Dissertationes Forestales 168

Sustainability assessment of forest resources – tools for a problem-orientated approach

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Academic dissertation

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ABSTRACT

Various methods and tools have been applied to assess the sustainable use of forests and other natural resources. However, interpretation of generated results is demanding, often leading to misleading conclusions. One solution to more advanced and transparent sustainability assessments is to combine quantitative and qualitative methodologies (hybrid approach). Qualitative methods could be used to structure the problem, whereas quantitative tools could be assigned to attain numerical information on the rankings of the alternatives.

As a result of sub-study I, it could be stated that hybrid approaches appear to be the most suitable methods to assess sustainability. In sub-study II, qualitative mapping technique and Multi-criteria analysis (MCA) were applied to identify and to rate cultural sustainability indicators for comparing four alternative wood-based bioenergy systems. The interviewed experts identified 49 indicators, but the transition phase between methods should be more coherent. In sub-study III, MCA and Life cycle assessment (LCA) were applied for comparing raw materials of pulp and biodiesel. The global biomasses received smaller environmental impact scores than local biomasses. However, it is possible that if biodiversity impacts could be included, the results would favour locally produced raw materials. In sub-study IV, different weighting techniques commonly used in MCA were applied for assessing the environmental impacts of alternative house types. The ranking of houses was highly dependent on the weighting technique and aggregation rules behind them.

The main result of this thesis is that sustainability can be assessed with various tools, but there are several methodological and behavioural challenges. There was some evidence of benefits of mixing quantitative and qualitative methods, but more attention should be focused on how the methods are tied together. A more problem-orientated approach for sustainability assessments, with active involvement of stakeholders, would alleviate the process in terms of transparency, operability and acceptability.

Keywords: criteria and indicators, life cycle assessment, multi-criteria analysis, problem structuring methods, sustainable development

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Joensuu 13.10.2013
Tanja Myllyviita

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on data presented in the following articles and manuscripts, referred to by the Roman numerals I-IV. The articles are reprinted here with the permission of the publishers.

I Myllyviita T., Hujala T., Kangas, A. & Leskinen P. 2011. Decision support in assessing the sustainable use of forests and other natural resources: A comparative review. The Open Forest Science Journal 50: 24-41.
doi: 10.2174/1874398601104010024

II Myllyviita T., Lähtinen K., Hujala T., Leskinen L., Sikanen L. & Leskinen P. Identifying and rating cultural sustainability indicators: a case study of wood-based bioenergy systems in Eastern Finland. 2013. Environment, Development and Sustainability. In print.
doi: 10.1007/s10668-013-9477-6

III Myllyviita T., Holma A., Antikainen, R., Lähtinen, K. & Leskinen, P. 2012. Assessing environmental impacts of biomass production chains - application of life cycle assessment (LCA) and multi-criteria decision analysis (MCDA). Journal of Cleaner Production 29-30: 238-245.
doi: 10.1016/j.jclepro.2012.01.019

IV Myllyviita T., Leskinen P. & Seppälä, J. 2013. Impact of normalisation, elicitation technique and background information on weighting results in life cycle assessment. International Journal of Life Cycle Assessment. In print.
doi: 10.1007/s11367-013-0645-6

The author was responsible for data collection and completed the analyses of the data in all sub-studies. She participated in designing the sub-studies along with the co-authors. The author was the main writer in all sub-studies.

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LIST OF ABBREVIATIONS

3CM	Conceptual Content Cognitive Mapping
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
CBA	Cost-Benefit Analysis
CHP	Combined Heat and Power
CM	Cognitive Mapping
C&I	Criteria and Indicators
DSS	Decision Support Systems
ISO	International Organization for Standardization
ITTO	The International Tropical Timber Organization
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
MAUT	Multi-Attribute Utility Analysis
MCA	Multi-Criteria Analysis
MCDA	Multi-Criteria Decision Analysis
NGO	Non-Governmental Organization
OR	Operational Research
PSM	Problem Structuring Methods
SMART	Simple Multi-Attribute Rating Technique
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNCED	United Nations Conference on Environment and Development

1 INTRODUCTION

Sustainable use of natural resources is challenged by various environmental, economic and social demands, which are often conflicting (Vierikko et al. 2008). For example, utilisation of wood for energy has been considered sustainable (Huttunen 2012) since it is expected to be economically feasible, socially acceptable and positive ecological features are also anticipated. However, when closer assessment is completed, the sustainability of wood-based energy can be questioned. For instance, the economic feasibility of harvesting raw material, at least without subsidies, is not always achievable (Petty and Kärhä 2011). Also, the assumed positive social impacts are negligible if the generated jobs are merely seasonal vacancies with minimal wages (Ministry of employment and the economy 2010). Finally, the climate change impacts of wood-based bioenergy may not equal to zero if the time frame of the emissions is elaborated (Cherubini et al. 2011). Therefore, sustainability cannot be based on assumptions, but it needs to be carefully evaluated considering all the dimensions of sustainability with suitable criteria and indicators (C&I) of sustainability.

Decision Support Systems (DSS) and other less formal methods, tools and approaches can bring a much needed structure to sustainability assessments (Mustajoki et al. 2011; Jalilova et al. 2012; Lindner et al. 2010; Myllyviita et al. 2013; Wolfslehner et al. 2005). However, different methods, even in cases where the same datasets are applied, may lead to different results (Özdemir et al. 2011). Particularly quantitative methods, which generally summarize sustainability into one-dimensional indexes, may induce suspicion, since it is not clear how the indexes are actually aggregated and what are the possible uncertainties and assumptions behind them (Gasparatos et al. 2008). Policy makers, company managers, consumers and other users of sustainability indexes should be aware of the assumptions behind the indexes and understand their limitations (Mayer 2008). Therefore, modifying methods to better fit the actual case studies and enhancing transparency have become much discussed topics in the fields of decision analysis and operational research (OR) (Rosenhead and Mingers 2001).

1.1 Paradigm of sustainable development

The sustainable development has become a dominant paradigm since the 1970's. However, a shift to the sustainable development has not been straightforward, and the process is still on-going. The problems related associated with shifting to sustainable development are related not only to how to operationalize sustainability but also to the actual meaning of the concept.

1.1.1 Sustainable development – definitions and dimensions

Sustainable development has been first described in detail in the famous report by Brundtland Commission (1987), where sustainability has been identified as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." However, sustainable development has been given various other definitions and interpretations (Pezzoli 1997; Glavič and Lukman 2007), leading to situations where it is not clear what is actually meant by "sustainability" in that particular case. Also, contradictions in the concept have been noted by several authors (e.g. Bell and Morse 2003) as it comprises of two conflicting dimensions, i.e. something to develop (to change) and to sustain (to maintain).

Because of the vagueness of the concept, institutions can claim their businesses are sustainable although the actual state of their businesses may be far from it (Jacobs 1999). It is questionable to automatically call businesses "sustainable" if only climate change impacts are minimized. A more holistic approach to sustainability should include various environmental aspects as well as economic and social issues (Pezzoli 1997). As discussed earlier, there are numerous definitions and interpretations for sustainability, therefore it is not surprising that several definitions for the dimensions of sustainability are also presented. The following definitions for the dimensions of sustainability are given by Gilbert et al. (1996). Economic sustainability occurs when development which moves towards social and environmental sustainability is financially feasible. Social sustainability is considered to be the cohesion of society and its ability to work towards common goals. Furthermore, personal needs such as health and well-being, nutrition, shelter, and education should be provided. Securing environmental sustainability requires that natural capital remains intact by minimizing the utilisation of non-renewable resources. Furthermore, cultural sustainability is presented as the fourth pillar of sustainability. In the UNESCO (2001) declaration on the topic, culture is regarded as ‘distinctive spiritual, material, intellectual and emotional features of society or a social group […] that […] encompasses, in addition to art and literature, lifestyles, ways of living together, value systems, traditions and beliefs’.

From a practical point of view, including the most relevant indicators in a sustainability assessment is more relevant than how the indicators are divided into the four (or more) dimensions of sustainability. However, from a behavioural perspective, acknowledging the cultural dimension, for example, as the fourth dimension of sustainability will most evidently put more weight on the cultural issues, compared to a situation where few cultural sustainability indicators are included under the concept of social sustainability. Furthermore, because sustainability indicators are often interlinked, concepts like socio-cultural and socio-economic can be applied (Rantala et al. 2012).

Different dimensions of sustainability may have congruent impacts on sustainability, e.g. using raw-materials efficiently is typically economically feasible but also environmentally reasonable (Pezzoli 1997). Still, often different dimensions of sustainability are contradictory, for example when economic sustainability is guaranteed but social sustainability is endangered. An example of this kind of contradictory cases would be companies that do not acknowledge the needs or the cultures of locals. Especially forest industries have regularly faced challenges like these in developing countries (Pakkasvirta 2008). Another example is forest management conflicts in Finland (Raitio 2012). The forest management in Finland has been considered sustainable, since annual removal has been smaller than annual growth. However, especially NGOs have criticized Finnish forest management for harvesting old-growth forests. The conflicts have even culminated into "forest wars". However, it has been demonstrated that with suitable problem structuring techniques and facilitation along with advanced decision support tools, different stakeholders are willing to make compromises (Mustajoki et al. 2011).

Besides different perceptions of the meaning of sustainability, there are different perceptions of the relative importance of the dimensions of sustainability. Before the concept of sustainability was ceremonially established, the economic sustainability was arguably the most advanced dimension of sustainability. Economy was considered the basis for the other two dimensions of sustainability, as portrayed in the "Mickey Mouse" model for the sustainable development (Figure 1) (e.g. Mann 2011). This is supported, for example, by the phenomenon of sustainable yield having been widely applied as an indicator of sustainable wood harvesting and fishery (e.g. Bell and Morse 2003). From a methodological point of view, this kind of sustainability assessment could be actualised by maximizing the economic profits and setting the other two dimensions as constraints. After the major environmental catastrophes such as ozone depletion and climate change in the last decades, attention has been shifted to the ecological dimension of sustainability. It has been anticipated that nature sets limits for the other two dimensions of sustainability and therefore it should be considered the very basis of sustainability (Ott 2003; de Carvalho 2011). Consequently, the other two dimensions of sustainability are achievable only after the ecological sustainability is secured, as portrayed in the "Russian doll" model for sustainability (O’Riordan et al. 2001) (Figure 2). Social sustainability is less established as a dimension of sustainability, however ensuring equity, removing poverty and famine, and an overall wellbeing of humankind have been set as fundamental objectives in order to attain sustainability (UNCED 1992). Interactions between the dimensions of sustainability are recognized in Venn diagram (Figure 3) (e.g. Mann 2011), where sustainability is achieved only by securing all three dimensions of sustainability.

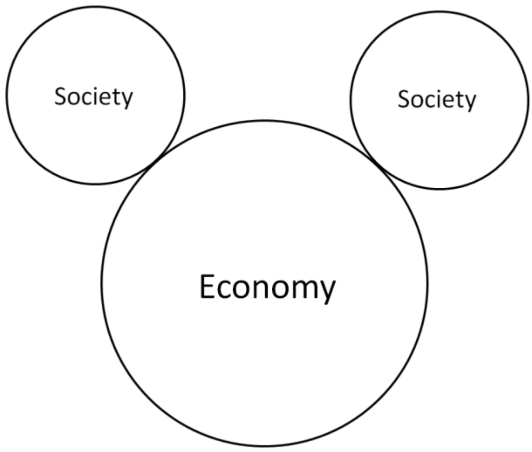

Figure 1. "Mickey Mouse" model for sustainable development (e.g. O'Riordan et al. 2001), where the environment and society depend largely on the economy.

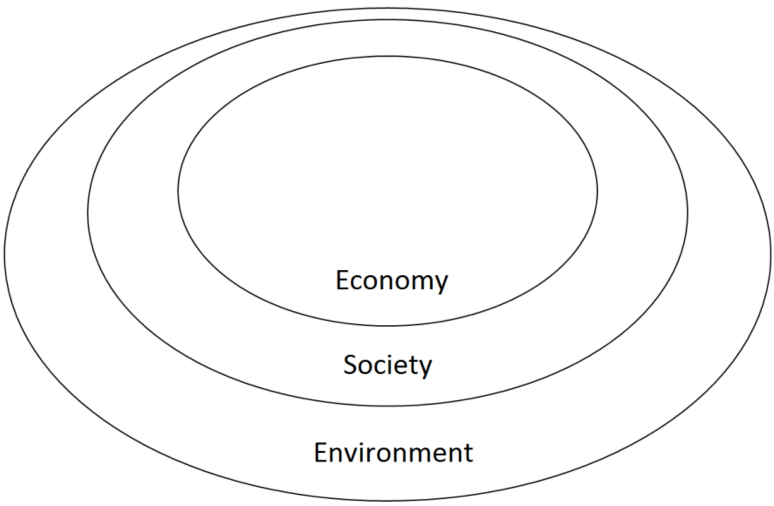

Figure 2. "Russian doll" model for sustainable development (e.g. O'Riordan et al. 2001). Economic capital is at the basis of wealth creation, constrained by the environmental and social dimensions.

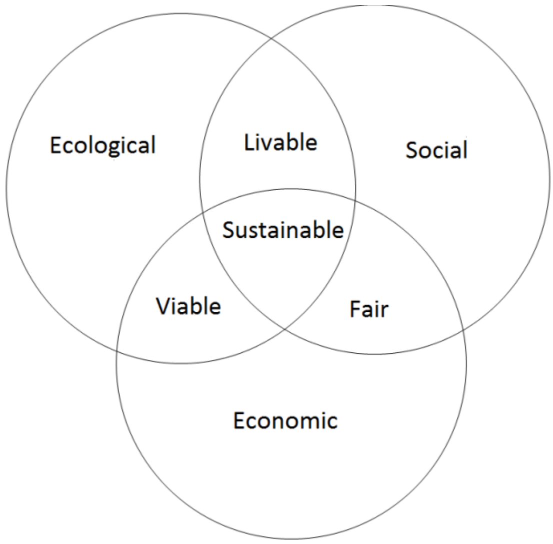

Figure 3. Venn diagram for sustainable development (e.g. Mann 2011).

Besides the relative importance of the dimensions of sustainability, possible trade-offs between different dimensions of sustainability is an important topic (e.g. Figge and Hahn 2012). Trade-offs may be found even within one dimension of sustainability, i.e. a product with positive climate change impacts may have negative consequences on biodiversity. The concept of weak sustainability allows compensation between different sustainability indicators (Neumayer 2003). For instance, a bad performance with respect to climate change can be compensated by building man-made capital or donating money to save endangered species. The concept of strong sustainability, however, does not allow compensation. Methods which do not allow compensation support the concept of strong sustainability (Polatidis et al. 2006). To implement strong sustainability, threshold values should be defined for the sustainability criteria (Martinet 2011). However, knowledge related to the threshold values of most of the sustainability indicators is still limited.

1.1.2 Criteria and indicators (C&I) of sustainable development

The criteria and indicators (C&I) of sustainable development are tools that are regularly used to assess and measure the state and trends of sustainability. A criterion is a category of conditions or processes with which sustainability can be assessed, whereas an indicator is a measure of an aspect of the criterion (Wijewardana 2008; Prabhu et al. 1999). C&I have become customary tools for assessing sustainability. C&I for sustainable development have been defined, with immense investments of time and effort, in national (ITTO 1998; Forestry Working Group 1995), regional, and local processes (Fraser et al. 2006; Mrosek et al. 2011; Jalilova et al. 2012). Identifying sustainability indicators should not be considered only a scientific "knowledge production" but also a political "norm creation" (Rametsteiner 2011).

C&I can be identified via bottom-up or top-down processes. In bottom-up processes, the perceptions of locals and other stakeholders are incorporated (e.g. Fraser et al. 2006), whereas in top-down processes the indicators are defined during political processes (e.g. European commission 2007). The problem in bottom-up processes is that the generated C&I may not be suitable for comparing different regions, since they may be relevant only for local uses. On the contrary, in top-down processes the generated C&I are likely to be suitable for comparative sustainability assessments, but the local circumstances may be ignored. Depending on the purpose and the scale of the sustainability assessment, bottom-up or top-down approach, or a combination of these two, can be recruited.

Indicators are often divided into quantitative and qualitative variables. Indicators of economic and ecological sustainability are often quantitative in their nature, whereas social and cultural sustainability indicators are more often qualitative (Myllyviita et al. 2013). Quantitative indicators are easier to process and evaluate than qualitative indicators (Lindner et al. 2010). However, besides measuring sustainability, sustainability indicators are applied to other purposes, as well, such as to support learning (Rosenström 2009). Problems related to quantifying social and cultural sustainability indicators are presumably the reason for the scarcity of social and cultural sustainability indicators in sustainability assessments.

Criticism on the C&I and the processes they have been identified with has emerged. There is little evidence on the actual utilisation of C&I in decision-making because of problems related to, e.g. the irrelevance of the indicators for the policy needs, technical shortcomings in the context and presentation, lack of user participation in the development process, non-existent dissemination strategies, and the lack of updating and promoting indicators (Rosenström 2009). Furthermore, impacts of C&I on policy development seem to be minimal (Walsh 2011). One solution to increasing the usability of C&I is to associate them with methods and tools that are commonly used to assess sustainability.

1.2 Methods, tools and approaches supporting sustainability

Sustainability has turned out to be a demanding concept to be measured with traditional tools and methods (Hector et al. 2009; Kunsch et al. 2009; White and Lee 2009). Optimisation methods have been used in sustainability assessments, but in most cases the focus is on the maximization of the profits, and other sustainability aspects are used as constraints (Eid et al. 2002). Multi-objective optimisation techniques (e.g. Eyvindson et al. 2010) could be applied to assess sustainability in a more unbiased manner.

Monetary valuation methods are another example of a group of methods that can be used to assess sustainability. Using money as a basis for measuring sustainability has received both support and opposition. Supporters consider money a suitable basis for sustainability assessments, since it is easy to interpret even by laymen, comprehensive to measure, and reveals not only the preference but also the intensity of the preference (Gasparatos et al. 2008). Monetary valuation methods have been criticized, because they have been considered ethically questionable and to include significant uncertainties and challenges related to the generalization of studies (Gasparatos et al. 2008).

Life cycle assessment (LCA) is a method that aims to analyse the environmental impacts of a product or a service from cradle to grave (ISO 1997). Although LCA has traditionally focused on environmental impacts, there has been progress to include economic and social values in a standard LCA, as well (Jeswani et al. 2010). LCA is regulated by the ISO standards (ISO 1997). LCA includes several mandatory phases (according to ISO standard), but several optional phases can also be implemented (Figure 4). The system boundaries are defined during a goal and scope definition. A functional unit, for which the impacts are being aggregated, is also chosen. The functional unit is an important basis for the comparative studies of alternative products. The functional unit could be, for example 1 MWh, or one laptop computer. During the goal and scope definition the impact categories are also selected. Impact categories are mainly environmental hazards, which are caused by manufacturing the product and raw materials, and all life-cycle phases of a product. Various impact categories such as climate change, acidification, and toxic emissions can be included in LCA. During inventory analysis the data on these impacts are aggregated. For instance, climate change impacts of a product are revealed by surveying all greenhouse gases emitted during a life-cycle of a product. After all impacts have been surveyed, outputs with similar impacts (e.g. carbon dioxide and methane are both included into climate change impact category) are characterised, i.e. they are transformed into one parameter based on their harmfulness. Each substance has a characterisation factor which they are multiplied with. In the impact category climate change, for instance, the carbon dioxide is multiplied by 1, whereas much more harmful methane is multiplied by 25. Several impact assessment methodologies are available for these phases, for example Eco-indicator, ReCiPe and CML2001. After characterisation, it is possible to continue to normalisation and weighting (which are optional phases) or continue to the next mandatory phase, i.e. conducting a sensitivity analysis. If the optional phases are actualised, the characterised scores can be externally normalised (Figure 4). External normalisation relates the characterised scores to a certain reference value, e.g. the total emissions of a certain geographical area in a specific time period. For instance, after external normalisation it could be stated that the product is responsible of 4% of one average European citizen’s yearly climate change impact, but only 1 % of acidification. External normalisation factors are available for European countries (Sleeswijk et al. 2008), Canada, and the United States (Lautier et al. 2010). After external normalisation, the impact categories can be weighted (i.e. their importance in relation to each other is determined) and a single score can be calculated based on the weighted scores (Figure 3).

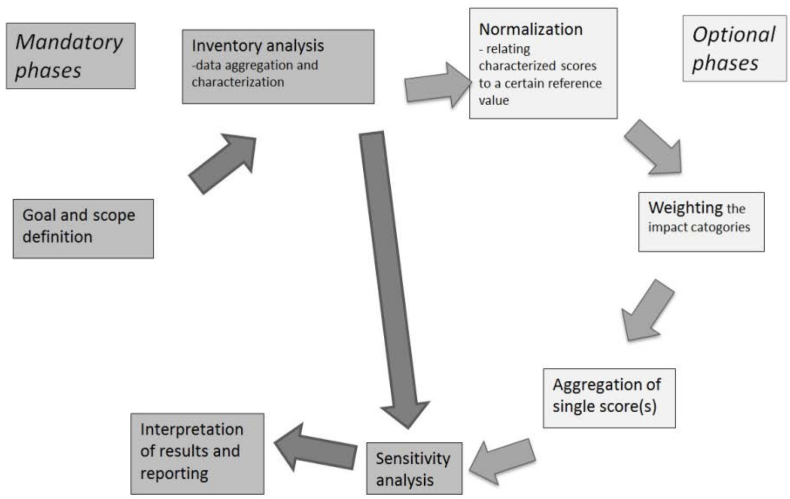

Figure 3. Phases of LCA: there are both mandatory and optional phases (ISO 1997).

Based on the single scores, it is possible to make comparative studies. Along with normalisation, weighting is an optional phase of LCA. Because of the subjectivity of weighting it has not been recommended for the comparative analyses aimed for the general public (ISO 1997). When MCA is applied in LCA to aggregate a single score, so-called internal normalisation is actualised (Norris 2001). In internal normalisation based on MAUT, a single score can be conducted according to the weighting obtained from two extreme options within the LCA study (e.g. Seppälä and Hämäläinen 2001). Internal normalisation can be actualised with other MCA-methods, as well, but the weighting techniques are different compared to the ones used in MAVT. The final phase of LCA is the interpretation of the results and reporting.

Multi-Criteria Analysis (MCA) (or Multi-Criteria Decision Analysis (MCDA)) is a family of methods which help decision-makers to identify and select preferred alternatives when faced with a complex decision problem characterised by multiple objectives (Belton and Stewart 2002; Von Winterfeldt and Edwards 1986; Keeney and Raiffa 1976). MCA is based on preference measuring, i.e. the decision-maker is able to state whether they prefer option A or B and the strength of his/her preference (in the case of utility-based, discrete MCA-methods). Both qualitative and quantitative decision criteria may be included.

Belton and Stewart (2002) present three phases that are typical for a decision problem solved with MCA: 1) problem structuring, 2) model building, and 3) using the results to support the decision-making. 1) During the problem structuring phase, the relevant aspects are identified and the overall purpose and goal are defined. 2) The model building phase focuses on defining the decision criteria and determining the relative importance or value attributed to each criteria (=weighting). The performance of decision alternatives is aggregated by using information on the decision criteria and the generated weights. 3) Finally, the critical phase is to learn what kind of conclusions can be drawn based on the results and how they influence the decision-making. Often it is highlighted that MCA should not be used to rank alternatives but to discuss and learn about the actual problem (Belton and Hodgkin 1999).

MCA methods can be categorized into discrete and continuous methods (Kangas et al. 2008) and discrete methods furthermore into elementary, outranking, Multi-Attribute Utility Theory and other methods. In discrete methods there are a definite number of alternatives and the superior is the one with the highest utility or value (Fig. 4). Multi-attribute utility/value theory (MAUT/MAVT) was one of the first MCA methods (Keeney and Raiffa 1976). In MAVT various criteria are transformed into a single utility or value to enable the comparison of decision alternatives. The difference between MAUT and MAVT is that MAUT takes uncertainty into account while MAVT does not. However, MAUT is challenging to apply and therefore real-life applications are scarce. Besides the MCA methods applied in this thesis (which are all discrete, utility theory based methods), there are several other MCA methods that could be suitable for sustainability assessments, as well. MCA methods differ in the way the idea of multiple criteria is operationalized, therefore it is not possible to go into the details of each method. For a more comprehensive review on MCA methods, see Diaz-Balteiro and Romero (2008).

All the methods discussed above are considered to support the reductionistic approach to sustainability. In the reductionistic approach various aspects are generalized and simplified, often resulting in one-dimensional sustainability indexes (Gasparatos et al. 2008). Therefore, it seems that sustainability cannot be extensively assessed by using only traditional, quantitative decision support tools.

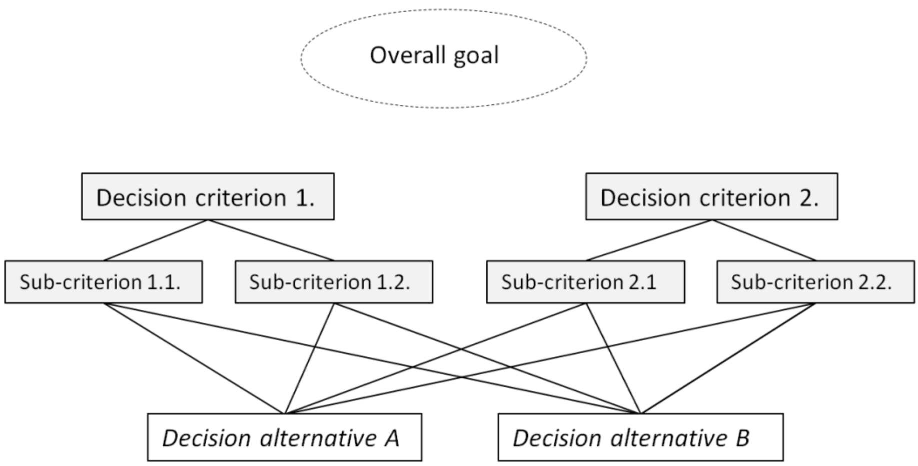

Figure 4. Structure of a discrete decision problem solved with MCA.

Problem Structuring Methods (PSM) is a group of methods that aim to assist to structure the actual problem well, rather than trying to solve it (Rosenhead 1996). These methods would be beneficial in sustainability assessments where the problem itself, decision criteria, and decision alternatives are difficult to define. One problem of PSM is that the processes may become lengthy and require skilled facilitators (Khadka et al. 2013). However, skilled facilitators may not be available and there are often limitations related to time-usage, as well (Hjortsø 2004). Furthermore, there are no clear instructions on how PSM should be correctly used, therefore using PSM may be challenging, especially for the first time.

PSM have received a two-fold reception in the field of Operational Research (OR). Some appreciate the problem-orientated approach and consider PSM a suitable tool for wicked, ill-structured decision problems (Rosenhead 1996), whereas others argue that PSM do not have a structured framework or any scientifically proven basis (Finlay 1998).

One of the most ambitious objectives in the field of OR has been combining PSM and more traditional, quantitative decision support tools. Although the idea of such hybrid-approach has been much discussed (Ackermann et al. 1997; Belton and Stewart 2002; Munro and Mingers 2002; Johnson et al. 2007), the actual case studies focusing on practical implementation are limited (Howick and Ackermann 2011). This could be because the choice of the method(s) seems to be highly dependent on the experience and the interests of practitioners (Munro and Mingers 2002), therefore there is a limited number of practitioners with sufficient experience of the methods in both disciplines.

It is crucial to acknowledge that not only PSM but also other less formal tools and approaches could be suitable for the problem structuring phase (Khadka et al. 2013). Suitable tools could be the ones used in collaborative planning, for example cognitive maps (CM), questionnaires, stakeholder workshops, Delphi, SWOT (Strengths, Weaknesses, Opportunities, Threats) and facilitated interviews (Vacik et al. 2013).

Sustainable development is a promising theme for hybrid approaches since it is a multi-dimensional endeavour involving conflicting objectives (Hector et al. 2009). Also, in most sustainability assessments there is a need to somehow summarize the available information (into sustainability indexes, for example). The problem orientated approach to sustainability assessment highlighted in this thesis has similarities with the hybrid approaches: the actual problem is structured well with stakeholder involvement, but a structured analysis on the benefits and the limitations of different decision alternatives are also needed.

1.3 The aims and scope of the thesis

The thesis consists of four sub-studies (I-IV). The overall aim of this thesis was to review and to assess methods and tools suitable for assessing the sustainable use of forest resources and to develop the tools and the methods to better fit the demands of the case studies. The methods given more focus in this thesis are MCA and LCA, and the benefits of mixing these with other tools and methods are studied in detail. The aims are described more specifically below.

In sub-study I, it was assessed how different methods and other less formal tools are being applied to sustainability assessments and what are the benefits and limitations of each method. The methods and tools were analysed with carefully selected success criteria how different methods support sustainability. The reviewed articles applied one (or two) DSS or other less formal tool or approach.

In sub-study II, a hybrid approach was applied to identify cultural sustainability indicators for the four alternative wood-based bioenergy production systems in Finland. So far, cultural sustainability has been a much discusses topic, but the concrete measurements for it, at least suitable for the specific case study, did not exist. The aim of sub-study II was both to a) identify cultural sustainability indicators relevant for assessing the sustainability of the four wood-based bioenergy production systems and to b) test and further develop a hybrid approach.

Sub-study III focuses on the application of MCA in the context of LCA. The aim of the two-phased questionnaire was to detect if experts of LCA consider a standard LCA comprehensive and which environmental impacts are the most relevant when comparing two alternative biomasses. With the information obtained from the questionnaire along with the data retrieved from an LCA database, environmental impact scores for four biomass production chains were calculated, and the problems related to the aggregation of the data were analysed and discussed.

In sub-study IV, different MCA methods were applied in the illustrative LCA case study. In sub-study IV, it was assessed how different MCA methods influence the weighting process and the results.

2 DATA AND METHODS

2.1 Data

Data for sub-study I was obtained from the research literature. Altogether 35 articles were obtained from the reviewed journals in Science Direct database (www.sciencedirect.com) and Google (www.google.com). The articles were selected by first typing suitable search words and then reviewing the abstracts of the discovered journal articles. A few articles were found by surveying the reference lists of the suitable articles. The articles included in the final evaluations assessed the sustainable use of natural resources with a certain decision support tool(s) or other less formal tools or methods. The methods were: optimisation methods, monetary valuation methods, Cost-Benefit Analysis (CBA), MCA, and hybrid approaches.

In sub-study II, 12 experts of cultural sustainability living in Eastern Finland were interviewed to identify cultural sustainability indicators. The 12 experts have sufficient amount of knowledge of the culture of forestry and bioenergy production in Eastern Finland and of sustainability assessments. The experts were identified by surveying researchers' CVs and publications. Interviews were based on previously defined questions and a more conversational part. The predefined questions were related to the definition of cultural sustainability and linkages between social and cultural sustainability. In the more conversational part, the experts were requested to compare the four alternative bioenergy systems and to identify which factors are relevant for cultural sustainability. Experts identified 49 indicators of cultural sustainability for comparing four alternative bioenergy production systems relevant for the Northern Karelian and Finnish perspective. The same group of experts also rated the indicators according to their importance. The sub-study was accomplished in collaboration with a project titled 'Multidimensional sustainability framework to evaluate forest and wood energy production – BioSus' (Myllyviita et al. 2013).

Data for sub-study III was obtained from various sources. Data for calculating the environmental impacts of palm oil, rape seed oil, and pulp were obtained from Ecoinvent database (Frischknecht and Rebitzer 2005). External normalisation factors were obtained from the study by Sleeswijk et al. (2008). The environmental impacts were rated by 22 experts of the environmental impacts of biomass production. In sub-study III, the experts were from Finland and they had experience on life-cycle thinking. Most of the experts were researchers but some were managers in companies or representatives in NGOs. The two-phased questionnaire process was actualised in sub-study III. In the first phase, the experts of LCA were sent an electronic questionnaire including a list of impact categories of ReCiPe impact assessment method (Goedkoop et al. 2009) and a chance to include new impacts to the list. Furthermore, the experts weighted the impact with MCA. In the second phase questionnaire, the same group of experts was sent a list of all the impacts identified by the group of experts. Now the experts weighted all the impacts (both the ones in the ReCiPe method and the ones identified by the group of experts). The weights defined by the group of experts were applied to aggregate a single score for alternative production systems.

In sub-study IV, the impacts of the illustrative houses were aggregated based on the ReCiPe methodology (Goedkoop et al. 2009). External normalisation factors were obtained from the study by Sleeswijk et al. (2008). The environmental impacts were weighted by 26 experts from Nordic countries, who were approached with a web-based questionnaire. The experts were identified by studying a list of the participants in NorLCA symposium 2011 and recent publications applying LCA. In the questionnaire, the experts weighted three environmental impacts with six different weighting setups. In the beginning of the questionnaire, the experts were given a short description of the purpose of the survey and in the final page of the questionnaire they were able to give feedback with their own words.

2.2 Methods

2.2.1 Multi-Criteria Analysis (MCA)

Three MCA weighting techniques were applied in this thesis: The Simple Multi-Attribute Rating Technique (SMART) (Edwards 1977), (sub-studies II, III and IV), SWING (von Winterfeldt and Edwards, 1986) (sub-study IV) and Analytic Hierarchy Process (AHP) (Saaty 1977) (sub-study IV). SMART is one of the simplest weighting techniques commonly used in MAVT, where the decision-maker is requested to rank the decision criteria by first selecting the least important criterion and giving it 10 points, and then ranking all the other criteria in relation to the least important one. A similar modification was used in all three sub-studies where SMART was applied, i.e. the decision-maker was first asked to select the most relevant criterion (and to give this item 100 points) and then rank all the others in relation to the most relevant one. In SWING, the importance of the decision criteria was defined by evaluating the importance of having a criterion transfer from the worst level of the criteria to the best. The most important criterion (when considering the importance of the transfer from the worst value to the best) received 100 points, others in relation to this.

The original AHP (Saaty 1977) assesses the decision-makers' preferences of the criteria and the alternatives by using pairwise comparisons based on a nine-point preference elicitation scale. Since it has been noted that different decision-makers interpret the verbal judgements in a different manner (Huizingh and Vrolijk 1997), several modifications on the original 1-9 scale has been suggested (Dong et al. 2008). In sub-study IV, the AHP setup was based on 0-100 scale.

2.2.2 Life Cycle Assessment (LCA)

Life cycle analysis (LCA) was applied for sub-studies III and IV. In sub-study III and IV, the life cycle impact assessment (LCIA) of the alternative biomasses was based on ReCiPe-methodology (Goedkoop et al. 2009), which is one of the most applied methodologies for characterisation in LCA. However, the approach in sub-study IV, where only three environmental impacts are included, should not be considered a comprehensive LCIA but merely an illustrative, simplified example suitable for assessing the impacts of the weighting process. In both sub-studies the mandatory phases (i.e. normalisation and weighting) were actualised, but sensitivity analysis was not included. Therefore, sub-studies III and IV are not compatible with the ISO standard (ISO 1997).

2.2.3 Cognitive Mapping (CM)

In sub-study II, a modification of Cognitive mapping (CM) (Axelrod 1976) was applied during the expert interviews to identify cultural sustainability indictors. CM consists of nodes and arrows whose direction implies causality (Axelrod 1976). The basis of CM is in the personal construct theory of Kelly (1955), which emphasises how humans make sense of their world by seeking to manage and control it. In the sub-study a modification of the Conceptual Content Cognitive Map (3CM) (Kearney and Kaplan 1997) was applied. 3CM highlights the issues that the participant considers relevant (Kearney and Kaplan 1997). In the sub-study the expert was able to focus on brainstorming the problem while an interviewer wrote down the generated sustainability indicators on small paper tags. When it appeared that the expert could not come up with more indicators, the interviewer showed the indicators written on paper tags and reviewed their meaning. After the expert and the interviewer had reached an understanding on the meanings of the generated indicators, the expert was requested to group the generated indicators. However, linkages between the indicators (which are a part of a standard 3CM) were not assessed.

3 RESULTS

3.1 Methods, tools and approaches to sustainability assessments

The main result of this thesis is that sustainability can be assessed with various tools, but there are several methodological and behavioural challenges. It seems that a more problem-orientated approach would alleviate both technical and behavioural obstacles and improve overall transparency. Nevertheless, the subjectivity of sustainability assessments cannot be completely erased, since there are several value choices to be made.

In sub-study I, it was revealed how different DSS and other less formal tools and approaches support the sustainable use of natural resources. The assessment of 35 articles revealed that internationally and nationally defined C&I were not widely applied, since the C&I were frequently defined by stakeholders or the authors who had written the journal article. There were differences how the methods supported sustainability. In most of the case studies economic and ecological sustainability were included but social sustainability was not regularly considered, especially in case studies where optimisation methods were applied. In optimisation case studies the participation of stakeholders, experts and the general public was infrequent. On the contrary, in the monetary valuation case studies the participation of the general public was applied, but in a passive role. Experts and stakeholders with an active role were typical in MCA and hybrid case studies.

Based on the results of sub-study I, it could be stated that MCA could be a suitable method for assessing sustainability, because it allows the inclusion of C&I for sustainable development and the active participation of stakeholders. However, MCA does not provide efficient tools as such for the problem structuring phase. Therefore, the ideal method for assessing the sustainable use of natural resources could be a hybrid of two methods with different backgrounds.

In sub-study II a hybrid approach was launched. The hybrid approach was based on 3CM and SMART. The purpose of sub-study II was to identify indicators suitable for assessing the cultural sustainability of four alternative wood-based bioenergy production systems in Eastern Finland. The process was considered successful, since a sufficient amount of relevant cultural sustainability indicators was identified. The 3CM allowed mutual understanding between the expert and the interviewer. The application of the SMART weighting technique enabled to identify the most relevant indicators, which were later included to the sustainability assessment framework (Myllyviita et al. 2013). Feedback was obtained from the experts after the process was over. The modification of 3CM received mainly positive feedback from the experts, but some of the experts were not satisfied with the process where the indicators were weighted. Based on the feedback, more focus should be given on how the hybrid approach is accomplished. Especially the transition phase between methods should be coherent.

3.2 Integration of Multi-criteria analysis (MCA) into Life cycle assessment (LCA)

Sub-studies III and IV focused on integrating MCA into LCA. In sub-study III, the experts of LCA revealed several environmental impacts such as biodiversity that are not included in a standard LCA. The experts also weighted environmental impact categories based on their importance when comparing alternative biomass production systems. The climate change was considered the most important impact category followed by natural land-use change and biodiversity. It is interesting that biodiversity, although not being a part of a standard LCA, was considered one of the most important environmental impacts. Furthermore, some of the experts acknowledged in their feedback that biodiversity is important, but the land-use change already includes biodiversity aspects and to avoid double-counting, biodiversity should not be included in LCA as an individual impact category.

Only the impacts for which inventory data was available were included when aggregating a single score of the environmental impacts of the compared biomasses. The compared biomass production systems were Finnish rapeseed oil vs. Asian palm oil and Finnish birch vs. South-American eucalyptus. The comparison of the aggregation with external normalisation factors (Sleeswijk et al. 2008) and with internal normalisation (Norris 2001) showed that the results were similar with both aggregation rules in the case of biodiesel production systems (i.e. rapeseed oil and palm oil). In both aggregation rules palm oil received a slightly smaller environmental impact score (i.e. palm oil has a less negative environmental impact compared to rapeseed). In the case of pulp production chains (i.e. birch and eucalyptus) the two aggregation rules were not consistent. In both aggregation rules eucalyptus received a smaller environmental impact score, but in the case of external normalisation the difference to birch was larger than in the case of internal normalisation. Therefore, it seems that the normalisation may have a significant impact on the results.

In sub-study III, the global biomasses (i.e. palm oil and eucalyptus) received smaller environmental impact scores than local biomasses (rapeseed and birch). The phenomenon has been previously identified in several studies and is in most cases explained by a faster growth rate of the global biomasses (Thamsiriroj and Murphy 2009). Although biodiversity was considered an important impact by the panel of experts, it was not included in the quantitative assessments because of data deficiency. If such data would become available, the benefits of using local biomasses would probably become visible. Overall, based on sub-study III it can be stated that there are several methodological assumptions and value choices behind LCA that can highly influence the results. Therefore, more problem-orientated approach would be suitable for LCA, as well.

It was acknowledged during sub-study III that the weighting in the context of LCA has not been thoroughly assessed. Therefore, in sub-study IV, different MCA methods along with different weighting techniques (i.e. SMART, SWING and AHP) that are based on different scales (interval or ratio) were applied in illustrative construction examples. The single scores of alternative houses varied depending on which aggregation rule was utilised: when externally normalised scores were applied, house type A was superior in most of the calculations, however, when the characterised scores were applied, house type C was superior. House type A was superior only in the calculation methods where externally normalised scores were used. Based on the results of sub-study IV, it could be stated that the results (i.e. the ranking of the alternatives) are highly influenced by the aggregation method that is being used to calculate a single score. Therefore, it would be suitable to use several methods to calculate a single score and to assess possible inconsistencies and reasons behind them.

4 DISCUSSION

4.1 Problem-orientated approach to complex case studies

In this work the aim was to assess and to support complex case studies focusing on the sustainable use of natural resources with a problem-orientated approach. Various methods, tools and approaches were reviewed (sub-study I) and the most promising methods and tools were applied in three case studies (sub-studies II-IV). The purpose was to analyse what are the limitations and the benefits of using certain methods and tools and how the problematic features could be solved. In most cases, it seems that a more case study orientated approach and a mix of different methods would benefit the process, but there are still several challenges related to mixing methods. Problems are both technical and behavioural.

Assessing the sustainability of natural resources use has become more complex and multi-dimensional. Therefore, traditional tools and methods may not provide acceptable results. In the field of OR, the problem has been acknowledged and more problem-orientated tools, such as PSM, have been developed (Rosenhead and Mingers 2001; Rosenhead 1996). Still, actual case studies applying PSM in sustainable natural resource management seem to be infrequent (sub-study I; Khadka et al. 2013). However, advanced MCA processes include the problem structuring phase (Mustajoki et al. 2011; Nordström et al. 2011; sub-study II), although PSM is not applied. Therefore, it has become apparent that problem structuring can be actualised without the utilisation of PSM. Various other less formal tools have been successfully used in supporting natural resource management, for example stakeholder- and decision-maker interviews (Pykäläinen 2000; Mustajoki et al. 2011), workshops (Jalilova et al. 2012), and SWOT analyses (Kajanus et al. 2012). In most cases, these approaches are not acknowledged as problem structuring methods, or the term problem structuring is not used.

Problem structuring processes, even in their most advanced form, seldom lead to concrete conclusions or action plans. Often there are decision alternatives to be compared; however, without advanced calculation methods it can be difficult to assess which one of the decision alternatives is the superior. In most cases, there are no superior alternatives (sub-studies III and IV), therefore value choices on the importance of the decision criteria and the ranking of the decision alternatives in relation to the decision criteria are needed. Value choices have to be made because of the subjective nature of sustainability.

4.2 Subjectivity and values choices in natural sciences

In the field of social sciences, subjectivity and value choices have been well documented. On the contrary, subjectivity and value choices in natural sciences are much less discussed. Indeed, the subjectivity of natural sciences has been denied and natural scientists have actively defended their role as "pure truth seekers" (Hacking 1999). Nevertheless, any research, regardless of topic and methods, is always influenced by values. Personal values of the researchers will influence how the problem is framed, for example, whereas values of the society will influence which topics are favoured in terms of funding and resources. Therefore, there is always a subjective nature present. The tools and approaches discussed in this thesis (sub-studies I and II) could assist in the subjective phases of natural resource management problems and to make them more transparent.

One of the topics of this thesis was the weighting in LCA. The weighting has aroused great suspicion since it is not considered to be based on science but purely on value choices (ISO 1997). However, there are several other subjective value choices in LCA, such as defining system boundaries or selecting impact categories and an impact assessment method. A problem-orientated approach for LCA would enhance the transparency of the process. If the relevant impact categories would be identified by a panel (sub-study III), objectivity would be enhanced since an expert panel represents a wider view compared to the compilers of a case study. However, as it has been shown in sub-study III, there are problems related to the problem-orientated approach in LCA in terms of data availability and different perceptions and interpretations of the panellists. Comprehensive databases would alleviate the problems related to data deficiency.

Another significant finding of this thesis was that the methods itself will not automatically guarantee sustainability or any other goal. For instance, process relying on MCA may be inclusive and open-minded when it comes to different interpretations and perceptions of various stakeholders (Mustajoki et al. 2011), but it may just as well be a process to rank previously decided decision alternatives (Stirling 2006). Therefore, the way the methods and tools are applied is also important.

4.3 Characteristics of an ideal process for sustainability assessments

Based on the results of the case studies (I-IV) and the lessons learned from the literature and experience, the characteristics of an ideal process for assessing sustainability are presented. It is apparent that the framework includes weaknesses and simplifications with respect to real-life limitations (e.g. time and resources). However, the framework summarizes some of the shortcomings related to sustainability assessments and provides a platform to further develop sustainability assessment studies.

First of all, the concept of sustainability should be specified. Since the concept of sustainability itself is vague, it would be beneficial to define what is actually included in the concept of that specific sustainability assessment. Also, if the goal is merely to support only one dimension of sustainability (e.g. to cut down carbon dioxide emissions) without acknowledging the economic, social, cultural and other ecological aspects, as well, it is questionable to call the target "sustainability".

Various stakeholders whose participation and approval are necessities should be included (Sheppard and Meitner 2005). Possible stakeholders include decision-makers, researchers, policymakers, business managers, NGOs, and members of the general public, for example. Stakeholders can be identified by using expert opinions, focus groups, semi-structured interviews, snowball sampling, or combinations of these (Reed 2008).

It would be beneficial if the stakeholders were incorporated at an early state (Reed 2008), so it would be possible to modify the actual decision problem based on the feedback received from the stakeholders. If the stakeholders are merely used to accept the ready-made decision alternatives and criteria, true participation is not accomplished (sub-study I).

When a decision problem has been framed with a mutual understanding with stakeholders, the relevant decision criteria (e.g. indicators of sustainability) can be identified. Various tools may be used when defining the decision criteria, e.g. CM and modifications of it (sub-study II), SWOT-analyses (Kajanus et al. 2012), stakeholder interviews, questionnaires (sub-studies III-IV) etc. Several other tools, which may not have a PSM status, may be suitable as well. Especially the tools that the participants are already familiar with may turn out to be fruitful. The crucial observation of sub-study II is that the sustainability indicators are indeed context-specific. Therefore, a top-down approach in most cases will not be successful, instead a more problem-orientated (i.e. bottom-up) approach is needed. Another problem related to C&I is that too much effort is being invested on identifying C&I, but there is no discussion on how and where they will be used (sub-study I). Unfortunately, in many cases it seems that the generated C&I are defined without considering any specific application for them. One of the most common problems related to the utilisation of sustainability indicators is that there are no available data on them (Rosenström 2009). Nevertheless, the C&I should not be defined based only on data availability, because then relevant sustainability aspects may be ignored (Myllyviita et al. 2013). Furthermore, the acquisition of data on relevant sustainability indicators may be accomplished during the process, thus there is no need to rely solely on available databases.

All the above-mentioned phases should be considered a part of the problem structuring phase (Figure 3). In some cases, the conclusion may be reached within the problem structuring phase, especially if the decision problem is simple and no conflicts emerge. In a rare case where one decision alternative outperforms other decision alternatives without any uncertainty in all the decision criteria and in a way that is accepted by all stakeholders, further sustainability assessments may not be needed. Nevertheless, it cannot be stated that the alternative is "sustainable" since based on the comparison it is only possible to state that the alternative is the most sustainable one of the alternatives considered. Typically the problem structuring phase will not reach a conclusion, and tools for problem solving are needed. In most cases, problem solving refers to the ranking of the decision alternatives.

As it has been discussed in this thesis, there are several tools and methods suitable to support the quantitative ranking of decision alternatives. Only MCA and LCA have been more closely evaluated, however, the suitable tools can be monetary valuation methods or optimisation (sub-study I), for example. However, most of the problems are not caused by the use of certain types of methods but by the way those methods have been used (sub-study I). Therefore, a skilled facilitator who is also familiar with the method that is being used is a necessity. Furthermore, the method(s) should be selected based on their suitability on the case study, not based on the previous experiences of the facilitators.

Since the ranking of the alternatives is highly dependent on the method that is being used, the process of applying different methods is not described here in detail. However, regardless of the applied method, attention should be given on how the results will be presented. Furthermore, a simplification of the results in one-dimensional indexes, for example, may arouse suspicion. Therefore, the results should be presented in a way that the participants and stakeholders are able to detect how the analyses have been compiled.

Also, a sensitivity or uncertainty analysis should be actualised although this phase is not much addressed in this thesis. If the uncertainty analysis reveals significant sources of uncertainties, i.e. it cannot be stated based on the results which one is the superior decision alternative, it is advisable to return to earlier phases of the process and detect the major sources of uncertainties. The uncertainties should be assessed in a holistic manner, since the uncertainties related to input data represent only one source of uncertainties (Mattila et al. 2012). For instance, if the problem would be framed in a different manner (e.g. including also cultural sustainability, sub-study II), the results could be remarkably different.

The results should be presented to the participants in a transparent manner, including all sources of uncertainties. If it is apparent that the results are not accepted, modifications may be needed. For instance, two decision alternatives can be combined into one more acceptable decision alternative.

It is crucial to notice that sustainability assessments should always be considered a simplification of an actual decision problem. Therefore, the results should be used to make the decision problem more concrete and to learn more about it, not to reach conclusions (Belton and Hodgkin 1999). Even in cases where a conclusion is reached it is not always clear how the results will be used in actual decision-making, since recommendations for the actualisation of the results are not given or the recommendations are vague. However, even the most advanced sustainability assessments are meaningless from the perspective of non-scientists if the results are not applied or no action plan is generated. Therefore, it is suggested that an action plan is identified or suggestions are given on how the results could support real-life decision making.

Generic features of the process are iteration between the phases and the overall pervasiveness of problem structuring. The overall form and the scope of problem structuring are highly dependent on the process. In complex sustainability assessments, problem structuring in most cases is the most relevant phase and should be given more focus.

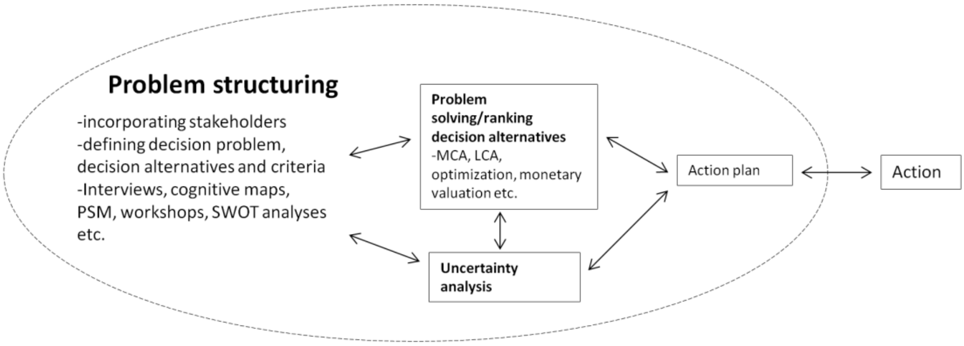

Figure 5. Characteristics of an ideal process for sustainability assessments: problem structuring can constitute most of the process. Iteration between the phases is another feature typical for the process.

4.4 Future research needs

Several research topics which have not been thoroughly assessed emerged during this thesis. Some topics, which would be relevant in the future, discuss a more advanced way of utilising sustainability indicators, developing a socio-cultural dimension in sustainability assessments and, finally, alleviating the subjective phases of LCA, especially weighting.

As it has been discussed in this thesis, a large number of different sets of sustainability indicators have been defined, but often without considering how and where they will be used. Therefore, the generated indicators may be irrelevant for actual case studies, or there are no abundant databases available. Therefore, it is suggested that more focus should be given on bridging the data-gaps related to sustainability indicators than on defining new ones. Also, the threshold values related to sustainability indicators have been discussed (Bertrand et al. 2008), but actual case studies are rare. Furthermore, cultural sustainability and the ways of measuring it (sub-study II) are not very well studied, although cultural values are highlighted in the literature (Chiesura and de Groot 2003; Parkins et al. 2001). Discussion about the importance of the concepts and the meanings of cultural sustainability should be shifted to also include discussion on how cultural values could be acknowledged in real-life case studies.

Despite the subjective nature of the weighting in LCA, the tools and methods used in the weighting phase can be based on scientifically proven methods. MCA has strong foundations in OR and has been considered one of the most promising methods for the weighting phase in LCA (sub-studies III and IV). However, as it has been demonstrated in sub-studies III and IV, there are still several challenges related to incorporating MCA (or any other weighting techniques) in LCA. The challenges are related to external normalisation factors: uncertainties concerning, for example, not only the impact assessment data, system boundaries and weighting factors, but also the behavioural aspects of the panellists who complete the weighting. If single scores are aggregated for comparative LCA studies, the above mentioned topics become relevant. Therefore, these issues should be assessed in a systematic manner.

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