncertainty.

2.2. Defining a Choice Space: Optimal vs Adequate Solutions

Sustainability appraisals are known to be extremely difficult for two main reasons:

1) the complexity of trying to resolve issues between variables that are not always comparable – economy, society and environment and
2) the intricacy of finding those 'right answers' that are very often so difficult to recognise. The range of variables and issues to consider is exceptionally wide and the ultimate mistake is trying to address everything by ways of a traditional scientific approach, particularly where political, economical and social dimensions play such a fundamental role in shaping the reality.

Many authors have already argued that 'traditional science' is not suited for the problems that sustainable development may present (Gallopín et al., 2001; Holling, 1998; Kates et al., 2000). Holling (1998), for example, has attempted to contrast the features of traditional science and its analytical traditions with a more 'integrative' approach that seems more appropriate in the context of sustainability.

However, the indispensable step that we need to undertake is to recognize that there is a fundamental difference between the sorts of problems we face in the scientific and policy realms. One way to understand the main differences between the problems encountered in the scientific and policy realms is to understand how solutions are regarded. For the scientist, theories (= solutions) stand or fall according to whether they are supported or refuted by evidence. The guiding principle is that there is only one true explanation and that through trial and error that answer might ultimately be discovered. Solutions to questions involving sustainable development are not usually like this, for here - while solutions must not ignore biophysical, economic or social constraints - many different organisational strategies or policies can deliver outcomes, which have the capacity to ensure social justice, well-being and inter-generational equity. Solutions to the problems of sustainability merely have to be sufficient or adequate in relation to society' values, not ultimate, and so we may be presented with a choice of many ways forward. We do not, in other words, need to find 'a best' or 'optimal' solution. Indeed there may not be one. 'Success' ultimately depends on finding a **sufficient solution** and the political process of choice.

The difference between 'ultimate' and 'adequate' solutions is well illustrated by different ways of thinking about land use patterns and sustainable development – the type of problem that is a central concern to projects such as SENSOR. As we look at future scenarios and at land use changes, we do not necessarily need to find the optimal arrangement to maximise ecological integrity as well as achieving basic human needs and for creating a sustainable environment as suggested by Forman (1995). Indeed the alternative vision envisages that if our goals include ecological integrity or continued human well-being, then many different spatial arrangements of land cover and use are likely to be able to achieve such ends (Potschin and Haines-Young, 2006). Thus while we might acknowledge that a certain level of woodland cover is necessary to maintain biodiversity, and that a certain degree of fragmentation should not be exceeded, those criteria can be met by many different arrangements of woodland parcels across a landscape.

It is now widely acknowledged that whatever sustainable development involves, it certainly embodies the idea that the output of ecosystem goods and services from landscapes or ecosystems should be maintained (MA, 2005). 'Sustainability' is, therefore, assessed more in terms of the ability to maintain functional outputs than by structural properties *per se*. Thus it can be argued that, in contradistinction to Forman (1995), the major challenge confronting land use science is to understand what possible spatial arrangements are sufficient to maintain the outputs of goods and services that people value, and what types of arrangement are unlikely to achieve such ends, and thus to identify the ***range of planning choices*** that are available to us (Haines-Young, 2000; Potschin and Haines-Young, 2006).

An understanding of the difference between 'ultimate' or 'optimal' and 'adequate' or 'sufficient' solutions in the context of sustainability is of fundamental importance for anyone attempting to design impact assessment tools. The search for adequate or sufficient solutions, rather than ultimate answers is, in fact, implicit in the 'adaptive' and 'flexible' approaches espoused by the champions of so-called 'sustainability science' and the ecosystem approach (Kates et al., 2000; 2001). Indeed, as Kemp et al. (2005) have pointed out, sustainability is best approached as an open-ended process, and that the notion of sustainable 'landing places' that is sometimes used by the European Commission is probably misleading. As Kemp et al. (2005) note, such ideas suggest that the problem of sustainable development can be 'solved' whereas in reality only specific issues can be resolved and managed.

In searching for appropriate problem solving strategies we need to look no further than the example of the process of evolution by natural selection, which also operates on the basis that at any one time, new forms do not need to be optimal, but simply sufficient to improve survival over other varieties (Sartorius, 2006). The difference between the two processes is merely that under sustainability planning, the strategy that 'survives' is determined more by social negotiation than competition. Sustainability impact assessment is essentially **normative** rather than **prescriptive**, and is based on an understanding of the ways in which economic, social and environmental considerations constrain our policy choices. Thus the Choice Space will be constituted by a set of 'adequate' solutions that can survive the economic, social and environmental constrains, creating the space for negotiation where the 'natural' selection of the policy options can occur.

2.3. Multi-dimensional decision making: a conceptual framework for the Sustainability Choice Space

In the context of projects like SENSOR, which is attempting to make sustainability assessments by considering land use change, the dimensions of the analysis from which eliciting or informing a decision are numerous, all apparently of equal importance. In addition to this, the goal of comparing policy options through sustainability assessment is not to discover some optimal solution, but to find strategies that are sufficient to maintain over time the benefits that land use systems can provide. In this case the tool(s) to be used necessitate(s) even more flexibility to enable 'scanning' over the various options. This aspects are also further complicated by the fact that all the indicators and dimensions included in these analyses are usually defined within ranges and limits, which, as described in section 1.2., cannot be fixed *a priori* and need to be defined by experts and/or be specified in a deliberative-participatory process, where they will be different depending on the user, interests group or regional stakeholders involved. Therefore, limits and their different nature and variability is another aspect to take into account when making impact assessments.

In fact, the discussion, identification and setting of limits is part of the 'democratisation of the knowledge' that many now see as an essential element of contemporary scientific and policy debates. The identification of limits across the three pillars of sustainability is important because these limits constrain our policy choices, where the various economic, social and environmental limits or thresholds frame the choices that we can make. Unfortunately the task is not an easy one, because different discipline areas approach the problem in different ways and the concepts of thresholds and limits is itself confused. However, as this is not the space for this discussion, the authors refer to Potschin and Haines-Young (2008) for a more comprehensive account of the subject.

As stated above, sustainability impact assessments are therefore difficult not only because they force us to compare variables that are not easily compared, but also because they are **multi-dimensional**. The tools that deal with these complex systems need to be capable to handle all the various aspect of the analysis, so to inform and support decision in the most appropriate way. There is little consensus on which decision support tools are best suited to different situations, or even on how best to select the appropriate decision support tool. The number of decision support tools is in fact very large[11] and for the inexpert can be confusing. In the case of complex systems such as that encountered with the SENSOR project, transdisciplinary approaches and tools have been often advocated (e.g., Ravetz, 1999) as they provide a framework with which to adapt the assessment tool to the perceptive, cognitive and discursive skills of the users and stakeholders as well as their values and preferences in order to support socially stable and scientifically founded decisions (Wiek and Binder, 2005). Some authors advise the use of **Multi-Attribute Decision Making** (**MADM**) tools, which are a type of outcome-based models answering the "What if?" question (Tompkins, 2003).

MADM methodologies are often used as a choice tool, to provide a framework in which to display data (a representation aid), and as a means of including stakeholders' preferences in the decision making process. Many MADM tools were developed in the 1970's and 1980's, stemming from the **Multi-Criteria Analysis** (**MCA**) methodology, and have been applied in a variety of contexts (Funtowicz et al., 1990).

Generally speaking, MADM-MCA forms of analysis involve the display of the impacts of different scenarios on defined criteria in an 'effects table', an *n x m* matrix in qualitative or quantitative terms. This can also be used to generate a preference ranking of different scenarios. The ranking is determined by normalising the values in the table, applying stakeholders' preferences weights and then trading off amongst the criteria. These kinds of frameworks have already been used in planning and environmental decision making (Dodgson et al., 2001) and require the construction of a dialogue process among many stakeholders, individual and collective, formal and informal, local and not (Munda, 2004). Fenton and Neil (2001) went a step further by using a combination of traditional **Multi-Criteria-Decision-Aids** (**MCDA**) complemented with probabilistic models such as the **Bayesian Belief Networks** (**BBN**), that proved to be very powerful for reasoning under

[11] See http://www.ifm.eng.cam.ac.uk/dstools/

uncertainty. The procedure consisted of identifying the objective and perspective for the decision problem, as well as the stakeholders, which lead to a set of actions, criteria and constraints. Values were then calculated by the BBN for each criterion for a given action, where MCDA would then combine the values and rank the set of actions.

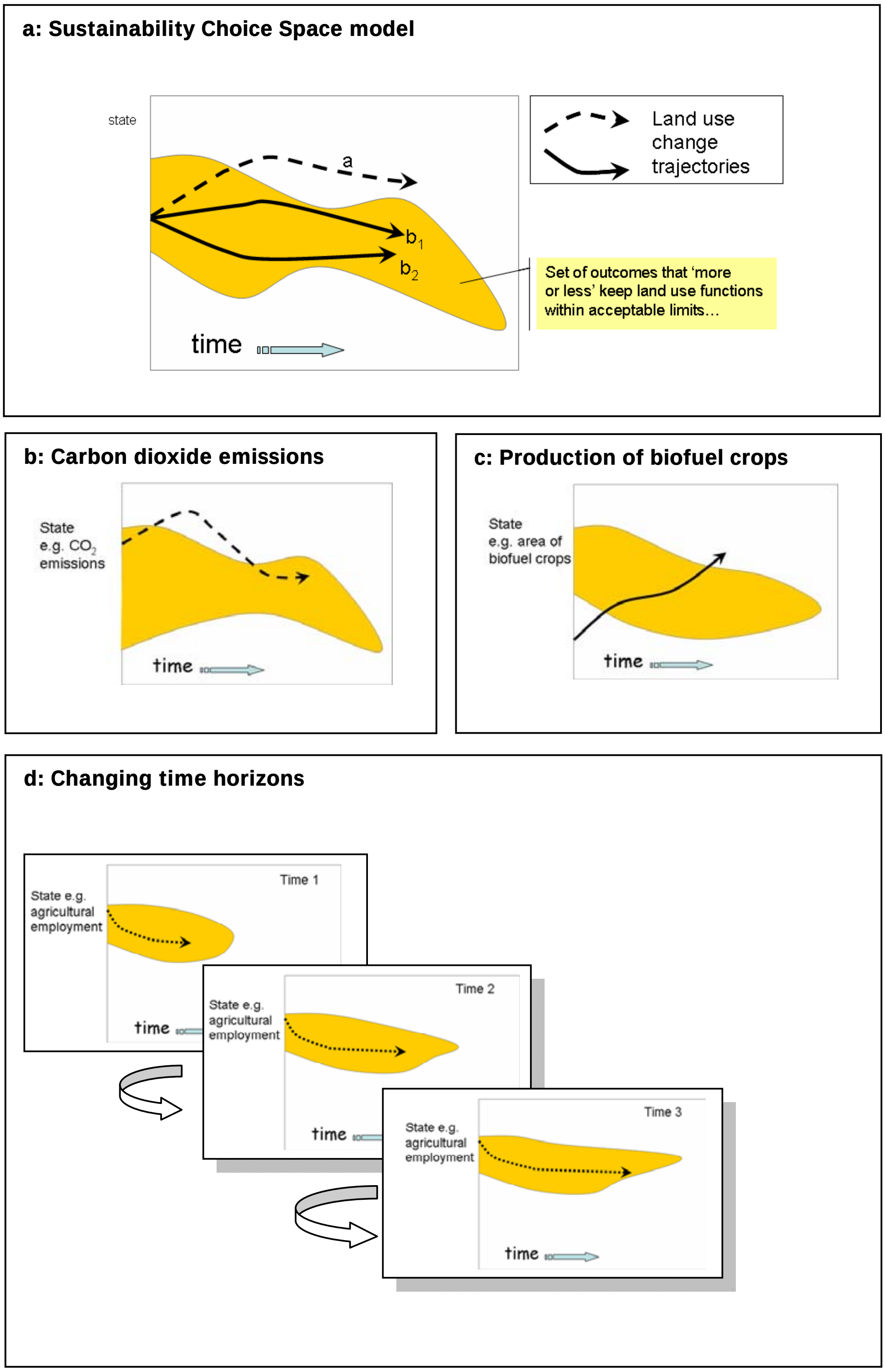
Many more techniques could be suggested to address the issues related to the analysis of the results of SIAs, as there are numerous methodologies, all with advantages and disadvantages, strengths and weaknesses, but none that can be deemed to be best-suited. However, it is clear that a multi-dimensional, more integrated and inclusive approach is needed. For this reason, and as anticipated in section1.3, a conceptual framework will be here introduced and discussed to try assisting with this issue.

We begin with considering the implications of some policy measures in terms of '**trajectories**', to assess whether these are falling outside a region determined by the limits and thresholds defined earlier. The suggestion is that this critical region can profitably be seen as the **Sustainability Choice Space** (**SCS**) that expresses the room that we have for manoeuvre in designing our different policy options.

The idea of a SCS in relation to issues of land use change is relatively new, and has mainly been discussed in conceptual rather than practical terms (Potschin and Haines-Young, 2006). As an emerging idea, however, it has resonance with thinking in other discipline areas. The idea is analogous with concepts discussed in the literature on sustainable consumption and production, where concepts such as 'sustainability spaces' (Binder and Wiek, 2001), 'solution spaces for decision-making' (Wiek and Binder, 2005), 'sustainability corridors' (Bringezu, 2006), and 'windows of sustainability' (Kontogianni et al., 2008) have been proposed as a way of looking at indicators and the messages they convey. In the more ecologically orientated literature, Kaine and Tozer (2005) have in the context of agricultural systems, attempted to conceptualise sustainability as a set of boundary conditions. These authors develop a 'pasture envelope' concept in the form of phase diagram in which the trajectories over time of key biophysical variables such as pasture biomass and composition are graphed against critical thresholds established on the basis of pasture growth rates and livestock growth requirements. The idea of a 'sustainable trajectory' through some kind of choice space is also echoed by recent discussions in the sustainable development literature on 'transition management' (Kemp et al., 2005; Tukker and Butter, 2007; Wiek et al., 2006). Transition management is a general term that deals with issues of governance related to sustainability, and is proposed in the Netherlands as a way of replacing outcome-based planning with more adaptive and reflexive approaches. The concept represents sustainability as a process or journey, rather than some end point, and stresses the fact that strategies should 'not aim to realise a particular path at all costs' but rather to explore all promising paths 'in an adaptive manner' (Kemp et al., 2005).

We can visualise these ideas in terms of the model described in Fig. 4, which illustrates the idea of a SCS in relation to different trajectories of land use change.

Figure 4. A simple model illustrating the concept of the Sustainability Choice Space.



In the simplest case we could characterise the dynamics of the system that we are interested in by a single indicator[12] that reflects these land use changes, such as 'CO_2 emissions or 'the area of biofuel crops'. As mentioned before, the key question is whether the land use trajectory is likely to take us out of the region beyond which some critical limit is reached for the indicator or aggregate indicator (LUFs) that we are interested in. This region is where sustainability is maintained and forms the ***choice space*** that can be used to evaluate the various options available to shape the policy. Here the options that may fall within the choice space may well be numerous, as they could all be 'adequate' or 'sufficient' to address the issues of sustainability. As described in section 2.2, there may not be an 'optimal' solution and the choice will simply be guided by a political process.

If instead current land use trajectories are likely to take us outside the critical region then we can ask questions about what types or level of policy intervention might bring us back within limits (Fig. 4, trajectory a). If we perceive that in the future our views of limits might need to be changed, then we might ask what options there are for ensuring that future trajectories continue to sustain the level of benefits we currently enjoy (Fig. 4, trajectory b_1 and b_2). In Fig. 4, since trajectories b_1 and b_2 are likely to keep us within acceptable limits then both can be regarded as 'adequate' or 'sufficient' in sustainability terms. The decision between them is essentially a matter of **social or political choice**, and it is within this space that trade-offs between various types of benefits can be discussed.

The model shown in Fig. 4 is simplistic, however, and several important features should be noted to see what insights it has for understanding real world situations. In reality the choice space is multi-dimensional. Sustainability assessments need to take account of many factors, and these can be expressed in different ways. The expanded Venn diagram of Fig. 5 introduces the kinds and numbers of dimension to be considered in a '**desert rose**' type of model. The model is illustrative of the complexity of the system, and it is not necessarily exhaustive of all the possible components that may take part in shaping a choice space. However, we can begin to see how **TIME can shape the choice space**.

A sustainable trajectory of land use is one which maintains the output of the goods and services that are important to well-being. That is, it remains within the limits that society has identified, or agreed on, as significant. This is the issue that is being captured by the indicator. However, clearly the view that society has about limits can change, and so a trajectory that was once thought of as unproblematic can become so. The problem of CO_2 emission is a case in point (Fig. 4b). Improved scientific knowledge now suggests that emission loads need to be significantly reduced - thus over time we can see that the choice space has been reduced in terms of the upper limits of emissions that are considered allowable. At the same time, there is probably a lower level of emission, below which the costs or risks of further carbon emission controls would probably outweigh the benefits. Again this may change with, say, changes in technology such as carbon storage. The point is, however, that there is scope for policy choices between these limits, and any informative sustainability assessment has to be framed around notions of where these limits lie.

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[12] In the case of SENSOR, a set of high level, aggregated indicators known as 'Land Use Functions' (see Pérez-Soba et al., 2008), will be used to summarise the effects of different policy. The argument presented here applies whether we use a single indicator or an aggregated land use function.

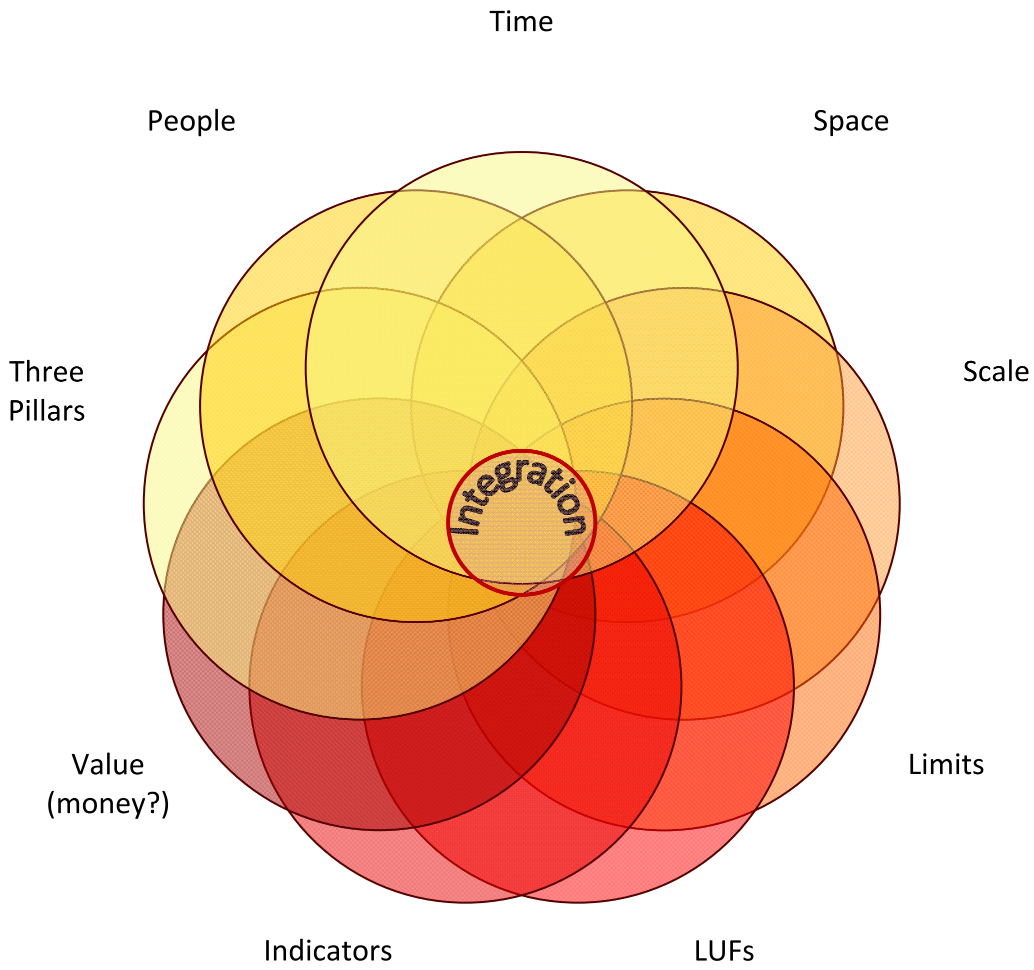

Figure 5. Multiple dimensions related to the concept of a sustainability choice space in a 'Desert rose' model.

The same point can be illustrated by reference to the biofuel case shown in Fig. 4c. Here we start from the position that biofuel output is probably below what society requires, given the need to reduce the consumption of fossil fuels. Thus while policy changes may stimulate the expansion of such crops, there is likely to be an upper limit to such an expansion in particular areas, beyond which the wider impacts of the new land use patterns become unacceptable. For example, given the need to sustain and enhance farmland bird populations, the replacement of traditional forms of arable farming with short rotation coppice, may conflict with this aim. Moreover, the expansion of large areas of woody crops may also impact on the visual and aesthetic qualities of landscapes. Once again views about what constitutes the upper and lower limits may change over time, and crucially may be contingent on the character of the particular landscape or set of landscape types that we are dealing with. This is illustrated by the example in Fig. 4d, which has been constructed around the issue of 'agricultural abandonment'.

In many areas of Europe, agriculture is economically marginal, and land abandonment has become an important driver of land use change in these areas (Swaffield and Primdahl, 2006). In Fig. 4d, the indicator used as a proxy for this process is the level of agricultural employment, which is shown to be declining slowly over time. At each time step, however, our view of the future may be different as our perspectives and understanding of economic, social and biophysical limits change. Thus a trajectory that was thought initially to be 'within tolerance limits' may eventually be judged to be 'unsustainable' if, for example, our notion of what constituted a minimum level of employment changed. This might arise, for example, as our views about the levels of rural population needed to maintain rural services evolved, or as the result of increased concern about the risk of fires in landscapes that are undergoing succession back to woodland as a result of land abandonment.

While the shape of the sustainability choice space may change over time, there are other variables that can influence its shape, even considering the same 'slice' of time. This is again illustrated by Fig. 5, where all the other factors listed may influence the nature and the shape of the space. It is generally impossible to identify some 'ideal' or 'final' state, as the number of variables involved is not definitive. In fact, although we may plot the state of the system in terms of a single **indicator** that reflects some aspect of the **economic**, **social or environmental** characteristics of the land use system (the 'three pillars' in Fig. 5), then we need to add other factors such as the notion of a **limit**, which can help us integrate thinking across the three pillars of sustainability in ways not easily achieved by current indicator approaches (see also Fig. 5). The level of agricultural employment in rural areas (Fig. 4d), for example, could be viewed as an economic indicator, but it clearly has environmental consequences, since it can affect a range of physical characteristics of an area. Withdrawal of farming may not only change risks associated with fires, for example, but also the visual properties of a landscape, which once gave it its 'sense of place'. Similarly the limits associated with an environmental indicator such as CO_2 emissions are ultimately also determined by social and economic considerations that include the costs and risks associated with the sorts of investment that might need to be made to trigger particular land use changes (e.g. reduced input agriculture) on a sufficient scale to make a difference.

Even though some aspects of 'multi-dimensionality' can be accommodated in the way limits are expressed, the representation and the shape of the choice space is further enriched and extended when we are using some aggregated, or 'high level' indicator, such as the land-use functions proposed in the SENSOR team. The **LUFs** can be represented within the SCS in exactly the same way as single indicators, but will of course contain more dimensions and information with respect to a single indicator. Figure 5 shows also how the representation of the choice space is further complicated by factors of geographical **space** and **scale**, and indeed by the inclusion of **people**'s opinions and preferences that can shift boundaries over many different directions. These aspects are of particular importance within the SENSOR framework, but more generally with sustainability impact assessments of land use change policies and will be explored and described in more depth in the following sections, together with the difficulties posed by the implementation and the representation of such multi-dimensional thinking.

2.4. The rationale for SCS development and implementation

All the elements described above can be translated into the tools developed in SENSOR, where both the model-based SIAT and the participatory framework can benefit from the implementation of the concepts included within the SCS framework. In particular, the SIA process should include the following characteristics, which are part of the SCS framework:

1. Ways of considering data and processes uncertainty;
2. Ability to allow for stakeholder engagement, including preferences and monetary valuation; and
3. Ability to assess the various scales of sustainability, geographical (from regional to local) and temporal, and vary the limits accordingly.

The above elements define in fact the task that will be explored in the next sections, where the ideas and concepts defining the SCS will be developed and applied in the context of the model-based SIAT and the FoPIA methodology.

As already stressed earlier, SENSOR developed two approaches, the technical-rational and the deliberative-participatory, as separate entities, but they present communalities in the logic chain and some of the fundamental assumptions.

The SCS advocates the amalgamation of the two approaches, where the combined strengths of the modelling and participatory approaches can help formulating better answers to the questions posed by the SIA.

Box 2.1: Key messages from section 2

- Sustainability Impact Assessments (SIA) deal with extremely complex systems, including a large number of factors and dimensions, and for this reason are naturally characterised by a very high level of uncertainty.
- Uncertainty can be classified, but not always quantified, as there are some types of uncertainties that are related to a political decision, some others are related to processes which are yet to be framed into models and rules.
- However, uncertainty should be taken into account, particularly when the analysis is intended to bring information to a decision, such as that of shaping a new policy.
- Different approaches exist to deal with uncertainty in modelling frameworks, but the SENSOR project deals only partially, if anything, with these issues.
- SIAs need to look at sufficient answers, rather than optimal solutions. For this reason, a number of adequate answers may be possible at the end of a sustainability appraisal. Sustainability Choice Space (SCS) looks at the room for manoeuvre available to shape a new policy; it opens to regional and local aspects of the sustainability, with emphasis on stakeholder participation.
- Systems looking at the group of possible solutions need to be flexible enough to consider the myriad of dimensions and factors involved in the analysis.
- Many kinds of tools need to be used, in a multi-dimensional way, to compare and analyse the outcomes from the SIA performed in SENSOR, and they can be integrated within the SCS conceptual framework.
- Time, uncertainty and variability are included in the analysis of trade-offs and options under the SCS framework.
- This constitutes the rationale for the development and application of SCS framework and should include all of the above points.

3. The SENSOR SIA tools: meta-model and participation

SENSOR aims to integrate the top-down data and indicator based modelling with a bottom-up, value driven participatory approach (Helming et al., 2008). The following sections describe the two approaches in more detail and introduce the rationale for combining them through the SCS concept.

3.1. The model SIAT (prototype III) and the top-down approach

Modelling and scenarios forecasting of land use change have recently emerged as a focus of appraisal methodologies (Veldkamp and Verburg, 2004; Verburg et al., 2006) and appear to be at the centre of a number of studies that placed land use into the logical chain of driving forces and impacts (ATEAM[13], EURURALIS[14], SEAMLESS[15], PRELUDE[16], etc.). The SENSOR approach is in line with these studies, but with the additional fundamental aim of performing a *fully integrated* sustainability assessment across social, economic and environmental impacts of policy driven land use change. A comprehensive study of end-users requirements and institutional settings preceded the design of the model-based SIAT (Thiel and Konig, 2008), which highlighted the need to produce a tool that is:

- Producing plausible results;
- User-friendly;
- Transparent in the way it is built (data used, scenarios produced, assumptions made and calculations performed); and
- Reliable (good track record in scientific and political assessments).

The planned SIA meta-modelling tool was designed to achieve multiple scenario simulations derived from a series of models (Fig. 6), where the results would create a solution space within which future policy option can be analysed (Sieber et al., 2008). The general method of designing scenarios can extend from purely probabilistic approaches, such as those employing stochastic simulations (Monte Carlo etc.) of parameter determinants (Samaniego and Bardossy, 2006), through to deterministic approaches, such as those dealing with economic and policy trends, where target oriented narratives are elaborated through the generation of logical parameter values for important driving forces (Rounsevell et al., 2006). This distinction is particularly relevant when issues of uncertainty and sensitivity of the outcomes are considered. In this context, the SIAT model was conceptualised and designed

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13 http://www.pik-potsdam.de/ateam/
14 http://www.eururalis.eu/
15 http://www.seamless-ip.org/
16 http://www.eea.europa.eu/multimedia/interactive/prelude-scenarios/prelude

more as a deterministic model capable of producing forecasting simulations in which future policy options could be compared.

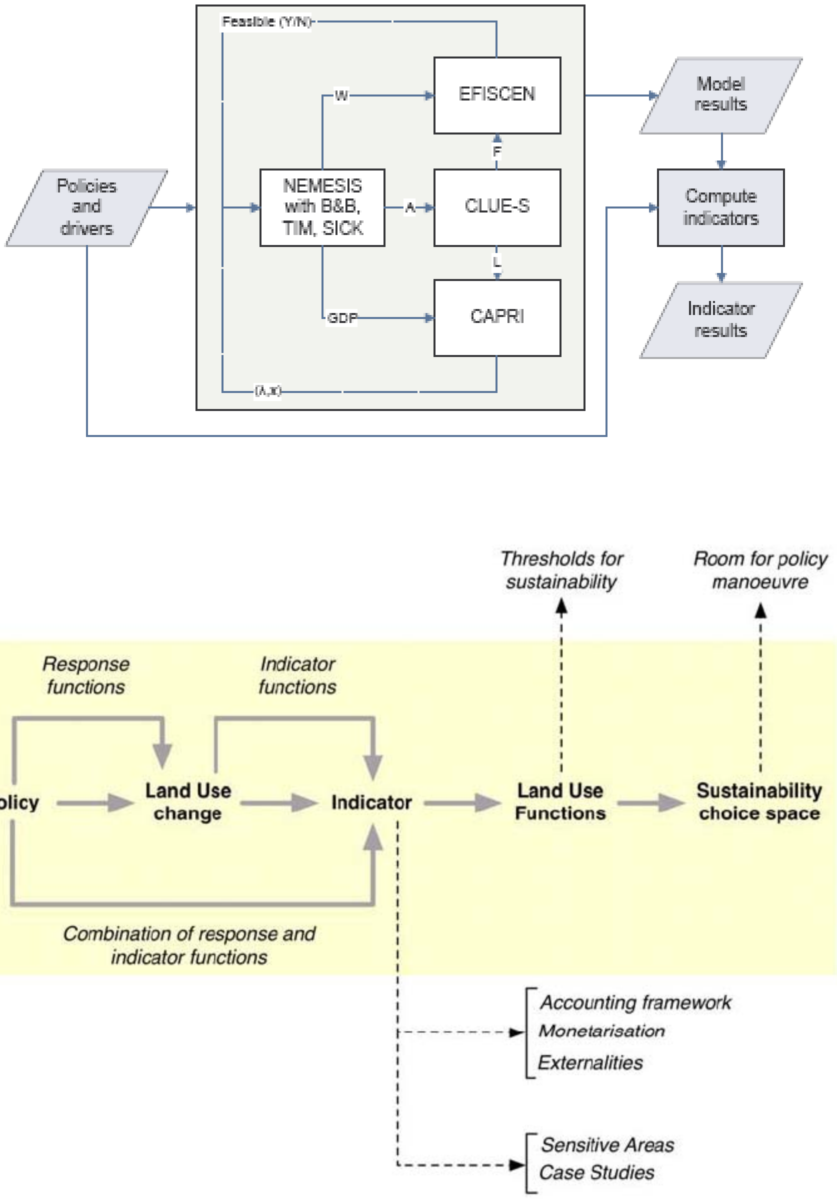


Figure 6. Information flow from policy to indicators within the modelling system (from Jansson, 2006, modified) and schematic layout of internal processes of SIAT, from policy to SCS (from Haraldsson et al., 2008, modified).

In SIAT scenario simulations are constructed using response functions derived by coupling a macroeconomic model called NEMESIS with sector models for agriculture and forestry, called respectively CAPRI and EFISCEN (tourism, urbanisation, transport and energy infrastructure land uses are already built in NEMESIS - see Fig. 6). Economic forecasts are then translated into land use simulations by linking sector models with the land use model CLUE-S.

Time and spatial dimensions and the extent of analysis are further characteristics of scenario design that SIAT had to deal with. The projection year of 2025 was selected to meet decision maker's requirements for medium perspectives (Helming et al., 2008). As already introduced in section 1.2., based on specific driving forces identified to affect the economic situations in Europe for this time scale, three scenario storylines were constructed: business as usual, high growth and low growth (Kuhlman, 2008), against which policy scenarios could be analysed. SIAT will therefore give access to real and modelled trajectories for a range of individual social, economic and environmental indicators at 'NUTS-X' level (Petit et al., 2008; Renetzeder et al., 2005). In addition to providing metadata for each indicator, the system will inform users about any limits that are associated with particular indicators, and thus begin to provide them with the types of information that can help them explore the implications of a particular policy case or option. To help performing an integrated assessment, individual indicators are aggregated into a set of nine broad '**land use functions**' (LUFs - see Perez-Soba et al., 2008). LUFs are built by weighting the different indicators that influence the specific functions and will allow the evaluation of the changes in individual indicators that might impact on the wider aspects of human well-being and the environment in a more integrated way. Limits were identified using expert-based knowledge both the individual indicators and the aggregated LUFs for a set of 30 'Cluster Regions' across Europe (Renetzeder et al., 2008; Renetzeder et al., 2005), and to construct profiles describing the sustainability issues that are important within each region.

This brief outline of the model-based SIAT in the above section points out that, in principle, users should have access to information when running simulations with the model. However, the way this information is reported, assembled and visualised is also, extremely important. For such a potentially large and diverse body of information to be useful in decision-support, tools to help users summarise the information are necessary. From the current prototypes available, it is felt that, however, despite the primary higher goal set for the tool, the model-based SIAT still needs some way to achieve a few of the requirements initially laid down. For example, in SIAT the alternative scenarios are outlined in a continuum of possible future situations in order to deal with uncertainty. The latter, however, is not dealt with in any other way and as we will see later in the discussion may represent one of the points to improve in future versions of the tool. Furthermore, a reference scenario is also necessary in order to present land use conditions that would be expected to develop in absence of any change in policy intervention. In fact, some of the initial efforts to present a conceptual framework for the SIAT model, included the possibility to access data from the present situation (Fig. 7), which would have been the first, valuable comparison that a user could have performed with the outcomes of a simulation to "get a better understanding of the impacts involved" (Haraldsson et al., 2005). However, despite the arguments to include the **present situation**, it was decided not to do this within SENSOR, and consider future '**business as usual**' as a reference scenario.

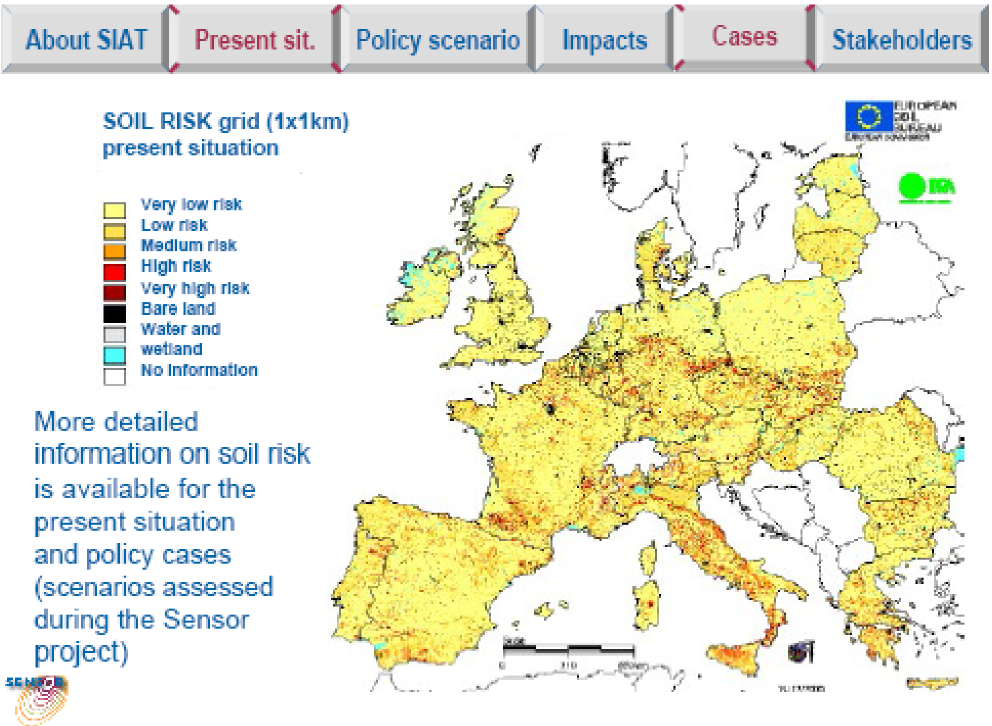


Figure 7. Earlier screenshot of a SIA model concept developed during the first phases of the SENSOR project. Note how the task bar on the top of the map included the possibility to open the analysis using stakeholder opinions and values (from Haraldsson et al., 2005, modified).

Much of the (initial) discussion and resources spent on the design of the model-based SIAT were focusing on aspects of information management, such as gathering, storage and organization of data, information and knowledge, as well as representation aids, such as maps, graphics, spreadsheets, etc., and less on the 'choice' and the 'outcome-based' models (i.e., where the SCS concepts fit) which should **analyse or help to narrow** the field of choice, using value and utility based approaches in a predictive way to describe impacts.

The ideas and concepts developed under the SCS framework have been constantly discussed with the SIAT development in mind and analytical strategies, designed to address some of the issues relating to the review of the outcomes and to provide users with a way of comparing results. These tools would enable the user to have a clearer understanding of the potential impacts of the different choices that might be made and this, ultimately, would be able to support and inform a decision. The tools will be discussed later in the report, but it is important to point out here that at the moment they represent the only framework developed and partially implemented to address issues of outcomes analysis and review. Without these functionalities the model-based SIAT would not use its potential in full.

3.2. The FoPIA framework and the bottom-up approach

As described earlier, where probabilistic and deterministic modelling frameworks to develop scenarios were outlined, a third framework to scenario development is possible and involves stakeholders' visions to design normative scenario narratives and are employed in cases where visionary projections and planning strategies are needed.

Following on the DPSIR (see section 1.2 of this report) scheme of the European Environment Agency, SENSOR aimed to expand the *Impact* component into several consecutive impact steps, seen as a bottom-up approach (Helming et al., 2008). These should include monetary and non-monetary valuation of indicator changes at regional and national scale, assessment of the changes in relation to regional and national standard and threshold values, and finally a multifunctionality approach with the SCS integrated assessment, which should be partly normative and partly participatory-based.

It was with this in mind, and recognising the inherent limitations of its central logic and modelling capacities when dealing with the complexity of the human ↔ nature system, that SENSOR made provision for participatory processes and stakeholder-inclusive research aimed at engaging critically with both the analytical scope and the outputs of the tools produced (Morris et al., 2008). This 'communicative-rational' approach was instead utilised to develop another of the SIA tools in SENSOR, the Framework for Participatory Impact Assessment – FoPIA - (Morris et al., 2009), which has the task to test the model-based SIAT, the model interface and the database development through processes of validation.

A stand-alone participation-based framework of sequenced methods for involving national, regional and local stakeholders in assessments of land use policy impacts, FoPIA is designed around the same logical framework that defines the design parameters of the model-based SIAT.

As already outlined in section 1.2, the FoPIA encompasses four analytical phases which are assembled to take into consideration what is sensitive to national and regional sustainability priorities. The whole logic flow is continuously informed by stakeholders and their knowledge of the local economic, social and environmental status. For this reason, analytical components such as those 'hard-wired' into the model-based SIAT (indicators, response functions and limits) are not predefined, but become the subject of discursive analysis during each phase of stakeholder engagement. The FoPIA framework recognises that the relationships between the elements of the analytical chain is conditioned by a number of socio-economic, environmental and cultural factors that are often specific to individual geographical contexts.

One of the main differences between the model-based SIAT and the FoPIA is the ability to analyse **sustainability criteria** (see phase 3 of the FoPIA analytical procedure), which stems from the need to explore the values and preferences at stake in defining the problems and supporting decisions. Different stakeholders draw different conclusions about what constitutes an appropriate course of action in the light of an impact assessment process. This aspect strongly resonated with many participants to the workshops organised by the FoPIA teams as part of the SIA, as a means of informing the perception and prioritisation of sustainability issues.

In this way, interdisciplinary, stakeholder-inclusive approaches can contribute to the analysis of policy impact highlighting the fact that the cause-effect relationship between changes in policy and the social, environmental and economic responses are not necessarily predictable in a simplistic way. Stakeholders' involvement can challenge the assumptions underlying the model-based predictions and introduce another dimension of complexity for more 'accurate' assessments of policy impacts, in order to better inform decisions on inevitable trade-offs, necessary compromises and possible win-win situations. In other words, it is necessary to include stakeholders into the picture so to bring the diversity of opinions relative to specific issues around policy-making and decision-support, but to highlight rather than solve. Furthermore, given that decisions will be made at EU level based on the forecasting of impacts in regions across Europe, there is also a strong ethical case for involving regional stakeholders in the assessment of criteria that can guide and inform difficult and delicate policy choices (see Morris et al., 2009, for more details).

Comparison and connections between model-based outputs and FoPIA results have not yet been performed, but preliminary evidence seems to suggest that the methodology may be useful in adding value to modelled SIAs. Eventually, the involvement of stakeholders and a bottom-up approach should have profound implications for the development of SIATs as it recognises that the bare results of SIA represented by changes in indicators or LUFs value need to be accompanied by some basis for interpreting and judging the relative importance of these impacts. Nevertheless, this amalgamation will add further layers to a system already characterised by an enormous complexity, enhancing the tension between understanding these complexities and the necessary simplifications that need to be introduced to facilitate the analysis.

Including stakeholder's opinions will necessarily add to the overall uncertainty, and might indeed increase 'decision uncertainty'. However, uncertainty is natural and for all important decisions this should be recognised as wholly acceptable, as understanding the sources and importance of uncertainty within the decisions we make is a key issue for making more informed choices.

Even though in SENSOR the link between model and stakeholders' views does not exist yet, the rich contextual knowledge characteristic of the various FoPIA workshops can be used to validate and complement the outcomes from the model-based SIAT. It has already been suggested that these two approaches should work synergistically (Tabbush et al., 2008). The SCS concepts, with the incorporation of the stakeholder's view and the uncertainty of the outcomes, can facilitate the amalgamation of these two methodologies, shaping the direction and the development of future models.

3.3. Connecting the SIA tool models with deliberative process

One of the 'integrations' that the SENSOR project aims to achieve in its analyses of SIA anticipates the amalgamation of methodological (top-down) and epistemological (bottom-up) procedures (Tabbush et al., 2008). As a result, the insights gained through the deliberative approach involving stakeholders can relate and feed into the insights gained through model-based analyses. It is recognised that this integration presents significant challenges, both from the conceptual and practical point of view. In addition, consideration should be given to issues of sensitivity analysis in order to acknowledge and deal with uncertainties.

Users will need to develop an understanding of the **sensitivity** of the outcomes to different input assumptions, and the key points where different policy options may deliver different results. Bertil (2006), for example, pointed out that new generations of decision support tools will have to elaborate all of the dimensions of uncertainty that are part of a problem, including conceptual uncertainty, which is at the root of so called "wicked problems" and conflicts related to "essentially contested concepts", e.g. the notion of "sustainability".

As already pointed out earlier in section 2.3, methodologies exist and are already applied for this purpose, such is the case of the **Multi-Criteria Decision Analysis** (or Aid – MCDA) frameworks which have already been used in planning and environmental decision making (Dodgson et al., 2001) and require the construction of a dialogue process among many stakeholders, individual and collective, formal and informal, local and not (Munda, 2004). These methods have also been combined with probabilistic models, such as the **Bayesian Belief Networks** (**BBN**), that proved to be very powerful for reasoning under uncertainty (Fenton and Neil, 2001). This 'integration' is advocated by many authors (e.g., Hisschemöller et al., 2001) and it is supported by the thesis that, whether modelling is necessary, it is also limited in its applications and may indeed benefit from an integration with participatory approaches. Modelling exercises are likely to yield their anticipated results that are probably more specific than those anticipated in participatory assessments, but the latter can add value to the SIAs and give more attention to the heterogeneity of views on a policy.

In the context of SENSOR, the current SIAT meta-model design allows the policy customer to gain insights into the potential impacts of particular policy options by working with individual and aggregated indicators (LUFs). As already stressed earlier, a more rounded sustainability impact assessment will require a systematic comparison between various policy scenarios with the inclusions of several levels of analysis. In order to ensure the greatest flexibility of the interface, it is envisaged that a range of information handling tools are provided where, ultimately, decisions about individual indicators (as well as the limits related to them) need to take account of all 'three pillars' and be grounded on an understanding of stakeholder values.

In fact, indicators and LUFs in SIAT are currently based solely on 'expert knowledge' but may well evolve in a compromise with stakeholder engagements in the future. SIAT users should in fact be able to review what might happen if particular limits vary by some margin or indeed more indicators were included into the making of the nine LUFs[17]. How would choices between policy options be affected? At the more sophisticated level, the policy customer would need to know how stakeholders might regard such indicators, their limits, and the LUFs themselves and how their values might change them or affect the weighting between the different dimensions of well-being and environment captured by the LUFs. One of the primary goals is therefore to enable users to review the possible consequences of different policy assumptions and to understand how sensitive the outcomes are on the basis of current knowledge. This issue is particularly acute in terms of the ways that ideas about economic, social and environmental limits are implemented and used within SIAT, which brings us back once again to the question of how 'stakeholder knowledge' might be handled

[17] The number of indicators deemed 'fit' to compile the LUFs was still under discussion at the moment of the writing of this deliverable, and it was limited by the lack of clear rules and/or lack of data of the source indicators. Work is being done to clarify these points and to increase the number of indicators to be included within the LUFs methodology (see Paracchini et al., 2009), which is now believed to include 24 indicators.

in SENSOR. This is clearly a major task, and it is recognised that this would be difficult to accomplish at European scales, where an incremental approach may be necessary.

Nevertheless, we envisage the emergence of models and frameworks that support and perhaps improve on reasoning by dealing with uncertainty. It is argued that this could be achieved by both the implementation of the **SCS** concept and potentially the employment of more probabilistic approaches amongst the set of SIA tools.

The following chapter intends to tackle this challenge, with the application of a probabilistic modelling framework to one of the tools developed by SENSOR, allowing the exploration of the SCS concepts and its practical applications.

Box 3.1: Key messages from section 3

- The modelling framework used in SENSOR aims to cover as many factors and aspect of the SIA dynamics as possible.
- However, the framework is weak in dealing with aspects of uncertainty and outcomes sensitivity.
- The SIAT model is more focusing on delivering results through a robust chain of assumptions (meta-model) but is not necessarily allowing users to explore the nature and significance of the outcomes.
- Even though using the same logic, the model and the participatory approach (FoPIA) are different in their way to handle indicators and limits, they develop two distinct focuses.
- The chain of events in the FoPIA method allows for an inclusive and adaptable deliberative process, where variability of opinions is taken into account.
- SCS advocates the amalgamation of modelling and participatory approaches, to enhance the validity of the SIA and to better inform decision for policy-making.

4. Why including stakeholder's views is necessary?

As discussed in the last section, the inclusion of the stakeholders view into the modelling chain is thought to be extremely important to give a more rounded connotation to the modelled SIA outcomes. In particular, the SCS advocates the amalgamation of modelling and participatory approaches, to enhance the validity of the SIA and to better inform decision for policy-making. In the following sections a pilot scheme will be explored to begin this process of incorporation, focussing on the use of probabilistic models on the existing SIAT-FoPIA frameworks.

4.1. A BBN's aided participatory impact assessment model

The work carried out in the SENSOR project over the analysis of stakeholder views and values (Morris et al., 2008; Morris et al., 2009) can potentially give us insights about how, in particular geographical or problem contexts, people view the limits that 'experts' have suggested as being significant for individual indicators or the aggregated land use functions. Engagement with stakeholders can be used to help us understand how limiting values might need to be modified, and how trade-offs between the thematic areas covering the nine land-use functions might be judged in different places. Engagement with stakeholders will also help us understand how different groups in society may vary in their responses. The 'contested' nature of economic, social and environmental limits needs to be conveyed in the design of SIAT. While the primary goal of SIAT is to give an assessment of policies at pan-European scales, the availability of a rich body of information derived from stakeholders for particular areas and issues will allow the policy customer to explore how judgements may need to be modified where this richer body of information is available. The information gained from stakeholders through SENSOR for particular areas certainly cannot be extrapolated to other regions. However, the availability of such data can be used as part of the 'learning cycle' that both researchers and policy customers need to go through to move SIAT into the 'real world' where the 'democratisation of knowledge' is a pre-requisite.

By designing the SIAT in such as way that assumptions about limits can be examined, and values changed on the basis of expert and stakeholder views, a much richer and more flexible decision support environment can be created. If we can show how 'stakeholder views count' in particular places and for particular issues, future work may be initiated to extend the availability of this type of information to other geographical areas as part of a wider programme of stakeholder engagement. At the moment, the model-based SIAT is not designed to take into account the deliberative-participatory approach, but the FoPIA tool can inform this aspect of the assessment. We therefore suggest that at this stage an external tool could be used to facilitate the process of stakeholder's engagement as well as the interpretation of data from existing and future FoPIA exercises.

As a result of several meetings and a final expert workshop with colleagues of modules 3 and 7, **Bayesian Belief Networks** (**BBN**) were identified as possible means to deal with this problem. BBN models have already been used in a number of fields, including as decision support tools (see Annex I for a brief introduction to the BBNs). The rationale for the use of

BBNs to represent FoPIA follows the idea that, even though there is an overall equivalence of methodologies between SIAT and FoPIA, these are developed as parallel tools. The development of a FoPIA BBN tool, instead, could allow meeting a number of objectives, including:

- amalgamate case studies in a single tool/database to relate to specific areas more easily;
- facilitate the stakeholder engagement through an interactive analysis of the preferences;
- enhance SCS concepts common to the SIAT model for the trade-offs analysis;
- open to elements of valuation to be included in the Participatory Impact Assessment (PIA);
- take into account uncertainty of the data/opinions, and
- consider the variability of the input data in a more systematic way.

In this sense, the development of a FoPIA-BBN tool would support and expand the participatory side of the impact assessment (in SENSOR but also outside SENSOR) as well as advocating a more combined 'model ↔ participatory' assessment, where the two approaches could feed one another in a more holistic manner.

4.2.1. Bayesian Belief Networks as decision support systems

BBNs have gained a reputation of being powerful techniques for modelling complex problems involving uncertain knowledge and impacts of causes and are increasingly used as **decision support systems**. BBNs are especially helpful when there is a scarcity and uncertainty in the data used in making the decision and the factors are interlinked, all of which makes the problem highly complex. BBN are increasingly used as **adaptive management tools** with the involvement of stakeholders in participatory integrated assessments. In resource management, for example, BBNs have been used in a broader decision-support framework, as conceptual or computer based tools that collectively facilitate the decision-making process (Cain, 2001). Cain et al. (1999) emphasised the utility of BBNs to facilitate stakeholder participation in resources management planning and decision processes.

As Ellison (1996) has pointed out, most decision-makers, public interest groups and legal professionals are not trained as scientists or modellers and are unlikely to understand technical jargon or tests of null hypotheses. Thus, a modelling approach that provides a readily understandable representation of complex systems and human influences, without sacrificing desired levels of accuracy and validity, can be of vast help in communicating with non-specialists (McCann et al., 2006). To this end, it has been found that BBNs facilitate communication through their interactive nature and ability to demonstrate graphically how assumptions affect the probability of outcomes (Cain et al., 2003; Kuikka et al., 1999; Varis and Kuikka, 1999).

In fact, various authors found that the part of the network defined by variables and links can be easily communicated to stakeholders (Bromley, 2005; Henriksen et al., 2007; Henriksen et al., 2004). However the part of the network that involves the quantitative component, with the numbers, the rules and the probabilities – here organized in what are called **conditional probability tables** (**CPTs** – see appendix I for more details) - is the step where negotiation between parties involved will emerge and become more difficult, but it is where the real participation occurs. Encoding and populating BBNs with numbers and CPTs are the most critical part of the construction process but at the same time the most important and powerful feature of BBNs, compared to more soft tools for participatory integrated assessment e.g. 'brainstorming', 'multi-criteria techniques', 'consensus conferences' etc. (Hisschemöller et al., 2001). The validity of BBNs can be improved when stakeholder groups are engaged in the construction process (Henriksen and Barlebo, 2008). As suggested by Nyberg (2006), the decision-making process can be supported by using **Bayesian Decision Networks** (BDNs) which are BBNs that incorporate nodes to represent potential management decisions and, optionally, utilities of outcomes.

Figure 8 shows how this *modus operandi* can be adapted to the FoPIA framework and how a Decision Network can be built on the basis of a deliberative/adaptive progression. The diagram was developed from the works of Henriksen and Barlebo (2008) who illustrate how BBNs can be used as an adaptive management tool, with full stakeholder's involvement, and includes all the steps described in the FoPIA methodology (Morris et al., 2009). The sequence of the steps begin from the definition of the context and the policy under assessment and follows the general cycle of events that are described elsewhere in the literature (e.g., the Problem-Options-Strategies-Results described in Hisschemöller et al., 2001). Obviously, as real situations may present different problematic, it is worth to stress that the progression of events in the chain is not prescriptive, is open to review at any stage of the cycle and can loop if necessary.

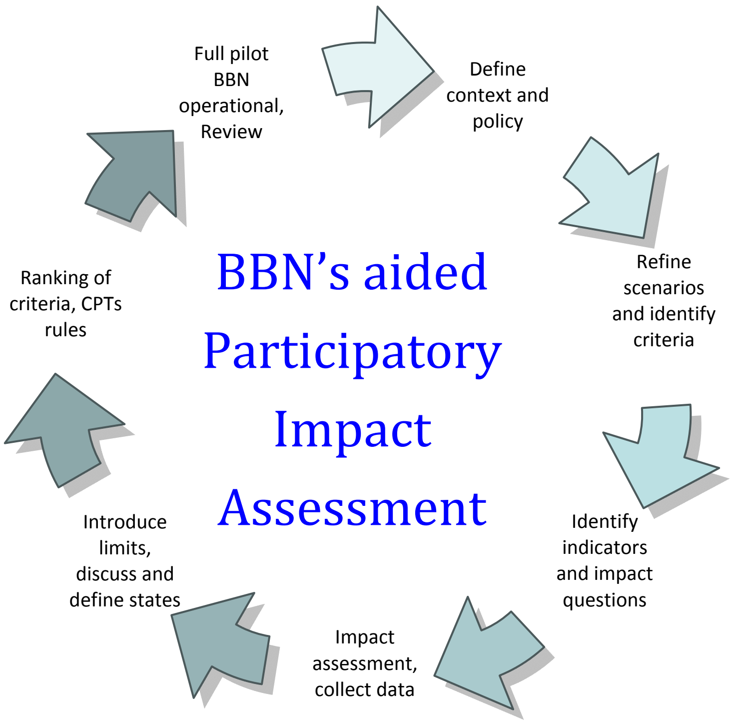


Figure 8. Steps for the construction of Bayesian Belief Networks with full stakeholder engagement (from Henriksen and Barlebo, 2008, and Morris et al., 2009, modified).

As a consequence of this procedure, a BBN can be generated and used to aid and further develop, if possible, the FoPIA process. Fig. 9 shows an example of such BBN, where all the SENSOR elements that are characteristic of the FoPIA framework have been included in a complementary way. The data used to generate the network have been derived from the work undertaken in Module 7, with stakeholders in Malta, who were asked to consider three alternative policy scenarios for biodiversity. The policy case selected for Malta was the Biodiversity, where key sustainability issues for the Maltese Islands were linked to important EU policy areas. These issues were also discussed preliminary with biodiversity experts from the Malta Environment and Planning authority (MEPA) and selected key stakeholders from the Ministry of Rural affairs and Environment (MRAE). The scenarios were then drafted in a first workshop (see Morris et al., 2009, p 34) and are touching areas of i) management objectives, ii) areas under agri-environmental schemes, iii) areas designated as 'non-development' and iv) plans for adaptation to climate change. In scenario 1 the objectives are not met, areas under various schemes decrease and there are no plans for adaptation to climate change, whereas in scenario 2 and 3 the objectives are increasingly met, areas under protection or scheme remain stable or increase, respectively, and adaptation plans are partially or fully integrated.

Within the FoPIA approach, after the identification of the policy to be scrutinised with its likely impacts (the first step in Fig. 8), the process starts with the definition of **regionally relevant scenarios** (**A**) that are a product of a discussion around the likely national (or regional) divergence from the implementation of European policy. The analysis includes sustainability issues, policy instruments likely to be adopted and their likely land-use change impacts. In the FoPIA framework, these scenarios are usually decided with national and regional-level policy-makers and experts and are therefore not necessarily coinciding with those set by the model-based SIAT. They constitute the first point of debate in the subsequent phases of stakeholders' engagement, encapsulated in the network in rows from **B** to **G**, and may be further refined in accordance to local knowledge.

The first row of nodes (**B**) of Fig. 9 represents the criteria defined through the discussion with stakeholders and broadly corresponds to the LUFs as defined in SENSOR. Following the FoPIA sequence, the relative importance of these key land use related sustainability criteria is initially discussed with the stakeholders as to what best represents the land use functions that are of priority in the specific geographical region or social context and in relation to the policy under scrutiny. Collectively, the Land Use Functions Criteria (LUFC) are an essential dimension of the analysis because they facilitate an exploration of the values inherent in each of the LUFs (Morris et al., 2008). Using these criteria, stakeholders are asked to score the likely impacts of each scenario across the nine functions using a scale ranging from -3 to +3 (that is from a strong decrease in the acceptability of the condition implied by the criteria through to a to strong improvement).

The particular contribution that representation of these criteria in terms of a BBN brings is that the *statistical distribution* of impacts predicted by stakeholders can be represented graphically, so that the degree of divergence in their beliefs about the future can be identified. Thus in terms of Fig. 9, we can see that when all scenarios are taken together, stakeholders believe that, for example, the impacts on employment are likely to be more positive than those on cultural and natural heritage (since the impact score are distributed more towards the positive end of the assessment scale). Similarly, the general outcomes for water are considered more neutral in their impacts than those for biodiversity.

The values included in the boxes of each node of row **B** of Fig. 9 represent the results of the initial impact assessment scoring exercise. The distribution of the scores is visible through the bar graphs depicting the different levels of belief on the right-hand-side of the node, and is thus a first indication of the perception of the impact of the policy on the various indicators and criteria. As the nodes are continuous or have state values defined, then their mean value (i.e., expected value) are also shown in the separate area below the belief-bars. The mean value is followed by a ± symbol and its standard deviation.

In Fig. 9 the BBN has been set up so that all the scenario outcomes are considered equally likely. The consequences of selecting any one of them is shown in Fig. 10, where we can see that stakeholders believe that the impacts of the different policy scenarios on agricultural production, for example, are progressively more positive as we move from scenario 1, through scenario 2 to 3. This Figure illustrates one of the major strengths of the BBN representation of the FoPIA data, namely that it can be used to easily and rapidly communicate the consequences of stakeholder views or changes in assumptions.

Using the BBN approach, the nodes shown in rows **C** and **D** of Fig. 9 represent the next phase of FoPIA, where the participatory process focuses on the acceptability of the impacts of each of the policy scenarios. At this stage, sustainability 'limits' are defined through a process of individual scoring, followed by a group discussion (Morris et al., 2008). These limits are to be considered in terms of minimum standards required for the sustained functioning of the relevant LUF. The scoring system for thresholds or limits also uses a scale from -3 to + 3, where a negative value signifies that a loss is acceptable (or desirable), whereas positive scores represent the need for that particular indicator to gain in functionality to be acceptable. These limits are represented by the nodes in row **D** and feed into the nodes of row **C** of Fig. 9, where the belief-bars represent the probability of the indicator to be above or below the defined limit and can change according to the scenario.

Once again the *distribution* of beliefs about the different sustainability limits for each criteria are known from the group of stakeholders, and this can be used within the BBN context to predict the *probability* or likelihood of a given criteria being above or below one of these limits. In order to simplify the graphical representation shown in Fig. 9, the distributions of beliefs about limits have not been shown – for convenience they are merely represented by labelled boxes (e.g. SOC1 defined limit). Nevertheless the merits of the BBN approach are clear, in that it can be used to represent the range of opinion or level of agreement between stakeholders, and thus some of the uncertainties that may exist about the likelihood of future outcomes.

The next phase of the deliberative-participatory approach begins to final assessment process. It involves revisiting the criteria initially set (LUFC), this time the score to assign to each of them according to their importance. The criteria are scored on a scale from 1 to 9 (in increasing order of importance), and in the FoPIA process are grouped, averaged, discussed and adjusted through the deliberative process. Using the BBN formalism, this stage of the process is represented by the nodes in row **F** of Fig. 9, where the belief-bars show the *distribution* of the importance scores as set by the stakeholders.

Figure 9. Example of Bayesian Belief Network constructed following the SENSOR-FoPIA framework. The values assigned in the network have been taken from the Malta case study (see Morris et al, 2009).

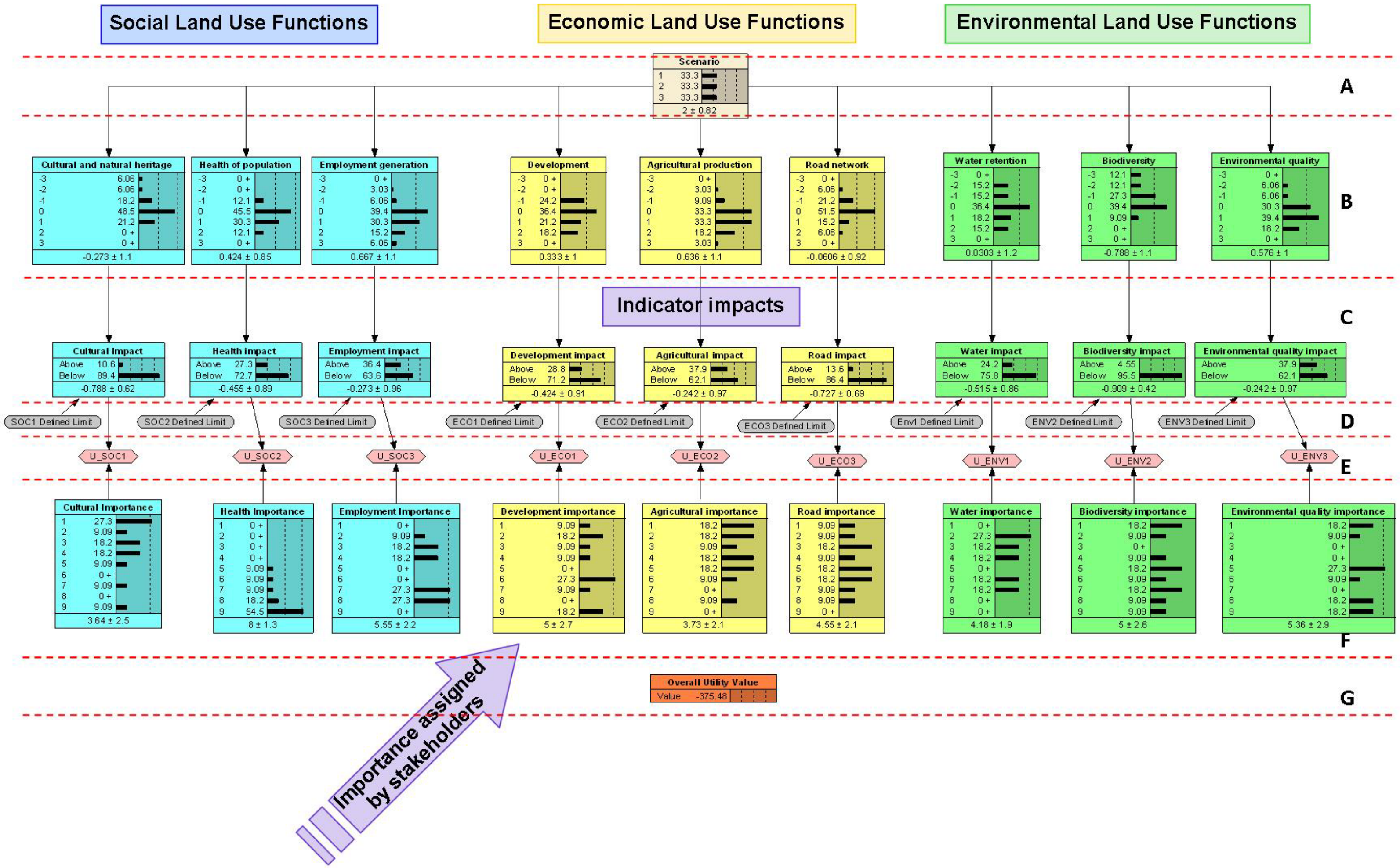
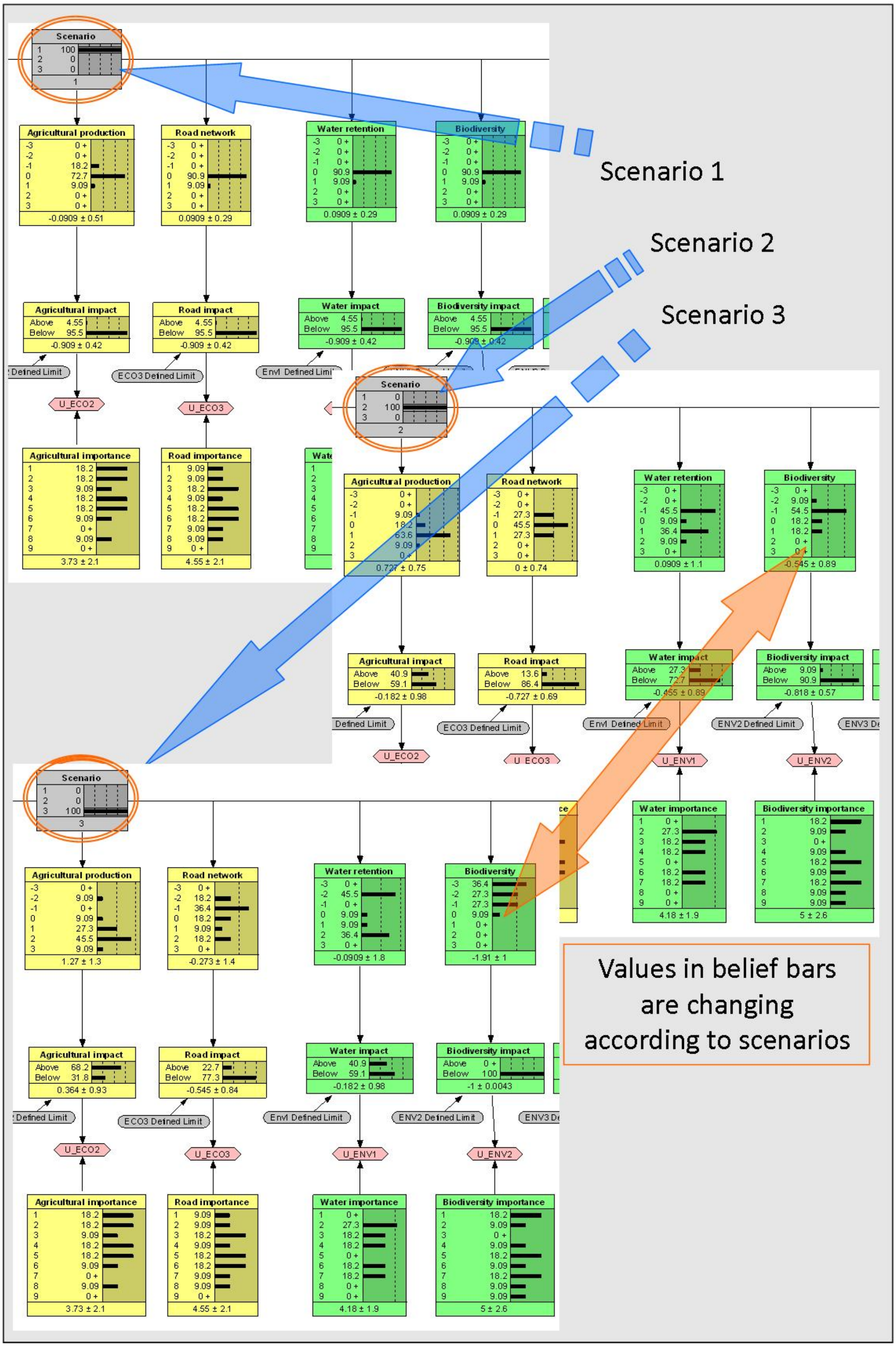


Figure 10. Close up of some of the nodes of the FoPIA-BBN presented in figure 9, with varying belief-bars values according to the three scenarios imposed. The values of the network have been taken from the Malta case study (see Morris et al., 2009).



As Fig. 9 shows, there is considerable difference in importance scores assigned by the stakeholder group in Malta. Not only do they clearly regard some criteria as more important than others (for example, scores for Health appear to be uniformly higher than those for Cultural and Natural Heritage) but also stakeholders are more divergent in their views about the importance of some criteria than others (stakeholders are in greater agreement about the importance of health than they are about, say road improvement).

The importance scores can be used to help stakeholders visualise the consequences of the different scenarios given their beliefs and values. Using the BBN approach, the nodes in row **E** and **G** of Fig. 9 have been used to construct a set of **Utility Values**, which can be expressed in monetary or non-monetary terms. The issue of the monetisation of impacts will be discussed in the next section. At present, in Fig. 9, the overall utility score for the impacts is the sum of the utilities for the nine assessment criteria, which themselves have been scored according to their importance and how far above or below a sustainability limit they are. A simple linear scale has been used; thus, for example, the utility score for ECO1 is the product of the average importance score assigned by stakeholders to this criteria and the probability that it is either above or below the sustainability limit that they have set (Fig. 11).

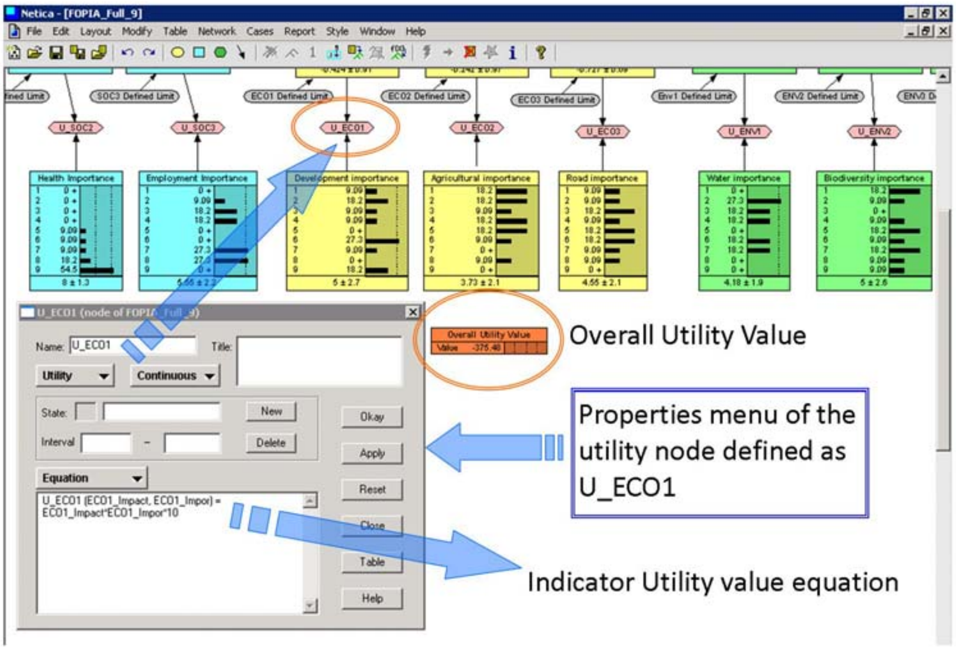


Figure 11. Close up of some of the utility nodes of the FoPIA-BBN presented in figure 9; the property menu refers to the node defined as U_ECO1 circled in red, and shows the equation for the calculation of the Indicator Utility Value. All the Utility Values are added up and are shown in the node called Overall Utility Value. The values assigned to the Indicator Utility nodes are here only illustrative.

Clearly the calculation of the utility values can be the subject of debate; however, the BBN approach presented here does illustrate that by using the methodology, the marginal effects of scenarios on outcomes can be explored and evaluated in a way that would have not be possible otherwise. It also permits stakeholders to revise their assumptions and value estimations and these changes to be tracked and their consequences displayed quickly. For example, the importance assignments used in Fig. 9 were the initial ones set by stakeholders. During the participatory process, stakeholders had the opportunity of revising them once they had seen some of the outcomes of the analysis. The changes in the distribution of importance's can be seen by simply reading a different set of stakeholder data into the BBN and reactivating the network. It is important to note that using the BBN approach all the belief-nodes are fully interactive and can be set in a way that a) all the states are equally likely or reflecting some known or assumed data distribution; or b) one of the states listed on the left-hand-side of the node is forced or preferred over the others. This is, for example, straightforward in the node related to the scenarios, where, in order to show the recorded effects linked to each scenario, one can select scenario 1, 2 or 3 and the values in the rest of the network's node will vary accordingly (Fig. 10). In the same way, it is possible to vary the importance of the LUFC or the LUFCI limits values and immediately see how the system-network responds and what the probabilities are to exceed the limits or to face different trade-offs.

Using the BBN formalism to represent the FoPIA results users can rapidly explore the consequences of the different policy choices given the values and assumptions they hold, and therefore explore the 'solution' or 'sustainability choice space' that apparently confronts them. By employing this approach the results of different stakeholder groups can easily be compared or combined, and the different kinds of response identified in relation to different types of policy question explored. The BBN approach can therefore potentially be used to capture and replay a growing body of stakeholder information to decision makers.

4.3. Adding monetary (or non-monetary) valuation into the picture

Following on from the description of the pilot BBN built around the SENSOR-FoPIA frameworks, it became apparent following discussions with members of Module 3 and Module 7, that the formalism could be used to explore the problem of monetary valuation and to bring in such value estimates to these kinds of analysis. As anticipated in the previous section, it is possible to use a specific node, represented in row **G** of Fig 9, to capture the **Total (or Overall) Utility Value** (**TUV**) calculated from various scores or values assigned to the LUFCs and LUFCIs by the stakeholders or the public, which are instead represented by the utility nodes of row **E** in the BBN of Fig. 9.

Thus stakeholders would either assign a direct monetary value or a score, and a deliberative process could also be introduced in much the same way as the FoPIA framework already carried out in order to enhance the adaptive nature of the process. Fig. 11 showed how values can be calculated according to importance and deviation from some sustainability limit. A monetary valuation can be included by adding a term to reflect this additional scaling criteria:

$$U = \sum \left(L_{LUFCI} \times I_{LUFC} \times V_{LUFCI} \right) \quad (1)$$

where

U = Utility value

L = Indicator limit

I = Importance

V = Monetary (or non monetary) value

It must be stressed that equation (1) is one of the many possible algorithms that may be used for the purpose of calculating the Utility Value. As Romano et al. (2008) pointed out, if at least one indicator is expressed in monetary terms, it is possible to calculate the monetary equivalents of all the other qualitative and quantitative impacts with the SWING method (see Annex 3 of Romano et al., 2008) for a detailed description of the method), and then a simple aggregation additive model, such as that of equation (1), can be used to calculate the utility value.

The discussion of monetary valuation of the environment, often referred to as **shadow pricing** or **non-market valuation**, has already spread from the project level and a concern for site specific recreational benefits to policy appraisal and international environmental problems (e.g. ecosystem management, biodiversity loss, global climate change) and therefore deserves an appropriate space for the evaluation of the various possible approaches (see Romano et al., 2008), for a comprehensive account of the subject). This group consists of tools that are not sustainability assessment techniques themselves, but rather an important set of tools that can be used to assist other tools when monetary values are needed for goods and services not found in the marketplace (Ness et al., 2007). Monetary values can therefore be estimated either by existing data and/or elicited with participatory techniques (e.g., group valuation, internet surveys, etc.). These can then be fed into the Bayesian Belief Network presented above, so to reflect another dimension of the SIA.

Table 1 shows values for the LUFCs established through the Malta case study (see Morris et al., 2009) derived from existing data published by Eurostat and OECD (Soma, 2009). The values have been calculated independently for Malta and the EU and expressed on a per km^2 basis. These values were entered into the pilot BBN and the resulting Overall Utility Value calculated according to equation (1). It should be emphasised that same statistics and indicators are not always available at both European and regional scale, and do not always coincide with the specific indicators identified by stakeholders; thus some interpretation and assumptions have been necessary. Nevetheless, the Table illustrates the kind of approach that can be attempted. The resulting 'Total Utility Values' calculated with the BBN for the three FoPIA scenarios and different sets of values are shown in Table 1.

These data suggest that whether the Malta specific or EU wide values are applied, Scenario 3 is considered more beneficial than the other options. By contrast, the consequences of Scenario 1 are considered far more unacceptable in terms of the Malta-specific values compared to the outcome if EU values had been applied. As the data in the main body of Table 1 suggests, the values assigned to issues linked to employment and housing are significantly higher in Malta than elsewhere. Clearly if a decision maker at the EU scale were interested in the outcomes of particular policy options for the Sensitive Areas, say, then such a representation would be of value in better understanding the geographical implications of different policy choices.

Table 1. Estimated values (in Euros) for a number of indicators corresponding to the Land Use Functions Criteria (LUFCs) as deliberated for the Malta case study (Soma, 2009); see also Morris et al., 2009, for the Malta case study. The table shows the TUV calculated in the BBN using equation 1.

LUFCs	Indicators*	Estimated economic values €/ km^2	Estimated economic values € / km^2
		Malta	**EU**
Employment generation	*Compensation of employees*	2,255,108	300,384
Physical and mental well-being	*Tourist nights spent in 2006*	939,975	21,417
Cultural heritage and national identity value	*Cultural employment*	125,876	35,930
Housing and workplace provision	*Total employment in densely populated areas*	14,007,983	1,598,967
Competitiveness and productivity	*Gross value added of the agricultural industry - basic and producer prices*	161,707	39,262
Infrastructure and mobility	*Energy consumption of transport*	-251,840	-23,222
Water status	*Freshwater status*	237,944	983,154
Biodiversity	*EU expenditure Natura 2000*	17,449	10,754
Environmental quality	*Emissions of particulate matter*	-13,723	-1,191
		Malta	**EU**
Total Utility Value	*Scenario 1*	**-546,793,645**	**-112,645,868**
	Scenario 2	**164,814,397**	**18,690,419**
	Scenario3	**554,816,309**	**106,388,221**

***Source: Eurostat and OECD web pages.**

In the analysis presented here the values were extrapolated from existing data (i.e., Eurostat and OECD, and considering total population and surface areas of EU and Malta - Soma, 2008), but, as mentioned above, values can also be elicited with a deliberative process (e.g., Group Valuation, see also Romano et al., 2008), with 'remote' stakeholder participation (Internet Survey) but also with other methodologies, including economic valuation approaches such as, for example, Contingent Valuation (CV), the Hedonic Pricing, the Multi-attribute valuation, etc. (see Romano et al., 2008). Group Valuation and Internet Surveys have been tested with SENSOR and their utilisation in a BBN-participatory impact assessment would be extremely valuable.

The flexibility of the BBN-system allows for rapid iterations of different scenarios and assumptions to be explored with stakeholders, and is useful in showing how the importance given by the stakeholders to the various criteria and indicators and the added monetary values are interlinked. Furthermore, the introduction of the Willingness-To-Pay or valuation could create further ground to substantiate and weigh up the choices available to both stakeholders and policy-makers. In the context of stakeholders' engagement and participation, introducing monetary valuation assumes a strategic significance, in that the economic dimension is explored and directly linked with aspects of social and environmental relevance.

To this end it may be interesting to point out to a small but growing literature concerns combining environmental valuation with various forms of deliberative process, introducing what has been defined **deliberative monetary valuation** (DMV)[18]. The idea is that deliberative-participatory approaches may, depending upon their institutional form and context, be more amenable to recognising policy formation as an ongoing process. Deliberation is then regarded as useful in providing insight into the processes by which respondents produce their willingness to pay or accept. This may be extended to allowing a deliberative process to determine the options or institutional context to be valued in the survey. Part of that process concerns how the public is allowed to have a say in policy and this can be expected to affect policy outcomes, which must be considered in a dynamic socio-economic context.

Bayesian Belief Networks proved to be able to provide the kinds of tools that enable this approach and could be the answer for the development of a participatory impact assessment which, based on the FoPIA process and steps, could allow for preference and valuation to be at the centre of the appraisal. This, in turn, is at the core of the SCS framework, underlining once more how the concepts framed by the choice space could enhance SIAs to more integrated processes.

4.4. Recommendations and future steps for the FoPIA-BBN development

In summary, the development of a FoPIA-BBN tool could allow to reach a number of goals, including:

1. the construction a single database of FoPIA case studies;
2. the ability to update the database with further case studies;
3. the interpretation of data in terms of beliefs;
4. the inclusion of uncertainty and disagreement;
5. the interactive analysis of (change of) preferences with stakeholders and experts alike;
6. the introduction of elements of valuation, via elicitation of estimation, in monetary or non-monetary terms;
7. the performance of back-casting for trade-offs analysis; and

[18] See http://www.clivespash.org/2001acp.pdf for a comprehensive introduction to the subject.

8. the production of a stand-alone, downloadable tool, but with potential combination with SIAT in future.

We recommend that a down-loadable FoPIA-BBN tool therefore be developed in any future iteration of the SIAT platform, and that a facility for storing and replaying the outcomes of participatory exercises is provided so that the experience and insights gained through such exercises can be shared more widely.

The presence of all the results in one single database and the possibility to add further case studies, would enrich the body of data and enhance the ability of data interpretation and representation. This would adapt and update automatically, continuing to take into account scientific uncertainty or disagreement as well as variability of the data, as this is an intrinsic characteristic of the BBN tools.

The FoPIA-BBN tool would facilitate a full stakeholder engagement through an interactive analysis of the preferences, but introducing also elements of valuation that can add further dimensions to the PIA. Furthermore, the ability to perform back-casting from specific desired goals to the inputs required for their realisation, would represent an added value of the system. At this stage, the FoPIA-BBN tool presented here could already be used as 'stand-alone', device, but future developments do not preclude the inclusion of such tools in the web-based SIAT, in a modular system. While it is generally accepted that participatory processes can never form the whole assessment, the presence of such module in a SIAT could allow the user to interrogate a different level of knowledge, to explore the dimension of the local conditions, which would add value to the impact assessment. This, as it will also be discussed later, could assist the identification of the conflicts between the 'sustainability ranges' existing at various scales and, in turn, inform the definition of sustainability choice space(s) by determining the linkages and the dynamics among indicators and LUFs at different levels. By better articulating the consequences of different policy choices, the FoPIA-BBN approach also operationalises a number of the ideas that are embedded in the SCS concept and particularly helps illustrate the nature of many of the uncertainties that exist in making sustainability impact assessments at local scales.

Box 4.1: Key messages from section 4

- The SCS framework recognizes the importance to include stakeholders' views into the process of SIA, but also to use an approach that allows taking uncertainty into consideration.
- The FoPIA methodology presents a very useful progression of steps, which are analogous to the ones used for the mode-based SIAT.
- Bayesian Belief Networks (BBNs) are recommended as one way to represent the FoPIA progression and capture the SIAT logic; they have already been used as decision support systems.
- BBNs can handle uncertainty and group all the existing FoPIA case studies (SACS regions) in a single database.
- The methodology was further developed, by adding stakeholders' valuation into the chain; a Total Utility Value was built in the network to assess the outcome of the 'participatory-simulation'.
- The BBN-FoPIA tool can be used as a stand-alone downloadable tool, and future development could see it as one of or part of the SIATs.
- The BBN-FoPIA tool encapsulates the main ideas expressed in the SCS framework representing, in essence, the first operationalization of the scheme.

5. SCS design and recommendations for the model SIAT

After considering the general issues surrounding the concepts of the SCS and its implementation as part of the participatory tool, this section turns to the specific problems associated with implementing the SCS as part of SENSOR's sustainability impact assessment toolkit. As described earlier, the SCS was thought to be integral part of the model-based SIAT tool to enhance the outcomes analysis and allow the comparison of the various options and choices available for the policy-maker. The following sections describe the main functionalities and milestones achieved, and include recommendations for future SIAT prototypes.

5.1. SCS tools and functionalities within the current SIAT framework

The ideas and concepts linked to the SCS have been discussed with the meta-model developers during the course of the SENSOR project, and at the time of the writing of this deliverable some functionalities have been already implemented, others are under construction, others form part of our recommendations for future development.

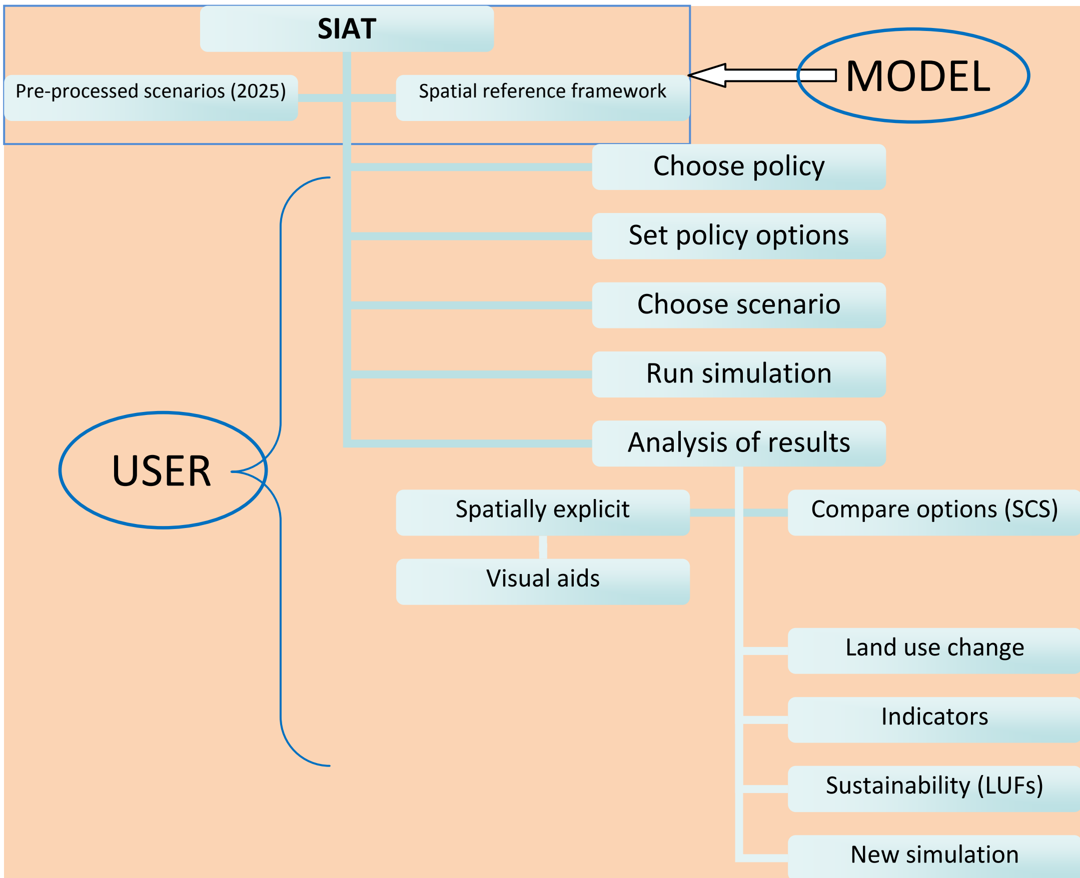


Figure 12. General flow diagram of SIAT simulation runs with Sustainability Choice Space tool.

With the current prototype (SIAT prototype III), simulations and analyses can be performed as for the flow-diagram described in Fig. 12. The diagram shows how you can select the policy, the policy settings, then run a simulation (or several of them) and then begin to explore the outcomes. SCS is at the core of the analytical end of SIAT, and it should allow performing a number of operations, via a set of tools and functionalities, that let users start to understand the choices arising from the performance of simulations for a given policy.

From the analytical point of view, the implementations of the SCS within the current model-based SIAT would require some specific design features. First of all, it is vital that **SIAT is capable to STORE and RETRIEVE both simulations and the information related to them**. In this way users will interrogate different simulations based on different sets of policy settings, e.g. for the CAP reform this would include simulations set at various percentages of direct support, with or without market support, and whether money is reinvested into Research and Development initiatives.

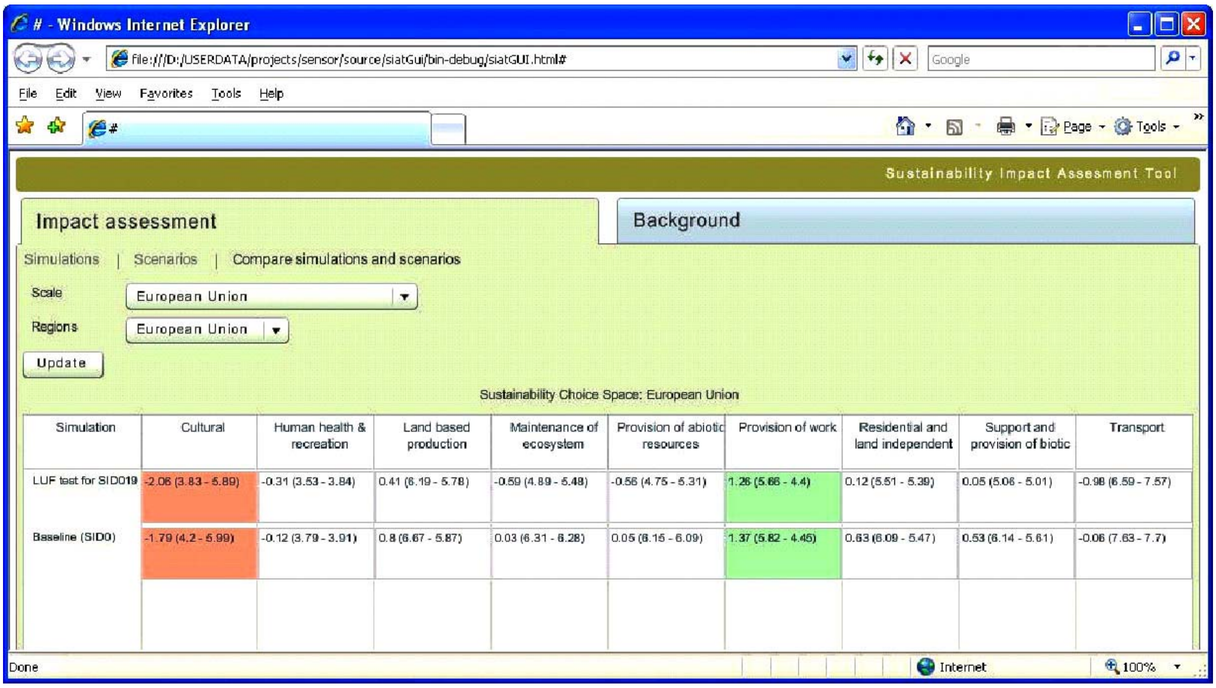


Figure 13. Example of League Table showing two dummy simulations. The menus allow for the specification of the spatial reference, the colours of the cells correspond to the likelihood of sustainability, the figures in the cells reflects the difference between the impact scores and the limits (Verveij, 2009).

Crucially, **SIAT will need to be equipped with tools to allow for comparison of the different simulations.** All the different simulations set as described above, should be allowed to be summarised in such a way to let the user having a first impression of the differences between the various simulations. We suggest that this can be done using a **SCS League Table** (see Fig. 13) where users can list the simulations previously set. The table can be organised in various ways, depending on the level and the type of analysis that the user intends to perform. Therefore, a first glance should allow the user to visualize the simulations in a very simple way. Subsequently, tools should be available to select, sort and drill down from the 'surface' to the 'root' of the matter. This League Table should encompass a number of features, including:

- ***Visualization of sustainability of the outcomes.*** By using shades of green and red the table will be able to show the departure from the limit (i.e. difference between LUF score and limit) around a region of no significant departure from the limit (coloured in yellow or grey). This function is still under construction, but at the moment the current design contemplates three grades (or shades) of green and red, with a legend to allow users to 'read' the results (see legend on Fig. 14). Intervals will either have the same 'normalized units' or could be expressed as percentage of departure from the limit, in which case we could have equal intervals on both sides of the limit as follows:
    - ±10% = no significant change (grey or yellow);
    - ±10-25% = likely to be sustainable (pale green) or unsustainable (pink);
    - ±25-50% = more likely to be sustainable (green) or unsustainable (orange);
    - >±50% = most likely to be sustainable (dark green) or unsustainable (dark red);
- ***Interchangeable spatial reference.*** From a set of *n* simulation listed in the League Table, the user should be able to select from the first column the **spatial level (or reference)** to be compared or analysed, i.e. whether to show Europe results, Country level – specifying the country, Cluster region level – specifying the cluster, NUTS-X level – specifying the region(s) (see Fig. 14).
- ***Dynamic selection of variables to analyse.*** The user should be able to highlight columns (for **LUFs or indicators analysis**), rows (for **policy settings or regional analysis**) and be able to generate the usual graphs from the selection made (i.e., bars, spider, tables, etc.) (see Fig. 14).
- ***Functional drill down.*** Each cell should have a live link (or 'drill down' function) to i) visualise what indicator(s) contributed to the outcome and in which way (rule), ii) show the departure from the limit, iii) show the difference from the Baseline scenario, iv) providing a link to a map (perhaps via a drop down menu for NUTS-X or CLUSTER, etc.) (see Fig. 14).

Through these SCS functions SIAT will allow users to identify how and where the broad impacts of different policy scenarios differ in terms of which **indicator** subsets or **land use functions** are affected and potentially driven outside specified limits. For example, it may be the case that under a given scenario one geographical region may mainly be affected by rising unemployment (e.g., by 11%), which could be visualised by either as a red coloured region on a map, or a red coloured cell in the League Table, both carrying the numerical information and the way it was calculated (drill down function); at the same time, in an adjacent region, under the same scenario the main issue may be given by environmental damage (e.g., by 12% provision of habitat loss or deterioration), which once again may be represented on maps and League Table as described above, while a third region could instead be affected mainly by a loss in land based production (e.g., by 14 %), and again displayed on maps and League Table as described above. The policy customer will need to understand where the 'pressure' points are for a particular scenario across the 'three pillars' and what policy choices are potentially available to resolve them.

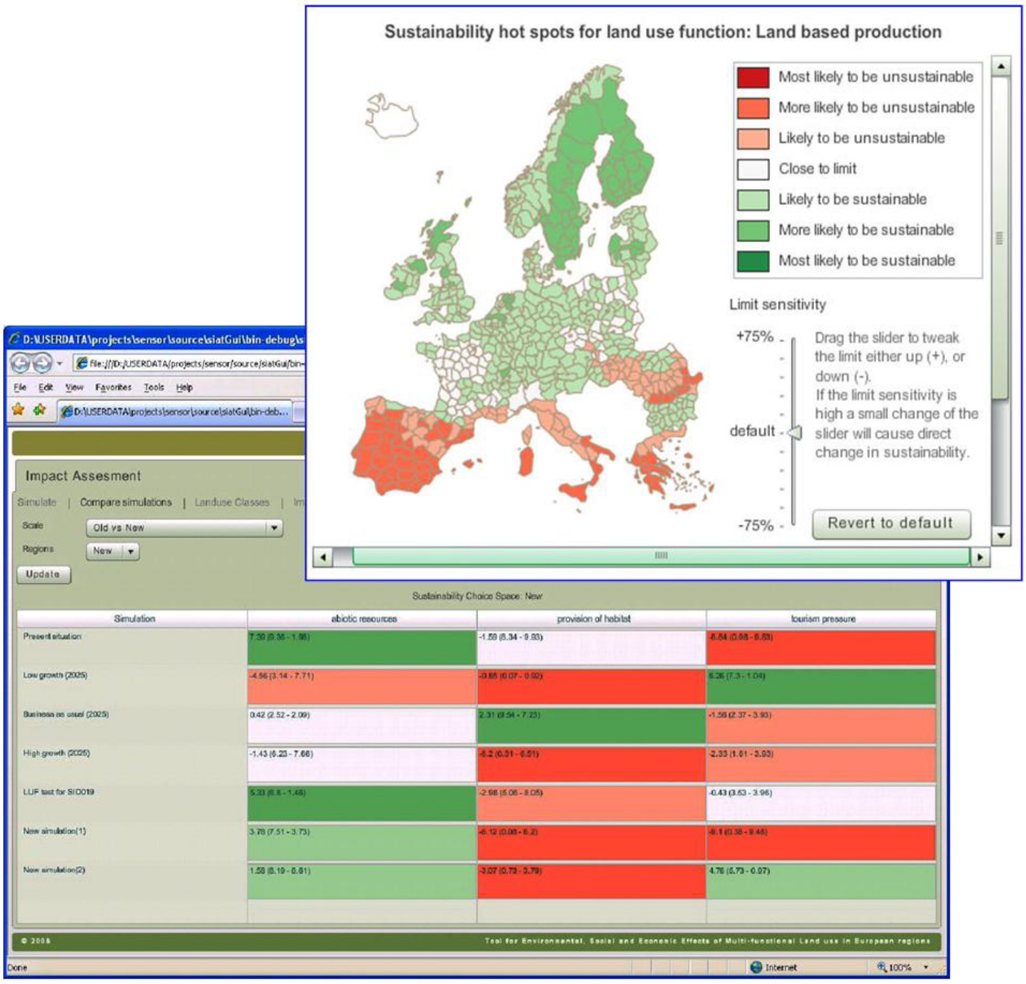


Figure 14. Close up of a League Table, with analysis of three LUFs, comparison with reference scenarios and interactive (drill down and sensitivity bar) geographical map generated for one LUF; see Fig 13 for detailed explanation of features (Verveij, 2009).

The trajectories of individual indicators and/or LUFs could be plotted under different policy scenarios to determine the sensitivity of outcomes to different policy assumptions (Fig. 15). This functionality, however, is not available with the current prototype of SIAT and is shown here as a desirable tool for future developments. The idea of showing the indicators or LUFs trajectories has been suggested by various authors as one of the most appropriate way for accounting for the diversity of indicator statuses and elaboration forms (e.g., Dahl, 1996; Hukkinen, 2003; Rey-Valette et al., 2007). As it will be discussed later, the trajectories, as well as maps and other types of representations, would greatly enhance the analysis if compared with the **PRESENT** situation, which would give an immediate picture of the validity of the simulation and policy settings.

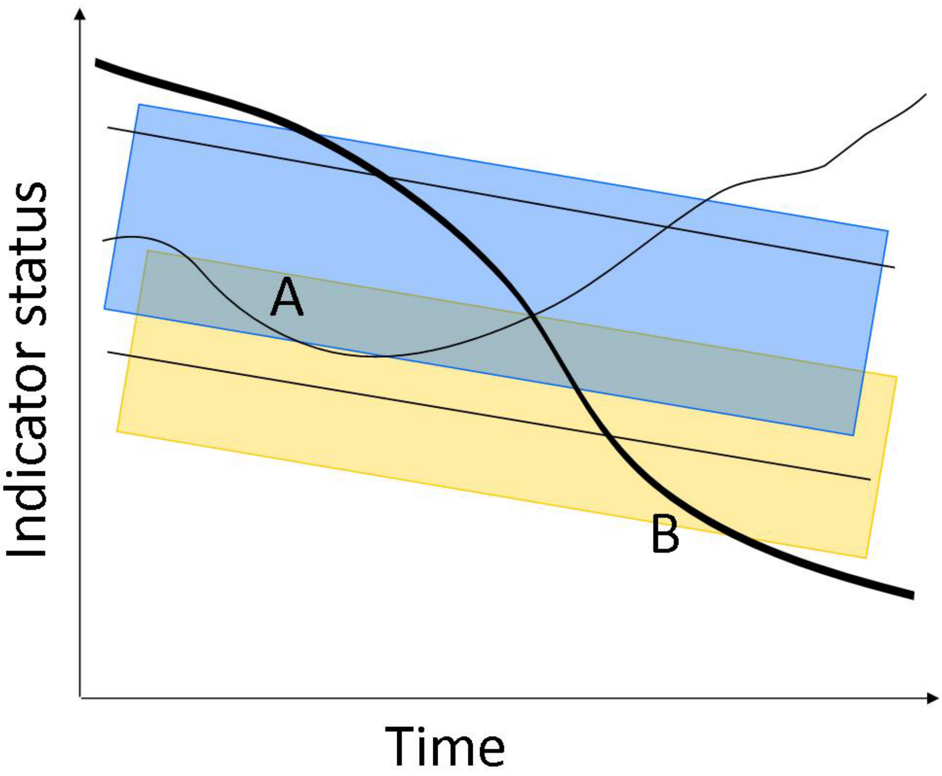


Figure 15. Indicator (or LUF) trajectories under different scenarios: A and B represent different indicators (or LUFs); the shaded blue and yellow areas represent two hypothetical scenario settings; the two solid lines represent the sustainability limits.

The SCS tools will also allow users to identify those **geographical areas** that are most sensitive to particular policy scenarios and to understand how outcomes differ between different policy scenarios. In this way the policy customer would be able to build up an understanding of the 'core' areas which might be impacted under any of the different policy options, and those where outcomes were more dependent on the policy choices made. The contextual information provided at various regional level (EU, Country, Cluster Region, NUTS-X) should be designed to help users understand what the key sustainability issues are in different areas, at least at the land use function level. For example, users should be able to compare the outcomes of the run of SIAT for the biofuel policy case, with assumptions of different world oil prices, and identify which areas are most likely to be impacted under any circumstances, and which areas are more 'marginal', being sensitive to only particular sets of modelled assumptions. At the NUTS-X level, units where sustainability limits are exceeded for a given indicator or land use function can be highlighted (Fig. 16a and b). Limits may vary by cluster region and be indicated by groups of coloured NUTS-X unit. The proportion of units within a region that are sensitive to a given policy case can be used as a measure of the impact of a policy. Alternatively, the user could recall two or more simulations and ask for a map 'of differences' to be shown, so that the areas departing from the limits could be easily identified and coloured according to differences from the limit but would also show the sensitivity, i.e. difference between the two maps. This type of function was already available on similar systems (e.g., EURURALIS) and could easily be implemented in SIAT too (Fig 16c).

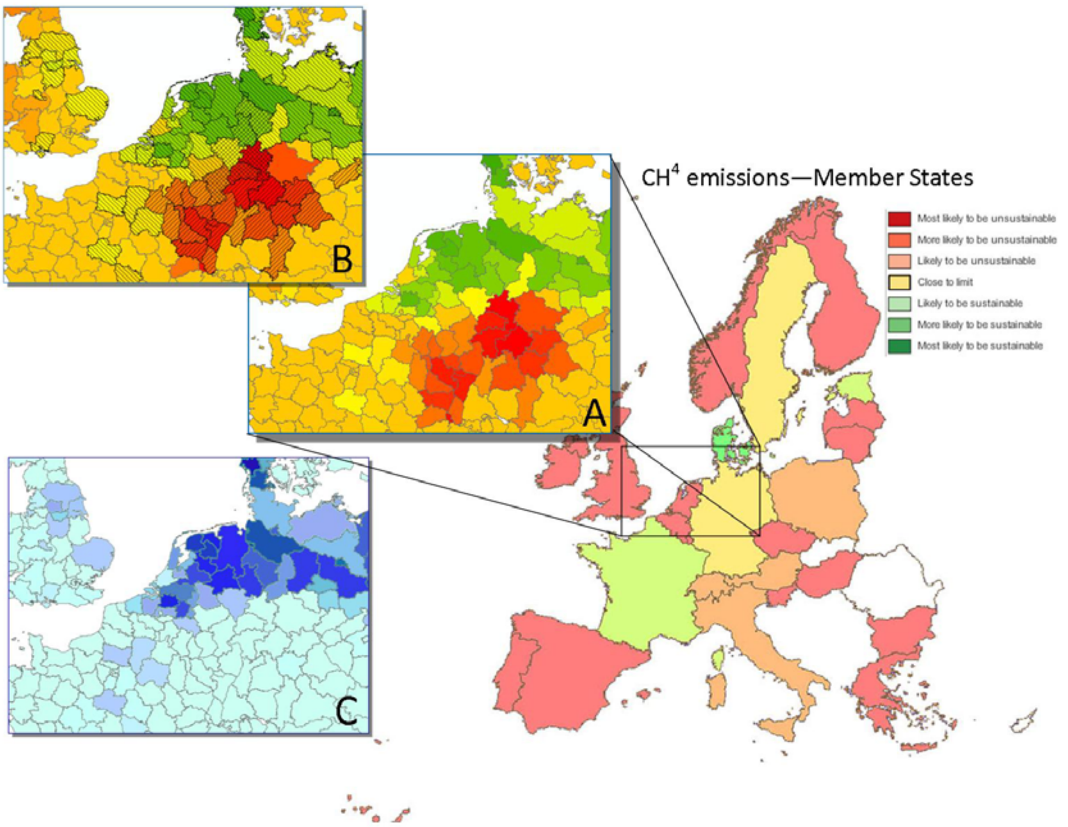


Figure 16. Map representation of an hypothetical SIAT simulation: the main map shows the results at Cluster Regions level for the chosen indicator or LUF; close-up A represents sustainability outcomes at NUTS-X level for a specific region, close-up B shows the same region but with different settings; close-up C would represent the marginal differences between the map A and B.

Furthermore, the analysis of the outcomes should allow users to look at any potential '**trade-offs**' that appear to exist in a given geographical area or set of areas, in the sense that one particular policy scenario might affect the suite of indicators or land use functions in one way, while a second policy scenario might affect them in another. For example, users should be able to consider the outcomes of the biofuel policy case under assumptions of different levels of economic growth, and identify those situations where, say, growth in jobs might be offset by greater environmental damage, and those other areas where the reverse might occur. Clearly, a comparison with the **PRESENT** situation would be the easiest way to understand where areas of improvement are, both geographically and from a sustainability point of view. Even though it is understood that this will not going be possible with the current SIAT development, it is recommended that future versions of SIAT allow this basic yet fundamental comparison. In absence of this, the **BASELINE scenario** (the state of affairs in 2025 without policy changes) can be used as a first general comparison. Radar or spider diagrams can be used to show how outcomes impact across the set of land use functions (LUFs) for a given region and how limits differ for each of the elements (Fig. 17).

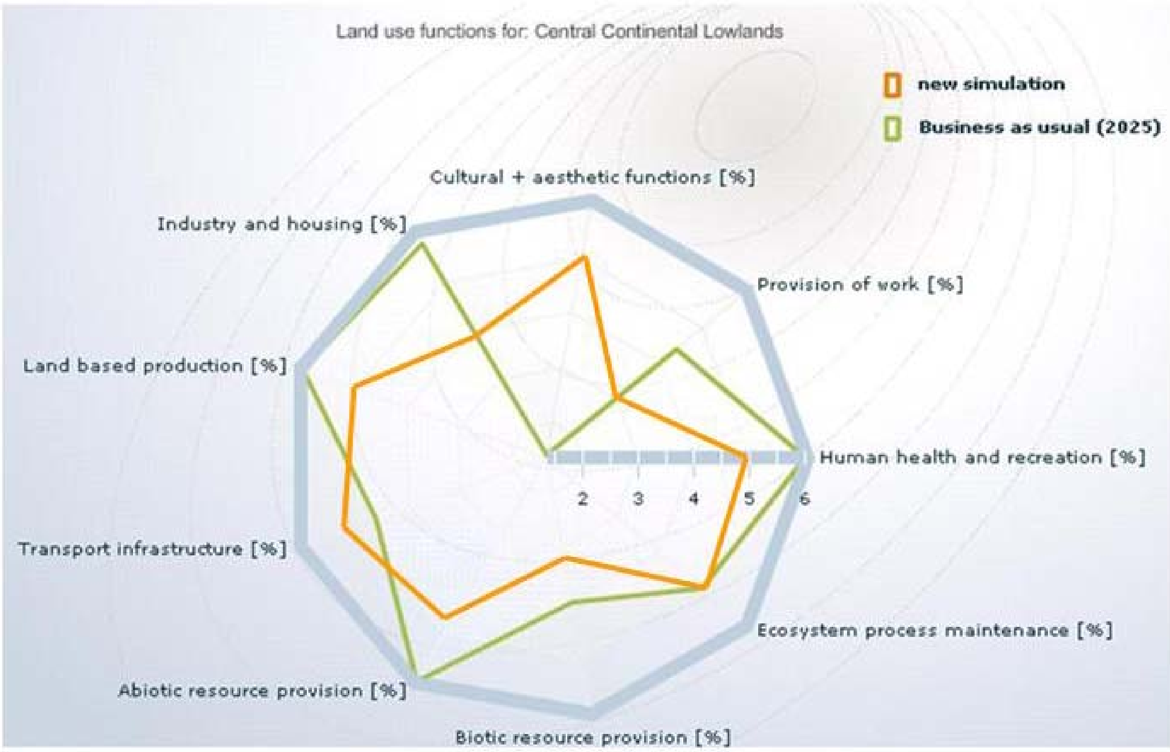


Figure 17. Spider diagram generated by SIAT prototype III, showing the results for one hypothetical simulation (orange line) compared to the 'business as usual' scenario (green line). The diagrams refer to LUFs of the Cluster region 'Continental Lowlands'.

These diagrams are already available with the current prototype, but could be improved, for example introducing an animated version to show how the situation changes over time. It is also understood that SIAT will be able to present differences from the limits in other ways, for example in form of bar charts with 'floating' limit levels. In addition to this, though, bar charts and spider diagrams could be produced for the different spatial levels (Europe, Countries, Cluster, NUTS-X), should the user want to enhance the analysis.

Finally, the system should allow the user to undertake all of the analyses suggested above '**dynamically**', so that the trajectories of different policy assumptions can be compared over **time** and **space**. For example, policy customers should be able to explore how differences between policy scenarios build up over time. If differences mainly only develop in the long term because of non-linearities, say, then given uncertainties the initial choice of policy option may not be so significant. Given the need to support decision making that is **adaptive** in character, policy customers should also be able to look at the effect of relaxing or changing particular constraints at some time in the future, to see if 'corrective' measures might be available should assumed trajectories not be realised.

The SIAT tool should also give the possibility to build a report with all the material (graphics, tables, maps or other means) generated during the performance of the analysis. Table 2 shows the current status of implementation of the SCS functionalities in the model SIAT: the list gives an indication of the kind of development that a hypothetical prototype 'X' of SIAT could follow in the future to meet its ambitions.

Table 2. List of tools and functionalities that SCS would need to have implemented in the model-based SIAT.

SCS component	Design options	Current status	Future
League Table	***Planned***	implemented	Cube? Inclusion of time
Drill down	***Planned***	Partially implemented	Full implementation, but with partial functionality
Storing simulations	***Possible***	Not implemented	Possible
Trajectory representation	***Not planned***	Not implemented	Desirable
Present situation comparison	***Not planned***	Not implemented	Highly desirable
Marginal differences representation	***Not planned***	Not implemented	Desirable
Report building	***Possible***	Not implemented	Possible
Sensitivity analysis	***Not planned***	Not implemented	Not implemented
Access to stakeholders data	***Not planned***	Not implemented	Desirable
User-assigned preference	***Not planned***	Not implemented	Desirable
User-assigned Value	***Not planned***	Not implemented	Desirable
Back-casting	***Not planned***	Not implemented	Desirable, but with major modelling implications

In particular, perhaps the three most desirable features that were identified during the course of the SCS concept development and that are hoped to be included in future developments of the model-based SIAT, are:

1. **Assigning preferences or changing LUF weights**. This is closely linked to the idea of including stakeholder or user preferences. At the moment the model-based SIAT is designed to give equal importance to all the nine LUFs. However, in the participatory framework stakeholders can assign an importance score. In the analysis and comparison of the scenarios, users could rank or give LUFs different importance to reflect the local or specific regional situation. The final LUF score would then reflect the new weight assigned during the comparison and the user could compare the results of: 1) LUFs equally important (default SIAT condition) vs 2) LUFs with different importance scores (or ranked). In this way the user can start to appreciate the different trade-offs corresponding to the various assumptions. Furthermore, this facility could introduce the user to other types of scores, e.g. an overall score for each simulation based on the product between the importance's and the divergence from the limit. This could be visualised both graphically and by maps.

2. **Assigning monetary or non monetary values to each LUF**. This is to have another alternative weight system for the LUFs and could reflect once again local or regional specific circumstances where the emphasis falls on some LUFS rather than equally on all of them. The user could then compare: 1) LUFs without monetary value (default SIAT conditions) vs 2) LUFs scored with monetary values. This in turn is bound to generate different trade-offs and the scenarios could start assume completely different significance that the user can start to appreciate and visualise graphically or geographically.

   The preferences, weights or monetary values to assign to the LUFs can be elicited directly from individuals, through a questionnaire or vote, but also separately from group discussions or workshops, or from deliberative processes such as that of the FoPIA framework, in order to generate group values that the user can then feed into the model. There seems to be agreement on preference formation and the majority of environmental economics and psychology literature seems to support the view that group preferences are constructed over time and that preferences are flexible and constantly influenced by other agents and networks, and not exogenous and fixed (Gregory and Slovic, 1997). The implication of this is that weights applied to SIA may or may not reflect stakeholder relative priorities or preferences, either as individual or as groups, with any measurable degree of accuracy. This issue lies at the heart of decision support and it needs to be explicitly recognised as decision support tools become more complex without necessarily becoming more accurate (Tompkins, 2003).

3. **Performing back-casting assessments and querying modelled data**. This is a desirable feature for future versions of model-based SIAT. The user, once performed a number of simulations in a 'forecasting' style and produced the League Table that summarises the results of the simulations as part of the SCS, could be able to specify some conditions, e.g. in terms of which LUFs or indicators have to meet certain standards or final state, and find out the minimum policy intervention that would meet that. The query function could also be used to find, or isolate, conditions that fall within sustainability, or isolate regions falling outside sustainability, etc.

It is important to say that all of the described desirable features would not undermine the multifunctional assessment and multi-dimensional interpretation, but would rather enhance the appraisal of the intricacies and interweaved economic, social and environmental implications. Often summarised as Triple Bottom Line (TBL) (Elkington, 1994), this approach has become standard in many studies related to land use and was espoused by the SENSOR project.

5.2. Preliminary concluding remarks

From the above discussion, it emerges that some of the SCS concepts and ideas have been implemented in the model SIAT and others are recommended. However, it is important to point out that, as things stand, the SCS cannot be implemented in the same ways described earlier for the FoPIA approach. The reason for this lies in the fundamental difference between the probabilistic nature of the BBN system employed for the operationalization of the SCS ideas with FoPIA, and the deterministic nature of the model SIAT.

The effort in relation to the SIAT tool in the first stages of the work that has contributed to this deliverable was focused around the better expression of choices within the current SIAT framework. This represented the first step to render operational some of the SCS concepts. However, the recommendations made earlier push the boundaries of SIAT development towards more probabilistic (or indeed a fully probabilistic) modelling framework. As a result it is possible to suggest a number of design issues that might be used to inform the development of the next generation of SIA tools.

Figure 18 indicates the kind of approach that should be possible by re-engineering and extending the existing model-base that underpins SIAT. The approach envisages using the existing database to look at the *distributions* of modelled outcomes to represent the likelihood of particular impacts either at the indicator or LUF level. In Fig. 18 only two LUFs are shown and only two indicators that contribute to them are considered. The BBN formalism represents the same analytical logic that underpins the existing SIAT tool with policy cases and policy interventions being selected, but this time the probabilistic nature of outcomes are highlighted. The representation of underlying uncertainties might be further extended using this approach by building in the levels of confidence assigned to particular indicator and LUF responses to given land use changes.

In Fig. 18(A), the network shows the kinds of outcome that might be anticipated if no prior information is provided in relation to likely futures or policy interventions. Fig. 18(B) shows the sensitivity of the system to likely changes under assumed conditions of 'low growth', 'high direct support' and 'intermediate levels of investment in R&D'. All of the probability functions used in these models have been assumed at this stage.
A novel feature of this way of representing SIAT results is that potentially the consequences of different stakeholder values can be modelled in the system and the marginal changes in some utility score assessed. This is shown by the blue box labelled 'value' on the right hand side of the diagrams. In the networks shown, rural and urban dwellers are equally weighted. This switch might be used to compare the views of different groups of stakeholders. Using this approach back-casting approached might also be supported by the SIA tool box, in that the outcome nodes can be set to achieve particular levels of certainty about increase or decrease in their condition, and the pre-conditions necessary for their realisation can be explored. In this way the sensitivity of choices to assumed changes in policy could be better explored, and the ideas of a sustainability choice space better articulated within the SIA toolbox.

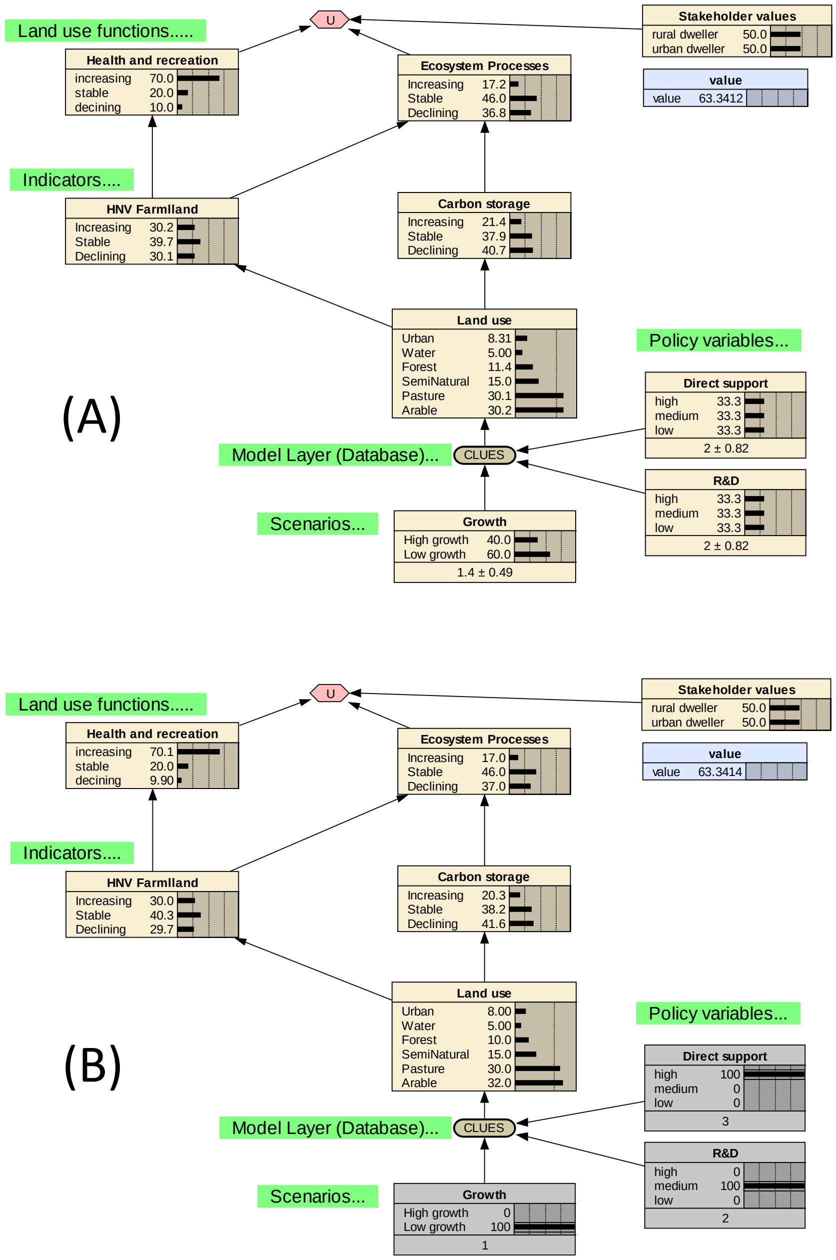


Figure 18. Illustration of how SIAT outcomes might be represented in a BBN formalism for the design of the next generation of SIA tools. Network (A) shows outcomes likely to occur if no prior information is provided in relation to futures or policy interventions; Network (B) shows the sensitivity of the system to likely changes under assumed conditions of 'low growth', 'high direct support' and 'intermediate levels of investment in R&D'.

In fact, the model-based SIAT would need a major conceptual shift to be able to perform these back-casting and query functions, as these are more 'familiar' to models based on probabilistic approaches than mostly deterministic models. The other conceptual shift that would be necessary concerns data storage, in that as the current SIAT is thought to act and perform in the fastest and simplest way, data query or interrogation may fall outside these parameters and become obstacles to achieve its 'light-weight' status. Nevertheless, this recommendation is made with users in mind, to give them more tools for analysis and exploration of the results of the scenarios and simulations, and is not thought to set against the SENSOR ideal modelling cascade and analytical chain, but rather reflects from the point of view of producing tools that could better inform decisions on policies at EU level.

In fact, a dialogue with potential users has to be established to find out exactly what their needs and the fears are when using these types of tools. In the following section this account turns to these issues from the users' standpoint, reporting the opinions of the participants to a workshop organised by our group. Users were invited to critically discuss SIA tools and models in the attempt to bring some light or share serious doubts on the nature of the process of supporting decisions by using these instruments.

Box 5.1: Key messages from section 5

- Some SCS functionalities have been 'already' implemented within the current SIAT prototype III.
- The SCS League Table allows the results of several simulations to be listed in a matrix, where LUFs and various spatial scales can be visualised.
- Users can select the cell(s) in the League Table of interest and drill down to understand assumptions, rules, indicators affecting the result, as well as the region(s) where the results show that value.
- The SIAT model could develop further functionalities to enable users to perform outcomes analysis where trade-offs can be highlighted.
- Future developments could include stakeholders' preference and valuations and the possibility to vary them.
- A BBN-type of modelling approach may be suitable to include all of the aspects described with the SCS framework, without losing the logical chain of the current SIAT framework.
- Functionalities need to be developed also through a dialogue with users.

6. Discussing SIA tools from the users standpoint

In order to test the concepts around SIA, SCS, and how easy it is for local, regional and national decision-makers to influence policies and policy-makers using these tools, a workshop was organised by the Centre for Environmental Management (University of Nottingham). The invitation was sent to people who could have a legitimate interest in this discussion and from now on we will refer to them either as 'stakeholders', 'users' or 'participants', without distinction.

6.1. What are policy makers thinking about these tools?

The stakeholders invited to the workshop were mostly UK based and were encouraged to discuss the tools currently available and developed to support decisions with regards to regional impacts of land uses changes and policy effects on sustainable development. The aim of the workshop was therefore to explore how these tools can be used at national and local level (UK), and whether they can also serve as a 'discussion-and-decision-support' tool by providing a common platform for critical engagement between policy-makers and stakeholders at EU, national, regional and local level.

The focus of the workshop was in particular on scenarios of the **Common Agricultural Policy** (**CAP**) reform which were presented to the participants for the whole EU as well as for UK national and regional level. Participants were at times divided in three working groups, mimicking local, national, and European 'policy-makers'. The workshop was interactive, allowing time for discussion and reflection. The participants were introduced to the main concepts of sustainability impact assessment and the particular objectives of the SENSOR project, but maintaining a wider view on the use of quick-scan tools for ex-ante SIA. Aspects of policy options, scenarios, land use change and indicators were touched upon and some of the most recent tools were described, including the model-based SIAT and the concept of LUFs.

Participants were guided to assess the scenarios for the CAP reform and the types of policy intervention that can be examined through the lenses of various tools (e.g., SIAT). As a first task, a list of indicators was distributed and participants, divided in the three groups (Local, UK and EU 'policy-makers'), were asked to

1. Try to match SIAT-type indicators with relevant LUFs, identifying positive or negative effects;
2. Suggest new indicators in the case of lack of relevant ones for the particular area;
3. Review the relative importance of the LUFs in relation to the policy case considered, assigning importance, weights and values to the LUFs;
4. Make a preliminary analysis of individual scenario outcomes in relation to the indicators available and identified as important, and the LUFs.

In addition to this, the workshop was planned to consider different points of discussion and bring some light to several issues, including the following questions:

i) **How relevant are the scenarios?**

ii) **How appropriate are the scales of the assessment (e.g., European, Regional and local)?**

iii) **How plausible are the outcomes from the model?**

iv) **Do the tools help in the identification and discussion of different trade-offs?**

v) **How well the tools inform the process of negotiation, decision support and decision making?**

vi) **What is the role of participatory tools for SIA?**

vii) **How choices are made? Is the Sustainability Choice Space providing the types of tools necessary for this?**

The scenarios employed at the workshop are listed in Table 3, where their assumptions are also outlined. As already mentioned, these scenarios were applied to the case of the Common Agricultural Policy and were explored with the intent to test the validity of the tools available for sustainability impact assessment.

6.1.1. Relevance of indicators and scenarios

Issue: Users were asked to question the **RELEVANCE** of the inputs of the scenarios for the assessment, reflecting on the significance of the indicators used to the region in question, their clarity and comprehensiveness.

Response: the analysis of this aspect some questions, as **some of the indicators were not relevant at local level.** Some participants focused on the specific example of the 'Health and recreation' LUF. The scenarios, the indicators, and hence the outcomes were judged insufficiently detailed for the local issues, particularly if they needed to inform decisions. It was noted how the questions that local decision-makers wanted to answer were not matched by the model, particularly by lack of indicators, perhaps because the model was more designed to be dealing with EU level scenarios.

Modelling implications: Scaling down was deemed not sufficient to represent local situations and **new indicators would be necessary to address the specific local reality**. Alternatively, users may have to interpret more accurately the outcomes of these models, by knowing the assumptions and perhaps further investigating them. More precise information is needed to match the questions that local level decision makers want to ask. The model should be flexible enough to have sufficient indicators in those areas of concern to allow customizing the analysis, possibly to ability to even add some local level information but crucially it would be more relevant in those areas. Remarkably, all these considerations seem to point to the direction of the FoPIA methodology, which deals exactly with these issues.

Table 3. Scenarios employed during the workshop, outlining the main assumptions and criteria (as taken from EURURALIS[19]).

SCENARIO	Assumptions
Global Economy	• WTO negotiations are successful; • Global trade will be fully liberalized; • A further Eastwards EU enlargement (including Turkey) will take place; • Technological change is high; • Poor countries will catch up and experience high economic growth; • This scenario shows the highest income growth for almost all regions.
Global Co-operation	• International co-operation will be successful; • Trade will be liberalized, but with limitations under certain conditions for people and planet (e.g. climate change) • Lower growth in economic terms and a lower economic development than in Global Economy, especially for the EU; • There will be a high growth rate in the EU accession countries (EU10+2).
Continental Market	• The focus is on markets, though national or continental interests prevails; • The USA, Canada and the EU create a Trans-Atlantic internal market; • Such a unity will yield welfare gains in these regions, in contrast with poverty in developing countries.
Regional Communities	• Both economic and non-economic values will be important whilst regional or national interests prevail; • Trade and agricultural policies will remain almost unchanged, except for export subsidies; • EU integration will only be partial and technological change will be limited; • The resulting economic growth is lower than in other scenarios; • Social values will lead to catching up of developing countries because they can adopt existing technologies from developed countries.

General remarks: It was recognised that there is a universal problem with indicators, scales and filters through which indicators have to go through, which was also encountered in SENSOR. What indicators are available, can they be modelled, and at what scale? Some indicators are indeed available at km^2, but there is still a tension between the universal and the specific.

The issues related to indicators and scenarios are also connected to issues of spatial resolution and thematic resolution, and this is discussed below.

[19] http://www.eururalis.eu/

6.1.2. *Scales of assessment, scales of thinking*

Issue: Is the model taking account of the different perspectives of value and harm? Are the scales of representation matching the demand of decision-makers at various levels (EU, National, Local)?

Response: the geographical boundaries and scales used for the representation were found not always to be the most appropriate, and users were questioning some of the choices made. For example, the inclusion of urban conurbation in some areas was not obvious.

Modelling implications: Customizable geography may be important for the different levels of analysis, as there are different beneficiaries at different scales, and one participant brought the example of the Humber estuary to depict this conflict, where local, regional and European decision makers and stakeholders are thinking about land use changes in very different ways. The obvious answer would be to have different regions, where most policies would have different geographical footprints. The cluster regions and NUTS-X adopted by SENSOR may represent a sufficient scaling framework.

Regionalising policies is not out of the question. This is a problem for the decision maker, not for the model, which instead is delivering what is supposed to deliver, highlighting geographical differences.

General remarks: it was agreed that regional experiences may shift opinions and that different levels of decision-making are identifiable, where time may also play an important part. European interests are not necessarily meeting local interests. The policy should be delivered at the level which is most appropriate; if major differences in outcomes are found, perhaps then the decision should be not to deliver the policy at that level, but to step down one level.

This observation was partly reflected in the subsequent scoring exercise, where participants were asked to give preferences and weights to the LUFs wearing their hats of local, national or European decision-makers, showing to focus on slightly different areas.

6.1.2. *Initial scoring of the LUFs*

Issue: what importance do we give to indicators and aggregated indicators (LUFs)? Users were asked to Review the relative importance of the LUFs in relation to the policy case considered, assigning importance, weights and values to the LUFs.

Response: Table 3 shows the scores and weights assigned by the participants. At this stage, the discussion focused on around the poor coverage of the indicators available for what were considered the most important issues, particularly at local level. The scoring may reflect some bias in the audience, however some distinct difference were noted and discussed at group level.

Table 4. Summary of importance scores, weights and monetary values assigned by participants to the SIA – SCS workshop. The importance figures were averaged and are presented with two decimal points to show the differences; weights were averaged and then a ranking created from the totals; monetary values were assigned by participants in percentages, and are here presented also as average proportion of the annual expenditure on the CAP (£3bn). See Annex III for a representation of the individual scores.

LUFs	Importance	Weight	Value
	0-1-2*	1-9†	% £M
Provision of work	1.35	5	8% £250M
Human health and recreation	1.73	3	13% £390M
Cultural	1.23	7	9% £267M
Residential and land independent production	0.92	8	6% £173M
Land based production	1.69	2	15% £457M
Transport	0.62	9	3% £93M
Provision of abiotic resources	1.73	6	13% £397M
Support and provision of biotic resources	1.81	4	13% £397M
Maintenance of ecosystem processes	1.88	1	19% £577M

*** 0 = not important, 1 = important, 2 = very important.**

† 1 = most important -> 9 = least important, with no ties and no repeat.

In general, the scoring and the ranking reflected the background of the participants, with emphasis Ecosystem processes (ENV 3), Land based production (ECO 2) and Human Health and recreation (SOC 2). However, it is interesting to note the difference of results when participants were left free to assign the same importance to more than one LUF (Importance score) and the case of the Weights, where the score needed to be individual and exclusive for each LUF. The environmental LUFs scored higher with the Importance compared to the Weights, when facing a choice other factors may begin to enter into consideration in people's minds. Interestingly, as the participants were also asked to average their scores as a group, different dynamics and adaptive mechanisms also intervened when the various scores had to be shared and explained. Some participants indeed adjusted their scoring, both in the Importance and the Weights, after the group deliberation.

Modelling implications: as it was discussed earlier in this report, the tools currently available for SIA do not allow the preferences for the indicators or the LUFs to be expressed and recorded in the modelling chain. The exercise of assigning preferences and monetary values by a group of users seems to suggest that this could add invaluable insight on the SIA process, but it clearly necessitate a major shift in modelling priorities. At the moment the 'quick-scan' tools are almost bare databases where simulations (run elsewhere) are stored and available for users to access and interpret. The models would need to be much more flexible should this functionality be introduced.

General remarks: This exercise highlighted one of the defining elements of the Choice Space, that is, the key role that the engagement with stakeholders and regional and local interests groups assumes in what should be a deliberative-adaptive process of informing decisions, at the various levels of decision-making. The difference in scoring also pointed out how stakeholders may respond with completely different attitude when confronted with different kinds of decisions to make. The planning stage of a participatory methodology, therefore, becomes extremely delicate, as the right tools must be provided to enhance the process of deliberation and *learning* (see Mayer, 1997, for a comprehensive account of the types of participation).

6.1.2. Plausibility of the outcomes

Issue: Users were asked to consider aspects of **OUTCOME PLAUSIBILITY**, questioning the types of outputs of the CAP scenarios, their meaning and the differences in the three groups.

Response: From the user point of view, two questions were continuously raised during the course of the exercise: **do I trust these models**? And **how do these results compare to my 'knowledge'**? In fact, after running the models under different assumptions and policy settings, it was noted that some of the mapped outcomes were not plausible. Users commented that finding results which were unrealistic or difficult to interpret for areas they knew, would **undermine the confidence in the model** and decisions would be difficult to support on the basis of those outcomes. Most importantly, it was also noted that outcomes from the tools presented at the workshop were given as **absolute values** with no indication of the **uncertainty** of the data and processes involved in the calculation, whilst users thought that knowing the degree of uncertainty linked to the outcomes is a fundamental requirement for plausibility. Again, this clearly pointed to the direction of the Choice Space framework, where uncertainty and outcome sensitivity represents one of the key elements for the achievement of better SIAs.

Modelling implications: The models need to be able to compare results with the present situation as this is the very first verification of the plausibility of the results, whereas its absence was inhibiting the understanding of the results. Understanding the rules and assumptions of the model was also pointed out as a desirable feature, but it was highlighted that some tools (SIAT) may develop this functionality. In this way users should be able to probe a cell and get the rule(s) that were behind the value of that specific LUF or region; it may be also possible to go back to the CLUES (or any other model compiling the tool) model assumptions. However, this may not be sufficient if **uncertainty** is not dealt with. A way of quantifying the degree of uncertainty linked to the outcomes must be included in this kind of models, such as that utilised by the BBN-systems piloted on FoPIA in chapter 4.

General remarks: The assumptions behind the model's calculations are often (for simplicity) hidden to the users, but in some cases these are needed to understand the results. Implausible outcomes may create confusion as users could think that: i) there were local effects ongoing that were captured by the model; ii) those outcomes were outside the range of coverage of a specific rule, or iii) these were merely the noise due to the uncertainty around the modelled indicator(s). Even if the outcomes are acceptable and accepted, one would still want to know more information and justify the results. Some participants advocated the presence of a help-desk to answer the questions about the underlying assumptions, or the possibility to access expert advice after the simulations. The current models are equipped with a number of Fact Sheets which should enable users to dig deeply into the models, its assumptions and background. However, the presence of a user community dealing with the same types of issues would enable that deliberative-iterative approach that may be necessary to 'understand' the results.

6.1.3. Creating the 'space' to support the process of decision-making

Issue: In terms of **DECISION-MAKING,** the questions were focusing mainly on whether and how these tools can help to articulate the concept of a sustainability choice space, in terms of identifying the 'room for manoeuvre' when deciding the new policy, and whether outcomes from scenarios can help to design the new policy and carry out an ex ante impact assessment of EU policies.

Response: There was a general feeling that these tools may currently be divorced from the political process instead of being involved in it, providing the room for negotiation, upon which decisions can be made in terms of political compromise. The current generation of tools does not seem to be able to generate this decision space, whereas **TRADE-OFFS** and alternative adequate solutions need to be identified and framed. For example, the simulations pointed out also some clear divergence and differences between national (UK) and European trajectories, which posed questions on how to deal with heterogeneities. Most of the participants reflected that there might be a point where the tools may have to stop and give space to the political debate and negotiation. They have to help us to shape the negotiating space, or the space we want to explore, from which the political and social debate can start and feed all the other elements that, together with model outcomes, will help making choices. This is the key area where the SCS concept seeks t make a contribution.

The provision of a tool may therefore not be sufficient in itself because this triggers a quantity of questions (about the tool and the results) that need to be answered. With the complexity of the systems analysed, it makes it very hard to perform it online, or there needs to be some form of human support if the tool is going to be respected, which poses questions on the 'sustainability' of the tool itself.

Users accepted that it is important for the decision-maker to be able to see the trends and the trajectories of change according to different policy choices, as that constitute already an added value that can possibly support a decision. However, they may need to have some prior knowledge to be able to recognise possible flaws (models failures, etc.) or counterintuitive results to be able to find the possible reasons.

Modelling implications: In order to be able to create this decision or negotiating space, the models would need to have a number of user-friendly features that allow user to drill down and to understand why the system has come up with a particular solution.

The idea of the **Sustainability Choice Space** represents an attempt to recognize this space for negotiation, where the 'red lines' are, where the constraints are identified and different set of choices (European, regional and local) are spelled out to inform the subsequent political decision. Somehow we need to be able to summarise the results and see what set of solutions are more acceptable and if there are any that cross the 'limits'; so, without trying to search for an optimal solution, we simply try to understand what kinds of policy options can give us adequate or sufficient outcomes.

General remarks: It was agreed amongst the participants that the decision comes certainly as a **compromise** of possible, adequate solutions, not necessarily finding the optimal solution, by discarding those that are not within the scope, then consulting on the ones that are in a range of negotiation. Interestingly, this process was branded as a '**risk assessment of policy decisions'** by one of the participants, drawing some attractive parallels with the SIA procedure.

One of the main general points raised was the recognition that there is a process driven by the use of these tools that is useful, that is the process of thinking critically across the borders of several areas. **The value of these models seems to reside in the process of debate and discussion that is generated and stimulated by the use of these tools.** These tools can perhaps be seen as a small ingredient to a participative-deliberative and adaptive policy making process, rather than in isolation as a desk-tool. Interestingly, in SENSOR the participative tools are seen as a relatively smaller tool, but instead this seems to be the very focus of the all process and we should be looking at tools to inform the debate rather than subvert it.

These prediction tools are at the interface where the negotiation process begins, but the key point is that they need to be sufficiently robust and trustfully. For example, the models should be able to highlight not only changes occurring on the whole agricultural sector, but also, and more crucially, within the various sub-sectors of agriculture, where it may perhaps draw attention to even more dramatic changes. This in turn may be extremely interesting at political level, because policy makers are often influenced by particular lobbies connected to specific agricultural sectors.

The implications of these observations on the current status of SIAT are that the exploratory character of the model should be more emphasised, giving priority or more importance to the role of visualisation of the options, enabling choices to be made (E.g., **SCS League Table, drill down functions**, etc).

6.1.4. The value of participation in SIA

Issue: Users were asked to discuss other instruments to help and support the SIA process, such as those introducing stronger elements of participation and deliberation (e.g., FoPIA, Group Valuation, Internet valuation, etc.). How important would be to access people preferences and importance, perhaps accessing to focus groups in various regions to see how differently they judged and valued the various criteria?

Response: elements of participation were introduced in the workshop in the shape of the scoring and ranking of the LUFs. The reaction to this from the participants was contradictory.

On one hand, this was seen with apprehension, pointing out the risk of introducing another level of assumptions and more uncertainty. Some participants responded that the trade-offs between the (LUFS) may be too difficult for members of the public to understand. Participatory approaches are only involving a limited number of people, and it is unlikely that these processes will ever have a proper sample of people. One user tried to fit a different government department to each LUF, because this is the kind of approach a political process would be made of. The stakeholder position would perhaps be considered by consulting with specific interests groups, or lobbying groups that have a political weight.

On the other hand, it was recognised that we are supposed to move towards more participative form of governance and democracies. The value of concepts such as those expressed by Ecosystem Services and LUFs is that they are putting in very simple and comprehensible terms what the benefits are when we are intervening to improve or preserve the environment. This way of thinking opens the door for more participative approaches to governance decisions.

Modelling implications: Models could, therefore, be integrated with other, more participative forms of framework. The strengths of participatory approaches are those of highlighting and analyse different views and initiating *learning*, resulting in new insights for policies that could not have been obtained otherwise.

General remarks: A model's value is determined by its ability to represent certain features of reality. In this sense, top-down approaches and not wrong *per se*, but are certainly incomplete. Models can be used in many ways, to inform a decision, or as an interactive framework with stakeholders to explore options. Outcomes from models can be treated by considering them absolute truth, but this is unrealistic, especially considering the level of uncertainty of the source data they are fed with. They, instead, need to be flexible tools, adaptive and socially robust to support the decision making.

6.2. Implications for SIA models' design

The points raised during the workshop were general enough to be considered for all types of modelling framework attempting to unravel complex systems. Nevertheless, the issues discussed were also pointing the finger at specific problems that some current tools for integrated sustainability impact assessment seem to present.

In particular, the questions of scenario relevance, outcome plausibility/uncertainty, appropriateness of scale, capability of choice exploration, inclusion of deliberative-participatory approaches, were all formulated with the intent to explore the validity of the Sustainability Choice Space framework for this type of assessments. Encouragingly, the findings seem to endorse the suitability of such framework, allowing making grounded recommendations for the implementation of these ideas.

In summary, on the basis of the discussion with users, some recommendations can be made. In particular, the areas of concern, or prone to some development, are:

- Inclusion of outcomes uncertainty (linked to data and processes uncertainties);
- Transparency, ability to access model assumptions at anytime;
- Flexibility of the system, to allow analysis to vary across regional scales, and include indicators or information (e.g., stakeholders) relevant at the specific level;
- Comparison of results, particularly with present situation;
- Data query, grouping results on the basis of specific demands (LUFs score, sustainability, regions, etc.);
- Creation of a sustainability choice space for looking at trade-offs and analysis of sensitivity of modelled outcomes to changed inputs; and
- Inclusion of deliberative process in the modelling chain, to allow stakeholders' participation and facilitate problems learning and owning.

One of the principal fears emerged from the workshop was that models like SIAT could appear as 'black boxes', which would undermine the value of the outcomes if these are not made clear and accessible to analyse and review. As a result, users of these tools may require access to rules and assumptions at a more basic level to be able to understand the results. It was highlighted how, for example, the absence of a basic reference such as the present situation was inhibiting the simplest of the comparison, and answering the simplest of the questions: where are the good places, and where the bad? Are they getting better or worse?

The model may need to be developed in a way that **data query** or interrogation are allowed at different levels, by allowing results to be linked to the underlying assumptions and rules, but it is recognised that this may fall outside its 'light-weight' status. The SENSOR ideal modelling cascade and analytical chain was thought to be straightforward, although some flexibility to include stakeholders' along the process was thought to be necessary to add more value to the assessment. As already suggested earlier, the integration of the FoPIA outcomes with the SIAT runs, through the application of valuation and weighted criteria, seems to suggest a more rounded approach to the SIA than considering these two as separate tools.

Clearly, the model-based SIAT would need a major conceptual shift to be able to include probability and uncertainty into the modelling framework, and performing back-casting and query functions, as these are more 'familiar' to models based on probabilistic approaches. The BBNs are perhaps well suited to be applied at least for the participatory SIA, as they seemed to be able to capture the logic chain in a comprehensive and accessible way, and may indeed 'unpack the box' of the SIAT model too.

In summary, the main questions raised at the workshop were mostly emphasising the importance of considering the various dimensions and the different scales of the assessment for sustainability impacts. Users reinforced the understanding of the diversity that exists within Europe at various levels (geographical, social, economical, environmental) when issues of sustainability and land use are considered. The value of modelling frameworks for the prediction of policy impacts and the construction of scenarios was firmly recognised, but the common feeling was that of supporting modelling frameworks which would enhance this kind of analysis ONLY if they were sufficiently robust and transparent. This is the position that clearly any potential stakeholder would embrace, should the process of deliberation and participation have a role at all in the course of decision-making. Models and tools must be able to create ownership of the problems through a process of *learning* that is only possible if enough 'space' is created to allow the analysis and the comparison of the options available.

Box 6.1: Key messages from section 6

- Users were invited to a workshop and asked to discuss the tools currently available and developed to support decisions with regards to regional impacts of land uses changes and policy effects on sustainable development.
- Modelling tools were not always clear in their assumptions and rules;
- There was an apparent lack of coverage in terms of indicators at local level; the systems were found to be little flexible to allow different scales analysis;
- Outcomes were not always plausible, posing question of reliability and sustainability of the models; uncertainty of the outcomes was not dealt with;
- The tools to analyse the outcomes would not facilitate the identification of trade-offs and the subsequent discussion; the Sustainability Choice Space may represent a possible framework for this process;
- The value of these models seems to reside in the process of debate and discussion that is generated and stimulated by the use of these tools;
- A way of including a deliberative process in the modelling chain, to allow stakeholders' participation and facilitate problems learning and owning, should be included.

7. Conclusions

The general objective of deliverable 3.2.3 of the SENSOR project is the design, implementation and testing of the **Sustainability Choice Space** (**SCS**) at various regional levels, including its validation through stakeholders, to provide tools to identify regional risks and showing the spatial distribution of Sustainability Problem Regions.

As a result, this report has explored the ideas and concepts defined as Sustainability Choice Space (SCS) and how these can help the process of sustainability impact assessment of new policies on land use changes. The SCS concept was introduced as a framework in which these complex types of judgements can be made in an integrated way, that is as a solution or decision space where policy advisors might visualise and explore what 'room for manoeuvre' they might have in the design of a specific policy.

In particular, the report examined:

i. The general framework for the SCS idea, and how this might be used to describe the acceptability of alternative policy outcomes for stakeholders and policy-makers across a range of criteria defined by the suite of indicators that are driven by land use change;

ii. The two approaches embedded in SENSOR, the technical-rational and the deliberative-participatory, the tools developed following those approaches (respectively, the **Sustainability Impact Assessment Tool** – **SIAT** – and the **Framework for Participatory Impact Assessment** – **FoPIA**) and how the SCS framework and ideas are applicable to both;

iii. The way SCS should be assembled using information derived from models **and** stakeholders to identify the dimensions of sustainability, which are important in the context of a specific policy and the limits and thresholds associated with them; and

iv. The importance of considering the various dimensions and the scale' diversity (geographical and non) that exists within Europe through the SCS evaluation, by allowing the limits to vary across the various regional scales (EU, Country, Cluster Regions, NUTS-X) and economic, social and environmental indicators to be more scale-specific.

7.1. The Sustainability Choice Space concept

The first point was discussed and analysed in section 2, where the main elements of the SCS framework were identified. The framework was therefore built around the examination of how choices are made for complex systems, and how this should necessarily include ways of measuring **uncertainty** to better inform the choices. The intrinsic multidimensional nature of integrated sustainability impact assessments of land use changes was explored to derive concepts of '**adequate**' or '**sufficient**' solutions to be pursued in this context, in contrast to optimal solutions. Following this idea, the SCS framework therefore envisages that in SIAs a number of adequate or sufficient solutions may be possible, pointing out the importance to visualise the range of options and the likely trade-offs to inform the choice. The variables that need to be included in this multidimensional analysis are numerous and encompass notions of time, scale, limits, stakeholders' opinions, indicators (or aggregated indicators). These will create the boundaries of the SCS within which the trajectories can be followed under the scenario assumptions.

7.2. Expert and stakeholder integration

The methodology was then tested with the two different approaches embedded in SENSOR. In section 3 the two approaches were discussed in detail, including the ways of shaping the tools under the SCS framework.

In particular, it was identified that the **FoPIA** methodology developed within SENSOR (under the deliberative-participatory approach), naturally lent itself to test and develop some of the SCS concepts outlined above, as it presented a very useful progression of steps, which are analogous to the ones used for the mode-based **SIAT** (developed under the technical-rational approach) and follows the same SENSOR logic.

In order to operationalize the SCS ideas through FoPIA, a **Bayesian Belief Network** (**BBN**) was successfully piloted on existing FoPIA data, as described in section 4. BBNs are mathematical models, based on probability theory, normally presented in a graphical way where each variable is displayed as a node with the directed links forming arcs between them.

As a result, the FoPIA-BBN tool allowed testing the fundamental basic principles that characterise the SCS framework: inclusion of uncertainty, allowing stakeholders' engagement, and modelling and visualising sustainability trajectories to allow for trade-offs analysis. Furthermore, the piloting demonstrated the possibility to build a Belief Network that can be used as complementary SIAT tool. BBNs can handle uncertainty and group all the existing FoPIA case studies (SACS regions) in a single database. The methodology was further developed, by adding stakeholders' valuation into the chain; a **Total Utility Value** was built in the network to assess the outcome of the 'participatory-simulation'.

On the basis of the work undertaken here, it is recommended that the FoPIA approach could be developed and supported via SENSOR through the provision of a down-loadable, FoPIA-BBN tool. The results captured using such a tools could be fed back into the SENSOR database, and replayed using a similar BBN formalism to other users interested in exploring stakeholder views at broader geographical scales.

7.3. Implementing SCS into SIAT

The process of the FoPIA-BBN piloting was very encouraging, which warrants the recommendation of the use of the FoPIA-BBN tool as a stand-alone downloadable tool, whilst future development could see it as one of or part of the SIATs.

The SCS concepts were also applied to the model SIAT, developed under the technical-rational approach in SENSOR. In this case, as described in section 5, the work was different compared to that applied on the FoPIA framework, as the SIAT model is based on deterministic modelling methodologies and is not yet including deliberative-participatory approaches.

The activities here focused on what functionalities could be implemented in the current prototype to allow for the choices to be made and begin the analysis of the marginal differences at various scales. The report therefore described how some of the key SCS concepts have fruitfully implemented within the SIAT model.

In particular, the SIAT prototype III has been provided with the **SCS League Table**, which allows the results of several simulations to be listed in a matrix, where LUFs and various spatial scales can be visualised. In addition, users can select the cell(s) in the League Table of interest and **drill down** to understand assumptions, rules, indicators affecting the result, as well as the region(s) where the results show that value.

Other functionalities were also recommended for future SIAT prototypes, to enable users to perform outcomes analysis where trade-offs can be highlighted. Crucially, this should include stakeholders' preference and valuations and the possibility to vary them for various scenarios.

The work carried out to apply the SCS concepts to the two SENSOR approaches in fact highlighted how the implementation of this framework cannot preclude from the engagement with stakeholders and hence the inclusion of the information derived accordingly. Unfortunately, the SIAT model is not yet equipped with the capability of deliberative-participatory processes, and this may prevent the visualization of additional insights that would not be available otherwise. The SCS framework envisages the identification of the dimensions of sustainability that are relevant to the specific policy and the regions considered, but this may only be possible if there is a full engagement with stakeholders and if the modelling framework allows for the trajectories to be scrutinised under the varying assumptions and preferences dictated by the stakeholders opinions.

For this reason it is recommended that future SIAT prototypes, besides opening to probabilistic modelling frameworks, should allow stakeholders intervention and inclusion. Once again, the BBN methodology appears to be suitable to allow this type of approach, and is therefore suggested as a viable route.

On the basis of the findings from our work, we recommend that for the design of the next generation of SIA tools, an approach based on a Bayesian Belief Networks would be of value. A BBN modelling approach would allow the logic of the current SIAT framework to be presented more clearly, and the idea of an SCS to be represented more completely in terms of the uncertainties involved.

7.4. SCS validity and users feedback

The validity of the SCS framework, together with the advantages and disadvantages of using SIA tools currently available, were also discussed in a dialogue with users during a workshop, as described in section 6. Users were asked to discuss how SCS and SIA tools can support decisions with regards to regional impacts of land uses changes and policy effects on sustainable development. The main points raised from this discussion were mostly underlying the importance of considering the various dimensions and the different scales of the assessment, as described in point (iv) above. Users reiterated the diversity that exists within Europe at various levels (geographical, social, economical, environmental) and endorsed modelling frameworks which would enhance this kind of analysis in a transparent way.

The findings are in accordance with those described earlier through the piloting of the BBN and the implementation of the SCS functionalities in SIAT, and include issues of a) clarity and transparency of assumptions, b) ability of indicators and aggregated indicators to cover different scales of the assessment, c) reliability and sustainability of the models, especially in terms of plausibility, d) inclusion of uncertainty of the outcomes, e) creation of an analytical space to facilitate the identification of trade-offs and the subsequent discussion, f) inclusion of the deliberative-participatory process in the modelling chain.

The Sustainability Choice Space represents a possible framework for these kinds of analyses to take place, particularly in consideration that the value that these models seems to reside in the process of debate and discussion that is generated and stimulated by the use of these tools. In particular, allowing stakeholders' participation can facilitate problems learning and ownership.

In summary, the discussion of the above-mentioned points highlighted the following main areas for development under the SCS framework:

1. The necessity to including ways of measuring data and processes **uncertainty**, as well as **outcomes sensitivity**, in the modelling framework;
2. The significance to allowing **stakeholders' engagement** in the SIA process, whose opinions and preferences, also in monetary terms, can feed into the modelling framework;
3. The need to build (model) functionalities to allow the sustainability trajectories to be followed within the scenarios assumptions, in time, space and under variable limits and scale.

Even though not all the objectives of the SENSOR project will be met, the questions arising from the various modules and the work packages are extremely valid and could lead to further developments for SIA frameworks and tools. It is perhaps safe to say that the hope of the project' participants is that the ideas and concepts developed will continue to be improved and complemented. The same is true for the concepts related to the SCS and the various frameworks that this includes.

However, both the construction of the pilot FoPIA-BBN and the implementation of SCS functionalities in the modelling framework have confirmed how the ideas developed under the SCS framework can clearly be used to describe how alternative policy outcomes are acceptable to stakeholders across a range of criteria defined by the suite of indicators that are driven by land use change, and how these information can be sieved and amalgamated to support the decision-making process.

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Appendix I – A brief introduction to Bayesian Belief Networks

A Bayesian Belief Network, also called a **BBN**, is a mathematical model normally presented in a graphical way where each variable is displayed as a node with the directed links forming arcs between them (Fig. 19 and Box 7.1). The model is based on probability theory implementing Bayes' theorem (after Reverend Thomas Bayes, 1702–1762) of probability so that the information content of each variable is represented as one or several probability distributions. This rule shows mathematically how existing beliefs can be modified with the input of new evidence.

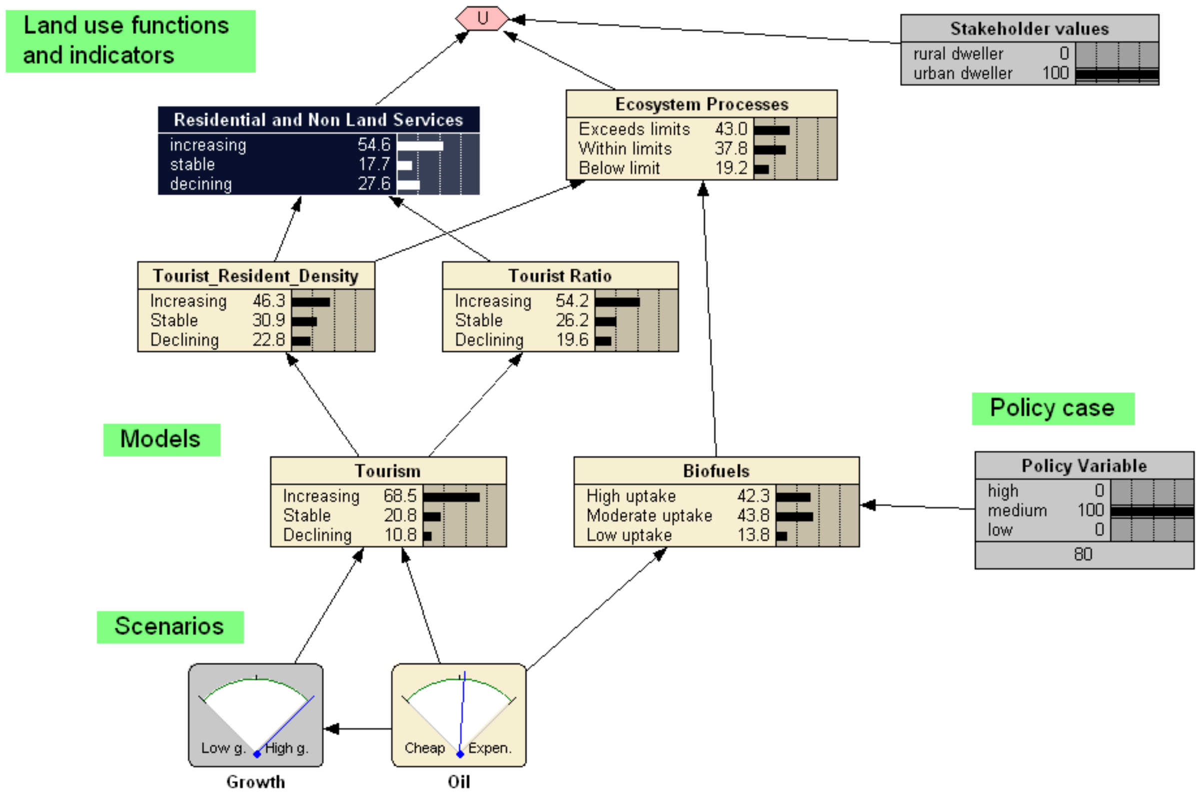

Figure 19. Example of a Bayesian Belief Network showing a simple SIAT-SENSOR model.

Box 7.1: Bayesian Belief Networs, a 'snapshot'.

BBN are composed of three elements:

1. A set of nodes representing system variables, each with a finite set of mutually exclusive states. These variables can represent environmental, social, or economic factors.
2. A set of links representing casual relationships between these nodes.
3. A set of probabilities, one for each node, specifying the belief that a node will be in a particular state given the states of those nodes which affect it directly (its parents). These are called **conditional probability tables** (**CPTs**) and can be used to express how the relationships between the nodes operate.

Elements 1 and 2 together form a BBN flow diagram (**directed acyclic graph**) while the addition of element 3 creates a fully functioning BBN.

BBN can present the following types of nodes:

Nature node - A *nature node* represents some variable of interest that in a decision network cannot be directly controlled by the decision maker (i.e. it is determined by nature). If a nature node has a functional relationship with its parents, it is called a *deterministic node*, whereas if the relationship is probabilistic, it is called a *chance node*.

Utility nodes - A *utility node* (also known as a "value node") is a node in a decision network whose expected value is to be maximized while searching for the best decision rule for each of the decision nodes.

Decision nodes - A *decision node* is a node in a decision network which represents a variable (or choice) under the control of the decision maker. When the net is solved, a decision rule is found for the node which optimizes the expected utility.

The probabilistic presentation of the interactions is one of the key points of BBNs (Reckhow, 1999), and it allows for the estimation of risks and uncertainties better than models that only account for expected values. The probabilistic presentation of knowledge also prevents overconfidence in the strength of responses obtained by manipulating certain parts of the system. This is an important improvement to deterministic models which may work well in theoretical examinations but remain fraught with uncertainty when applied to problems with real data (Wikle, 2003).

BBNs organise the body of knowledge in any given area by mapping out **cause-and-effect** relationships among key variables and encoding them with numbers that represent the extent to which one variable is likely to affect another (Jensen, 2002). Furthermore, by using Bayes's theorem, BBNs can calculate not only the probability distributions of children (nodes) given the values of their parents (nodes), but also the distributions of the parents given the values of their children. That is, one can proceed not only from causes to effect, but also deduce the probabilities of different causes given the consequences.

Factors, associations and probabilities can be adjusted and validated as BBNs are powerful for integrating data and knowledge from different sources and domains, as well as being capable of handling uncertain information in a practical and understandable way (Henriksen et al., 2004; Jensen, 2002). Very often environmental data often include missing values, since problems in sampling may mean that some unique event or point in time is missed. However, a very useful aspect of BBNs is that there are no minimum sample sizes required to perform an analysis, and BBNs can show good prediction accuracy even with rather small sample sizes (Kontkanen et al., 1997).

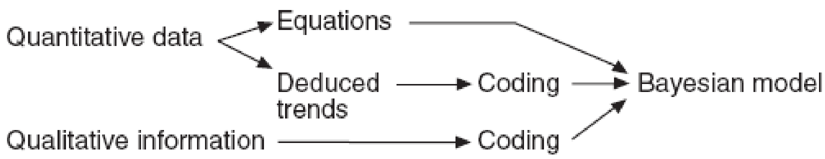

Figure 20. Possible input for a Bayesian network (after Baran et al., 2006)

Furthermore, BBNs can combine different types and sources of knowledge, using prior information. Priors reflect our knowledge of the subject before the research is conducted, and can be either highly informative and detailed, in case there is a lot of knowledge about the subject already, or very uninformative, if not much is known.

These priors are then updated with data, to obtain a synthesis of old knowledge and new data. This synthesis can then be used as a prior in a new study. This mechanism makes the scientific learning process explicit, and also makes the assumptions made by the scientists transparent and open to discussion.

Bayesian network models also have the advantage that they can easily and in a mathematically coherent manner incorporate knowledge of different accuracies and from different sources. Expert knowledge can be combined with data (Marcot et al., 2001) regarding variables on which no data exist. Data measured on different levels of accuracy (e.g. absence/presence and quantity data) can be also combined.

In environmental research as well as in many other fields, data and parameters often have continuous values. Bayesian networks can, however, deal with continuous variables in only a limited manner (Friedman and Goldszmidt, 1996; Jensen, 2001, p. 69). The usual solution is to discretize the variables and build the model over the discrete domain. There is a trade-off, however, as the discretization can only capture rough characteristics of the original distribution (Friedman and Goldszmidt, 1996), and we may lose statistical power if the relationship between the variables is, in fact, linear (Myllymaki et al., 2002). On the other hand, we gain the ability to use the reasoning machinery of BNs, which is especially efficient if the relationships between the variables are non-linear and complex (Myllymaki et al., 2002).

Bayesian networks are used for the analysis of data and expert knowledge especially in fields that are fraught with uncertainty, since they make it possible to treat uncertainty explicitly.

They are also used to create “expert systems” that model and include expert knowledge about a complicated domain and can also be supplemented with decision support tools (Jensen, 2001), which are a natural addition to the ability to treat uncertainty in the first place. For a comprehensive introduction to these systems see Uusitalo (2007).

BBNs have gained a reputation of being powerful techniques for modelling complex problems involving uncertain knowledge and impacts of causes and are increasingly used as **decision support systems**. BBNs are especially helpful when there is a scarcity and uncertainty in the data used in making the decision and the factors are interlinked, all of which makes the problem highly complex. This is done by using the probability as a measure of uncertainty: Beliefs about values of variables are expressed as probability distributions, and the higher the uncertainty, the wider is the probability distribution. As information accumulates, knowledge of the true value of the variable usually increases, i.e. the uncertainty of the value diminishes and the probability distribution grows narrower (Gelman et al., 1995; Sivia, 1996).

BBN are increasingly used as adaptive management tools with the involvement of stakeholders in participatory integrated assessments. In resource management, for example, BBNs have been used in a broader decision-support framework, as conceptual or computer based tools that collectively facilitate the decision-making process (Cain, 2001). Cain et al. (1999) emphasised the utility of BBNs to facilitate stakeholder participation in resources management planning and decision processes.