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Research strategy, programmes and exemplary projects on life cycle sustainability analysis (LCSA)

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Research strategy, programmes and exemplary projects on life cycle sustainability analysis (LCSA)

Deliverable 22 of Work Package 7 of the CALCAS project

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Contents

Preface

This document is deliverable D22 of work package 7 (WP7) of the CALCAS project.

CALCAS is the EU 6th Framework *Co-ordination Action for innovation in Life-Cycle Analysis for Sustainability*. The aim of CALCAS is to structure the array of LCA approaches that have emerged during the last two decades, and indicate how the analysis might be improved.

D22 bears the title *Research strategy, programmes and exemplary projects on life cycle sustainability analysis (LCSA)*. It thus represents the proposals for research to fill the identified gaps in LCA theory, practice, and use within the context of sustainability support. It does so by first presenting the main organization of topics that are to be addressed, and then to discuss a number of exemplary projects.

D22 is one of two documents that develop research programmes and/or projects. The other document is D14 (Zamagni et al., 2009a). D22 and D14 both develop research programmes and/or projects but their scope is different. Whereas D14 focuses on research issues that more ore less remains within the boundaries of ISO-14040/14044 based LCA (abbreviated to "ISO-LCA"), D22 focuses on research issues identified for expanding ISO-LCA to Life Cycle Sustainability Analysis (LCSA).

D22 is not a stand-alone document, but builds on issues, topics, opportunities and threats around LCA that have been identified in many of the 21 earlier deliverables of the CALCAS project. Identification of LCSA research programmes and topics is based on the inventory of gaps and research issues that has been made in the Blue paper (D20), and thus in all previous CALCAS deliverables as the Blue Paper builds on the results of these previous deliverables. On top of that, topics have been derived from several open workshops that have been held as part of the CALCAS project, like the Leiden workshop on deliverable D1 and the CALCAS-ESF workshop in Brussels, and from SAT workshops and several projects done as part of the European Platform on LCA (http://lct.jrc.ec.europa.eu/eplca).

The research strategy is worked out in programmes and in exemplary projects, and as a road map linking these.

Though looking practical and final, the strategy, programmes and projects presented in this document should be seen as a first step towards well-developed LCSA. In further steps towards implementation, further research groups and communities and further public and private stakeholders should exert their influence.

Summary

CALCAS is an EU 6th Framework Co-ordination Action for innovation in Life-Cycle Analysis for Sustainability. The aim of CALCAS is to structure the array of LCA approaches that have emerged during the last two decades by:

- "deepening" the present models and tools to improve their applicability in different contexts while increasing their reliability and usability;
- "broadening" the LCA scope by better incorporating sustainability aspects and linking to neighbouring models, to improve their significance;
- "leaping forward" by a revision/enrichment of foundations, through the crossing with other disciplines for sustainability evaluation.

These objectives will be partly accomplished within the CALCAS project, as new practical strategies in LCA. For the other part, tasks will be formulated as research lines and as a road map, in terms of a number of research lines and a number of exemplary research programmes for sustainability decision support. This document presents the research strategy for expanding current ISO-14040/14044 (abbreviated to "ISO-LCA"; see text box) based LCA to Life Cycle Sustainability Analysis (LCSA) elaborating research required at several levels, "as a research strategy with main research programmes and exemplary research projects, including procedural aspects on how they may be incorporated in EU and national research programmes, in academic curricula, and in R&D in firms".

Broadening, deepening and cross-cutting research for integration are proposed as the main topics of three research programmes with related exemplary projects:

- Programme 1: broadening and deepening the scope of indicators (sustainability indicators for LCSA);
- Programme 2: deepening the scope of mechanisms and particular mechanisms (mechanisms in empirical modelling);
- Programme 3: cross-cutting research for integration.

As broadening and deepening of sustainability indicators can only be disconnected in an artificial and inefficient way, these two are swapped together. Under the headings of these three programmes, all potentially relevant research projects are listed in separate chapters.

Within each programme, a distinction is made between more application-oriented research (to be funded primarily, e.g., by the EU or national governments) and more science-oriented research (to be funded primarily, e.g., by the European Science Foundation (ESF) or national science organisations). Exemplary projects are formulated for both application-oriented and science-oriented project topics.

On top of this, far reaching co-ordination is needed. For this, co-ordination actions for two levels are proposed:

1. within a specific research programme, between the various projects of that programme;
2. within the LCSA strategy as a whole, between the three programmes.

Extended Summary

Introduction

CALCAS is an EU 6th Framework Co-ordination Action for innovation in Life-Cycle Analysis for Sustainability. The aim of CALCAS is to structure the array of LCA approaches that have emerged during the last two decades by:

- “deepening” the present models and tools to improve their applicability in different contexts while increasing their reliability and usability;
- “broadening” the LCA scope by better incorporating sustainability aspects and linking to neighbouring models, to improve their significance;
- “leaping forward” by a revision/enrichment of foundations, through the crossing with other disciplines for sustainability evaluation.

These objectives will be partly accomplished within the CALCAS project, as new practical strategies in LCA. For the other part, tasks will be formulated as research lines and as a road map, in terms of a number of research lines and a number of exemplary research programmes for sustainability decision support. This document presents the research strategy for expanding current ISO-14040/14044 (abbreviated to “ISO-LCA”; see text box) based LCA to Life Cycle Sustainability Analysis (LCSA) elaborating research required at several levels, “as a research strategy with main research programmes and exemplary research projects, including procedural aspects on how they may be incorporated in EU and national research programmes, in academic curricula, and in R&D in firms”. We here remind that:

- the term LCSA as adopted in the CALCAS project in deliverable 20 is not restricted to broadening ISO-LCA to also include economic and social aspects, but relates to both broadening and deepening and will go beyond ISO-LCA constraints (see D20);
- LCSA is not a method in itself. It comprises of a variety of methods, models and tools (either or not on top of a basic LCA) that all may have an independent meaning and may be applied in addition to each other when addressing life cycle sustainability questions.

In the original CALCAS proposal New LCA was used as the term to indicate all developments in LCA that go beyond the boundaries of LCA as defined in the ISO 14040:2006 (E) and ISO 14044:2006 (E) Standards (abbreviated to ISO-LCA). The term “New LCA” was changed into Life Cycle Sustainability Analysis in the course of the CALCAS project, as this better indicated the contents of the developments and as the ‘shelf life’ of the term ‘new LCA’ was considered to be restricted.

Within the CALCAS project we needed a reference for determining where LCSA starts. The published ISO standards, i.e. ISO 14040:2006 (E) and ISO 14044:2006 (E), constituted the most obvious reference for this. By ISO-LCA we thus mean the written text of these two standards. It is explicitly not our intention to classify the ISO standards as static documents that will not be adapted anymore in future. On the contrary, we hope of course that they will be adapted particularly when some of the CALCAS research topics have matured and become daily LCA-practice. Moreover, issues for new LCA may already have been discussed in ISO TCs and there may very good reasons not to adopt these issues within ISO for other reasons. LCSA is not in contradiction with ISO-LCA, but it builds on ISO-LCA extending its current boundaries to LCSA.

LCSA and the main problems in sustainability

The function of Life Cycle Sustainability Analysis (LCSA) is to improve decision-making by better reckoning with sustainability consequences in a life cycle perspective regarding decisions on technology systems.

Decisions on technologies virtually always relate to many aspects of sustainability, requiring a broad view on all relevant aspects in a balanced way. The role of sustainability analysis is not directly for mechanically choosing between options but to support the decision-making process. Most larger and hence more important decisions are not made by individuals but by many actors together in concert. The governance situation, see deliverables 8 and 13 of the CALCAS project, also determines what information is required, and in what form. LCSA is to cover the relevant issues in decision-making on technologies. Therefore, it is an integrative method of analysis, linking knowledge of different disciplines and domains into science for sustainable development.

Sustainability analysis on the one hand links to the micro level of actions of individuals and organisations, with their effects on the environment, and on the other hand to the aggregate or macro level at which most sustainability issues reside, be they of an environmental, social or economic nature.

Sustainability science for decision support links the needs of tomorrow with the actions of today. The key link between the socio-economic domain and our physical surroundings lies in the technosphere. There, affluence is created by combining natural resources and human ingenuity, mostly at an environmental cost. Technology is the link, not the aim. Technologies develop on the basis of economic mechanisms, institutions and political actions, ultimately guided by culture, and by necessity within the constraints of nature. LCSA analyses the options and constraints for sustainable development, helping create our common future. Its responsibility is to create the relevant knowledge for decision-making in large scale, complex, partly determined, non-linear systems.

The conclusions for the research programming here are the following.

- There are no easy generally applicable short cuts from specific decisions to their sustainability performance. The interrelated empirical chains are to be linked to the value areas of sustainability. There are no well developed methods available for this analysis.
- Simplified methods will either leave out relevant mechanisms and aspects or will have a limited domain of valid applicability. However, core methods and domains of simplification are actively to be developed, both as bottom up and as top down methods, always linking to the general level of sustainability values. The challenge is thus to broaden and deepen the analysis *while managing or counteracting the resulting increase in complexity*.
- Main domains involved in sustainability effects are energy use, materials use and land use, all linking to all aspects of sustainability depending on the technologies involved. All three are linked to specific choices on products and technologies, requiring a full chain life cycle analysis.
- A time horizon of several decades requires reckoning with substantially increased volume of economic activities, due to population growth, decrease of poverty and general increase in affluence.

- The linking of decisions to their sustainability consequences is to be done as much as possible in an open way, to allow for deviating and dissenting views, also in participatory processes. This open nature of the analysis should not jeopardize the feasibility of the analysis and should not increase the complexity of the analysis to an unmanageable level.

Research programming for LCSA

Which technologies should be developed and, if necessary, enhanced in their development through institutional and policy measures, initiated by the relevant social and cultural developments? How can we deal with the myriads of tiny decisions, together creating major developments? Which technologies will evolve depends on economic, socio-political and cultural feedback mechanisms, assuming they first come to technical fruition. Which technologies will come to fruition is hard to predict.

For small scale decisions on products and technologies, LCA has been developed. LCA maps the environmental performance of products, reckoning with their life cycle, covering all the activities technically required for delivering their function, from cradle to grave or, more wishfully, from cradle to cradle. The basic modelling assumption is that for most economic activities performance in the past is indicative of performance in the future. Simple extrapolation is the basic modelling approach, adapting volumes required in the life cycle, and without further behavioral mechanisms. For decisions with limited broader impacts, and with a limited time horizon, this will remain a most valuable approach to practical modelling for decision support. Improvements in modelling are well possible within this ISO defined modelling framework, both for covering a broader set of sustainability aspects, for more standardized and focused data supply, for linking to more detailed process modelling as in engineering models, and for incorporating more adequate environmental models. Further improvements relate to better guidance on how to define questions and link them to most adequate levels of modelling, of which the ISO type is only one, the most easily applicable. Also, the interpretation stage can be improved by a more systematic uncertainty analysis, covering both data uncertainty and model uncertainty, and by further developing quantified methods for sensitivity analysis, contribution analysis; and by linking to multi-criteria analysis, including formalized weighting procedures. Questions on choice between different biofuels constitute one core case for treatment. This level of analysis does not answer the question if large scale biofuel is attractive from a sustainability point of view. Only the choice between different fuels as for second generation biofuel is considered, implicitly assuming not “too large volume changes”.

However, it is clear that when questions on more substantial changes are to be answered, usually with a longer time horizon involved, the simple type of extrapolation model, with hardly any behavioral relations covered, is not adequate any more. It leaves the then most relevant mechanisms out of account. Discussions on biofuels have indicated that simple LCA may easily support very wrong larger scale decisions, requiring different questions and different models for answering them. With more substantial changes involved, relevant behavioral mechanisms enter the modelling set-up, with full totals specified to reckon with the non-linearities involved. While product LCA could analyze a product system size independently, using the functional unit, broader questions will require a broader system model, in order to answer the question *how a choice will work out overall*. For such questions on change in broader technosystems, the analysis may develop in two directions. One is to incorporate more mechanisms in the analysis, moving towards more causal models, either endogenised in one model or through a set of more softly linked heterogeneous models. The model uncertainty of the too simple LCA model, too simple for more encompassing questions, can thus be resolved, at least to some extent. As the future is not determined, because open choices can be made creating the future, there is a limit to where causal modelling can guide us. The other direction is to specify scenarios, technology specific, in which the technology options considered can function, with causalities modeled partially within the scenario framework. For questions on larger scale technology options, as on new energy supply systems, such scenario based modelling seems most adequate.

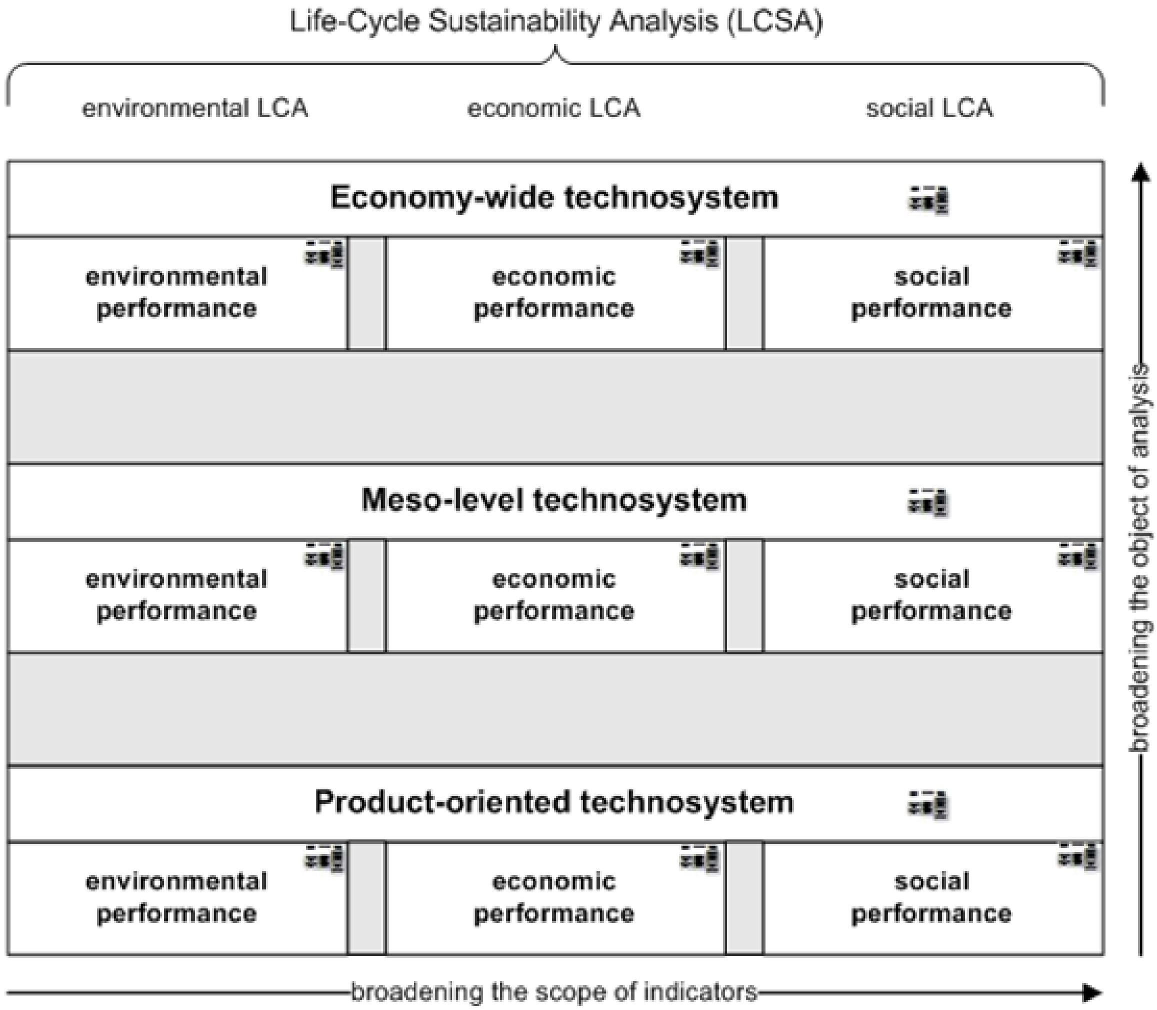
Neither the causal models nor the scenario based models are available for the operational analysis and evaluation of technologies. The research programmes developed here will first focus on advancing LCA. With broader sustainability aspects covered it becomes part of LCSA, Life Cycle Sustainability Analysis. The next level of LCSA is on improving the causal analysis, for middle range questions like on car propulsion – improved diesel; biofuel; hybrid plug in; electric car; etc. For still more basic questions, the scenario modelling will be developed, like for new energy supply systems. Examples are the artificial leaf and advanced algae growing systems, both capable of increasing the solar energy efficiency of photosynthesis by at least an order of magnitude as compared to plant based agriculture. These newly emerging systems should then be compared to alternative systems of solar energy conversion as well, including analyses of resource and land use needs when up scaling these systems to production levels that significantly contribute to society's energy demand.

<u>The research strategy</u>

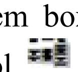
The research strategy refers to the main elements according to which different research issues, programmes and projects can be defined. For the research for LCSA these elements are:

a) broadening the objects of analysis relating to different levels of questions:
   - product-oriented question;
   - meso questions; and
   - economy-wide questions.
b) broadening the scope of indicators:
   - environmental;
   - economic;
   - social.
c) deepening of the scope of mechanisms by also including:
   - physical relations;
   - economic relations;
   - cultural, institutional and political relations;
   - normative analysis as to sustainability.
d) deepening a particular mechanism by going beyond state-of-the-art modelling of:
   - technological relations;
   - environmental mechanisms;
   - physical relations;
   - economic relations;
   - cultural, institutional and political relations;

- normative analysis as to sustainability.



Research strategy for LCSA.

Deepening can be done in each box of the above Figure, either a technosystem box or an environmental, economic or social performance box and is indicated by the symbol  in each of these boxes. Deepening thus is at right angles to broadening in this Figure. Zooming in on this symbol shows us the structure for deepening as presented in the Blue Paper (D20), which is illustrated in next Figure.

Structure for deepening.

Most of the broadening and deepening research issues, programmes and projects will be valid for all three levels of questions (product-oriented, meso-level, economy-wide) while they will at the same time require separate elaboration for each level. On top of this, there will be issues that are cross-cutting the broadening and deepening directions.

We therefore adopt broadening, deepening and cross-cutting research for integration as the main topics of three research programmes with related exemplary projects:

- Programme 1: broadening and deepening the scope of indicators (sustainability indicators for LCSA);
- Programme 2: deepening the scope of mechanisms and particular mechanisms (mechanisms in empirical modelling);
- Programme 3: cross-cutting research for integration.

As broadening and deepening of sustainability indicators can only be disconnected in an artificial and inefficient way, we swapped these two together. Under the headings of these three programmes, all potentially relevant research projects will be listed in the subsequent chapters.

Within one programme, we will then make a distinction between more application-oriented research (to be funded primarily, e.g., by the EU or national governments) and more science-oriented research (to be funded primarily, e.g., by the European Science Foundation (ESF) or national science organisations). Exemplary projects will be formulated for both application-oriented and science-oriented project topics.

On top of this, far reaching co-ordination is needed. For this, co-ordination actions for two levels are proposed:

1. within a specific research programme, between the various projects of that programme;
2. within the LCSA strategy as a whole, between the three programmes.

The first type of co-ordination should facilitate optimal collaboration and harmonization within a specific research program. The second type of co-ordination should facilitate collaboration and harmonization between the three LCSA research programmes, which should result in the alignment of the results of these three programmes.

Different levels of questions

There are three levels of questions: product-oriented, meso-level and economy-wide.

- Products are defined as in the ISO 14040 Standards and comprise any goods or services. Single products with the same function are compared. An example could be the comparison of switch grass versus stover ethanol as biofuel.
- Meso-level refers to a level in between product-oriented and economy-wide. It may include groups of related products and technologies, baskets of commodities (e.g., the product folio of a company), a municipality, a household, etc. An example question for this level might be the introduction of biomass as a major car fuel. Sustainability Assessment of Technologies (SAT) questions generally are meso-level (or economy-wide) LCSA questions.
- Economy-wide refers both to economies of states or other geographical/political entities including continents, the European Union (EU), the Organisation for Economic Co-operation and Development (OECD), the Association of Southeast Asian Nations (ASEAN) etc. and eventually the world. An example question for this level might be the comparison of options for technology domains, like for example strategies for phasing out fossil energy.

Exemplary projects

The table on the next page summarizes the exemplary research programmes that are described in more detail in Chapters 3-5.

Coordinating the implementation of the Research Strategy for LCSA in EU and (inter) national research programmes

Implementation of these three trans-disciplinary research programmes LCSA will not easily fit in just one funding organisation. Some projects and some elements of projects have an applied nature, making their funding through ESF, national research councils and the European Research Council (ERC) not well possible. Other projects and parts of them have a more abstract and scientific nature, which makes their inclusion in the EU Framework Programme and by DGs and national governments a complicated issue. Since several funding organisations will likely be involved, coordination between these seems required.

	Application-oriented research	Science-oriented research
Programme 1: sustainability indicators for LCSA	3.3.1 Options for indicators: aligning environmental with economic and social indicators 3.3.2 Framing the questions and a decision tree 3.3.3 Co-ordination action Broadening	3.4.1 Options for ethical positions and societal values in LCSA 3.4.2 Schools in sustainability analysis of technologies 3.4.3 Governance
Programme 2: mechanisms in empirical modelling for LCSA	4.3.1 Scenario development for LCSA 4.3.2 Co-ordination action Deepening	4.4.1 Modelling options for meso-level and economy-wide technosystems 4.4.2 Options for modelling physical relations for LCSA 4.4.3 Options for modelling economic relations for LCSA 4.4.4 Options for modelling cultural, institutional and political relations 4.4.5 Uncertainty analysis in LCSA 4.4.6 Handbook of modelling options
Programme 3: cross-cutting research for integration	5.3.1 New ISO-standards for LCSA 5.3.2 New ILCD Handbook for LCSA 5.3.3 Simplified LCSA 5.3.4 Answering sustainability questions 5.3.5 Sustainability oriented decision-making methodology 5.3.6 Standardization of LCSA for policy 5.3.7 Participatory approaches 5.3.8 Co-ordination action Cross-cutting	5.4.1 Modelling framework and roadmap for LCSA 5.4.2 Heterogeneous models aligned 5.4.3 Connections between different levels of questions and modelling 5.4.4 Aligning time frames in life cycle sustainability modelling 5.4.5 Integrating dynamics of socio-economic and environmental modelling

1 Introduction

1.1 Objectives of WP7

CALCAS is an EU 6th Framework Co-ordination Action for innovation in Life-Cycle Analysis for Sustainability. The aim of CALCAS is to structure the array of LCA approaches that have emerged during the last two decades. Besides LCA as defined in the ISO-14040 (Anonymous, 2006a; Anonymous, 2006b) Series of Standards (abbreviated to "ISO-LCA"; see text box), various other LCA approaches have emerged taking into account more types of externalities (economic and social costs) and more mechanisms (rebound, behaviour, price effects), handling of time ((quasi-)dynamic, steady-state), handling of space (spatially differentiated or spatially independent) and/or meeting specific user needs such as in simplified LCA. CALCAS will thus go beyond the boundaries of ISO-LCA. Going beyond ISO-LCA, was in the CALCAS proposal referred to as (new) LCA and is now (since the Blue Paper; Zamagni et al., 2009b) referred to as Life Cycle Sustainability Analysis (LCSA).

> In the original CALCAS proposal New LCA was used as the term to indicate all developments in LCA that go beyond the boundaries of LCA as defined in the ISO 14040:2006 (E) and ISO 14044:2006 (E) Standards (abbreviated to ISO-LCA). The term "New LCA" was changed into Life Cycle Sustainability Analysis in the course of the CALCAS project, as this better indicated the contents of the developments and as the 'shelf life' of the term 'new LCA' was considered to be restricted.
> Within the CALCAS project we needed a reference for determining where LCSA starts. The published ISO standards, i.e. ISO 14040:2006 (E) and ISO 14044:2006 (E), constituted the most obvious reference for this. By ISO-LCA we thus mean the written text of these two standards. It is explicitly not our intention to classify the ISO standards as static documents that will not be adapted anymore in future. On the contrary, we hope of course that they will be adapted particularly when some of the CALCAS research topics have matured and become daily LCA-practice. Moreover, issues for new LCA may already have been discussed in ISO TCs and there may very good reasons not to adopt these issues within ISO for other reasons. LCSA is not in contradiction with ISO-LCA, but it builds on ISO-LCA extending its current boundaries to LCSA.

The general objective of CALCAS is to structure the array of LCA approaches and to develop ISO-LCA by:

- "deepening" the present models and tools to improve their applicability in different contexts while increasing their reliability and usability;
- "broadening" the LCA scope by better incorporating sustainability aspects and linking to neighbouring models, to improve their significance;
- "leaping forward" by a revision/enrichment of foundations, through the crossing with other disciplines for sustainability evaluation.

These objectives will be partly accomplished within the CALCAS project, as new practical strategies in LCA. For the other part, tasks will be formulated as research lines and as a road map, in terms of a number of research lines and a number of exemplary research programmes for sustainability decision support.

The objective of WP7 as specified in the CALCAS Description of Work (DoW) focuses on the latter issues, specifying "new LCA strategies as practically as is possible and, corresponding to the LCA advances identified, to develop overall research lines and a roadmap for their further development, with exemplary research programmes". These programmes are intended to function as "a coordinated input for Life Cycle Analysis research in EU and national public research programmes, in R&D in firms, and in academic curricula, so as to fill in gaps in our knowledge for sustainability oriented decision-making in a most focused and efficient way".

WP 7 will result in two deliverables:
D20 ***Blue Paper*** on New LCA "stating the main lines of scientifically feasible; sustainability governance relevant; and stakeholders applicable New LCA. Some lines can be practically formulated and implemented already, while other lines need further research, and all lines need further development".
D22 ***Research strategy*** for expanding New LCA elaborating research required at several levels, "as a research strategy with main research programmes and exemplary research projects, including procedural aspects on how they may be incorporated in EU and national research programmes, in academic curricula, and in R&D in firms".
The report at hand here is deliverable D22.

The distinction between the deliverables D15 (Heijungs et al., 2009), D20 (Zamagni et al., 2009b) and D22 has developed during the course of the CALCAS project. At the project's Convergence meeting (M4) in Brussels in March-April 2008, it was defined as follows. D15 describes the scientific framework of deepening and broadening sustainability analysis of technology systems, D20 describes what is already available of this framework in contemporary sustainability analysis and identifies the gaps/research issues, and D22 drafts a research strategy, programmes and exemplary projects to close the gaps.

In D20 – the Blue Paper - a *road map for life-cycle sustainability analysis (LCSA)* was adopted, which will serve in D22 as the basis for the research strategy. We here remind that the term LCSA as adopted in the CALCAS projects is not restricted to broadening ISO-LCA to also include economic and social aspects (Klöpffer & Renner, 2008; Klöpffer, 2008), but relates to both broadening and deepening and will go beyond ISO-LCA constraints (see D20). Furthermore, we here emphasize that LCSA is not a method in itself. It comprises of a variety of methods, models and tools (either or not on top of a basic LCA) that all may have an independent meaning and may be applied in addition to each other when addressing life cycle sustainability questions.

1.2 Reading guide

In Chapter 2, the road map for LCSA as proposed in the Blue Paper will be converted and elaborated into a research strategy for D22. In Chapters 3-5 three research programmes together with exemplary projects are presented. Chapter 3 deals with "Programme 1: sustainability indicators for LCSA". Chapter 4 presents "Programme 2: mechanisms in empirical modelling for

LCSA" and Chapter 5 presents "Programme 3: cross-cutting research for integration". In Chapter 6 the co-ordination of the LCSA strategy as a whole is discussed and presented as an integration project. In Chapter 7 implementation in EU and National research programmes and implementation of life cycle topics in academic curricula and European networks is discussed. Finally, Chapter 8 concludes with some final notes and observations.

1.3 Results of the open consultation on the Blue Paper and other inputs to D22

The research programmes and exemplary project presented in this deliverable D22 are the result of all work done in the CALCAS project. All CALCAS work packages and all deliverables produced – including the reports of the Brussels governance, the Leiden D1 and the CALCAS-ESF workshops – as a result of these work packages have contributed to D22. Whereas the Blue Paper D20 already took the research suggestions from these deliverables as input, D22 has also taken into account the main results of the Blue Paper open consultation round. Detailed reactions provided as part the Blue Paper open consultation round can be found on the CALCAS website: http://fr1.estis.net/sites/calcas/.

2 Research strategy for LCSA: programmes tuned to levels of questions

2.1 LCSA and the main problems in sustainability

The function of Life Cycle Sustainability Analysis (LCSA) is to improve decision-making by better reckoning with sustainability consequences in a life cycle perspective regarding decisions on technology systems. Decisions on population policy, on wild life management and on educating the poor are of tremendous importance but not the subject here. Of course, a bio-based economy may be well possible with a global population of one billion but not with one of ten billion, or with a consumption level of 5.000 Euro per head but not with 50.000 Euro per head. So in the background such aspects will play a role.

Decisions on technologies virtually always relate to many aspects of sustainability, requiring a broad view on all relevant aspects in a balanced way. This requirement can never be realised in full, but may serve as a goal to be approached. One basic limitation is that the balancing is dependent on views on what is important, which may differ between persons and groups. So the definition of what is important is fluid, developing in discussions, and of course depending on developments in the world. The role of sustainability analysis therefore is not directly for mechanically choosing between options but to support the decision-making process. Most larger and hence more important decisions are not made by individuals but by many actors together in concert. The governance situation, see CALCAS deliverable 8 (D8; Vagt et al., 2008) and 13 (D13; Jacob & Rubik, 2009), also determines what information is required, and in what form. However, though there is dissenting opinions and quite some difference in details, there is substantial agreement on factors which are important, both in general terms as defined by sustainability concepts and specifically as in terms of problems of climate change, biodiversity loss, health problems and human welfare. Technology choices on energy production clearly have a large influence here: fossil resources used now are not available for future generations; nuclear energy conveys cost to future generations; and biomass based energy increases farm income and reduces income of city dwellers (in constant prices). Similarly, mineral resources tend to be located in developing countries, reducing their income by reducing our use of these resources.

LCSA is to cover the relevant issues in decision-making on technologies. Therefore, it is an integrative analysis covering a wide array of methods and tools and linking knowledge of different disciplines and domains into science for sustainable development. The complexity in empirical relations of today's main environmental challenges requires a systems perspective linking different disciplines. The variety of issues involved again requires inclusion of all sustainability aspect, i.e. economic, environmental and social aspects.

Sustainability analysis on the one hand links to the micro level of actions of individuals and organisations, with their effects on the environment, and on the other hand to the aggregate or macro level at which most sustainability issues reside, be they of an environmental, social or economic nature.

Sustainability as an area of research directly relates to the historical discontinuity of science driven industrialisation in the last centuries, and the explosion in production volumes in the last decades. (See the box below). Human activities have grown so dramatically in recent decades that the world system reaches boundaries.

Urgency of sustainability research

$4*10^9$ Life evolved in four billion years.

$4*10^4$ Humans conquered the world around forty thousand years ago.

$4*10^9$ Over four billion people were born the last forty years.
That is around one fourth of the number of humans who ever lived in human history.

$4*10^1$ Industrialisation exploded forty years ago.

$4*10^1$ Global consumption, hence production, will increase fourfold in the next forty year.

The core sustainability issue is how global society will be able to combine unavoidable further population growth and substantial increases in affluence with an equitable distribution of amenities, with an environment supporting life, with welfare also in the longer term, and with a rich nature as an essential part of human life.
These challenges require a combination of efforts:

- basic research in the natural and social sciences;
- the application of research results in engineering;
- suitability of results to support sustainability oriented decision-making in government, in business, and in research and development (R&D);
- and the education of (future) researchers and decision-makers to help create a sustainable future for society.

Sustainability science for decision support links the needs of tomorrow with the actions of today. The needs are huge. Nine billion persons do not fit on the world in 2050, with our affluence and with our current habits and technologies. The metabolic syndrome of the world requires substantial redressing, now already. A healthy global system in terms of the natural system, of the economy, and of our social basis summarises the goals of sustainability. Good intentions will not bring us there. The key link between the socio-economic domain and our physical surroundings lies in the technosphere. There, affluence is created by combining natural resources and human ingenuity, mostly at an environmental cost. Technology is the link, not the aim. Technologies develop on the basis of economic mechanisms, institutions and political actions, ultimately guided by culture, and by necessity within the constraints of nature. The sustainability aim is cultural: to meet the needs for all now, within constraints of meeting the needs of all tomorrow, that is by keeping the global system intact. LCSA analyses the options and constraints for sustainable development, helping create our common future. Its responsibility is to create the relevant knowledge for decision-making in large scale, complex, partly determined, non-linear systems.

So what are the core sustainability issues to be covered by LCSA, with improvements in coverage through research? In an ideal situation, we would know the ultimate value domains involved, and then derive what is important in terms of decisions, based on our empirical knowledge. The value domains relate to affluence and happiness, definable both at a personal micro level and collective level, and to justice, as in distributional issues with always larger segments of the population involved. So, what are the factors determining welfare and justice, even if we don't fully agree on what exactly they constitute and how trade offs between them may be formulated? The first steps backwards in causal chains involved relate to environmental quality and economic welfare and their distribution in space and time. A stable climate clearly is important for affluence and happiness. Of course the required level of stability may be disputed, and dealing with uncertainties involved in climate analysis, as involving low chance runaway effects, may lead to very differing decisions. But whatever the exact positions, systematic knowledge on climate changing mechanisms is essential in sustainability decision-making. Similar reasoning holds for other aspects of environmental quality as related to human health and ecosystem health and stability, the last two both as values in themselves and as factors instrumental in affluence and happiness. The endpoints and midpoints in current life cycle impact assessment cover the field, though not in a systematic way yet. The welfare and distributional effects are covered in the socio-economic domain of analysis, linkable to decision-making on technologies to some extent as well.

How far can we go back in these causal chains, in an ordered, agreed upon way? There are key domains of activities related to midpoints and endpoints, to use the LCA terminology. Energy production and use is one such a domain. Materials production and use is another one, though mechanisms linking to ultimate values are more complex there already. Or can we go back still further in a reasoned way? Can we specify the sustainability performance of transport and housing in a general way? Hardly, as the technologies involved in their life cycle chains will determine this performance. Of course, there are exceptions. A bio-based economy for ten billion rich people does not fit into the available space of this world. Even this statement may be too strong, as productivity increase per hectare with super algae, also using the sea surface, might be a feasible way out of the land shortage in the next half century.

The conclusions for the research programming here are the following.

- There are no easy generally applicable short cuts from specific decisions to their sustainability performance. The interrelated empirical chains are to be linked to the value areas of sustainability. There are no well developed methods available for this analysis.
- Simplified methods will either leave out relevant mechanisms and aspects or will have a limited domain of valid applicability. However, core methods and domains of simplification are actively to be developed, both as bottom up and as top down methods, always linking to the general level of sustainability values. The challenge is thus to broaden and deepen the analysis *while managing or counteracting the resulting increase in complexity*.
- Main domains involved in sustainability effects are energy use, materials use and land use, all linking to all aspects of sustainability depending on the technologies involved. All three are linked to specific choices on products and technologies, requiring a full chain life cycle analysis.
- A time horizon of forty years (see text box above) requires reckoning with substantially increased volume of economic activities, due to population growth, decrease of poverty and general increase in affluence.
- The linking of decisions to their sustainability consequences is to be done as much as possible in an open way, to allow for deviating and dissenting views, also in participatory processes. This open nature of the analysis should not jeopardise the feasibility of the analysis and should not increase the complexity of the analysis to an unmanageable level.

2.2 Research programming for LCSA

Technological development plays a key role both in causing economic growth, with detrimental and positive effects on the environment, economy and society. It can also play a key role in creating affluence and solving environmental and social problems, if directed to these goals adequately. How do we know that we are on the right track towards sustainability, first having defined what the right track is? Which technologies should be developed and, if necessary, enhanced in their development through institutional and policy measures, initiated by the relevant social and cultural developments? How can we deal with the myriads of tiny decisions, together creating major developments? Which technologies will evolve depends on economic, socio-political and cultural feedback mechanisms, assuming they first come to technical fruition. Which technologies will come to fruition is hard to predict. The Sterling motor has been the most efficient motor for nearly two centuries now, without ever having played a serious role. Technologies may be ideal but have to be embedded. Even with very substantial investments, as with the Sterling motor, they may get stuck, locked in, as innovation researchers call it.

So, how do we know what to do, as one of the myriad decision-makers striving for sustainability? In addition, how should larger decisions on technology and society be supported with relevant information? For small scale decisions on products and technologies, LCA has been developed. LCA maps the environmental performance of products, reckoning with their life cycle, covering all the activities technically required for delivering their function, from cradle to grave or, more wishfully, from cradle to cradle. The basic assumption is that for most economic activities performance in the past is indicative of performance in the future. Simple extrapolation is the basic modelling approach, adapting volumes required in the life cycle, and without further behavioural mechanisms. For decisions with limited broader impacts, and with a limited time horizon, this will remain a most valuable approach to practical modelling for decision support. Improvements in modelling are well possible within this ISO defined modelling framework, both for covering a broader set of sustainability aspects, for more standardised and focused data supply, for linking to more detailed process modelling as in engineering models, and for incorporating more adequate environmental models. Further improvements relate to better guidance on how to define questions and link them to most adequate levels of modelling, of which the ISO (Anonymous, 2006a; Anonymous, 2006b) type is only one, the most easily applicable. Also, the interpretation stage can be improved by a more systematic uncertainty analysis, covering both data uncertainty and model uncertainty (see Draper, 1995; see also Lloyd & Ries, 2007), and by further developing quantified methods for sensitivity analysis, contribution analysis; and by linking to multi-criteria analysis, including formalised weighting procedures. Questions on choice between different biofuels constitute one core case for treatment. This level of analysis doesn't answer the question if large scale biofuel is attractive from a sustainability point of view. Only the choice between different fuels as for second generation biofuel is considered, implicitly assuming not "too large volume changes".

However, it is clear that when questions on more substantial changes are to be answered, usually with a longer time horizon involved, the simple type of extrapolation model, with hardly any behavioural relations covered, is not adequate any more. It leaves the then most relevant mechanisms out of account. Discussions on biofuels have indicated that simple LCA may easily support very wrong larger scale decisions (Doornbosch & Steenblik, 2007), requiring different questions and different models for answering them. With more substantial changes involved, relevant behavioural mechanisms enter the modelling set-up, with full totals specified to reckon with the non-linearities involved. While product LCA could analyse a product system size independently, using the functional unit, broader questions will require a broader system model, in order to answer the question *how a choice will work out overall*. For such questions on change in broader technosystems, the analysis may develop in two directions. One is to incorporate more mechanisms in the analysis, moving towards more causal models, either endogenized in one model or through a set of more softly linked heterogeneous models. The model uncertainty of the too simple LCA model, too simple for more encompassing questions, can thus be resolved, at least to some extent. As the future is not determined, because open choices can be made creating the future, there is a limit to where causal modelling can guide us. The other direction is to specify scenarios, technology specific, in which the technology options considered can function, with causalities modeled partially within the scenario framework. For questions on larger scale technology options, as on new energy supply systems, such scenario based modelling seems most adequate.

Neither the causal models nor the scenario based models are available for the operational analysis and evaluation of technologies. The research programmes developed here will first focus on advancing LCA. With broader sustainability aspects covered it becomes part of LCSA, Life Cycle Sustainability Analysis. The next level of LCSA is on improving the causal analysis, for middle range questions like on car propulsion – improved diesel; biofuel; hybrid plug in; electric car; etc. For still more basic questions, the scenario modelling will be developed, like for new energy supply systems. Examples are the artificial leaf and advanced algae growing systems (Pandit et al., 2006), both capable of increasing the solar energy efficiency of photosynthesis by at least an order of magnitude as compared to plant based agriculture. These newly emerging systems should then be compared to alternative systems of solar energy conversion as well, including analyses of resource and land use needs when up scaling these systems to production levels that significantly contribute to society's energy demand.

2.3 The research strategy

From the road map for LCSA as presented in the Blue Paper (D20), the research strategy can be derived. The research strategy refers to the main elements according to which different research issues, programmes and projects can be defined. For the research for LCSA these elements are:

a) broadening the objects of analysis relating to different levels of questions:
   - product-oriented question;
   - meso questions; and
   - economy-wide questions.
b) broadening the scope of indicators:
   - environmental;
   - economic;
   - social.
c) deepening of the scope of mechanisms by also including:
   - physical relations;
   - economic relations;
   - cultural, institutional and political relations;
   - normative analysis as to sustainability.
d) deepening a particular mechanism by going beyond state-of-the-art modelling of:
   - technological relations;

- environmental mechanisms;
- physical relations;
- economic relations;
- cultural, institutional and political relations;
- normative analysis as to sustainability.

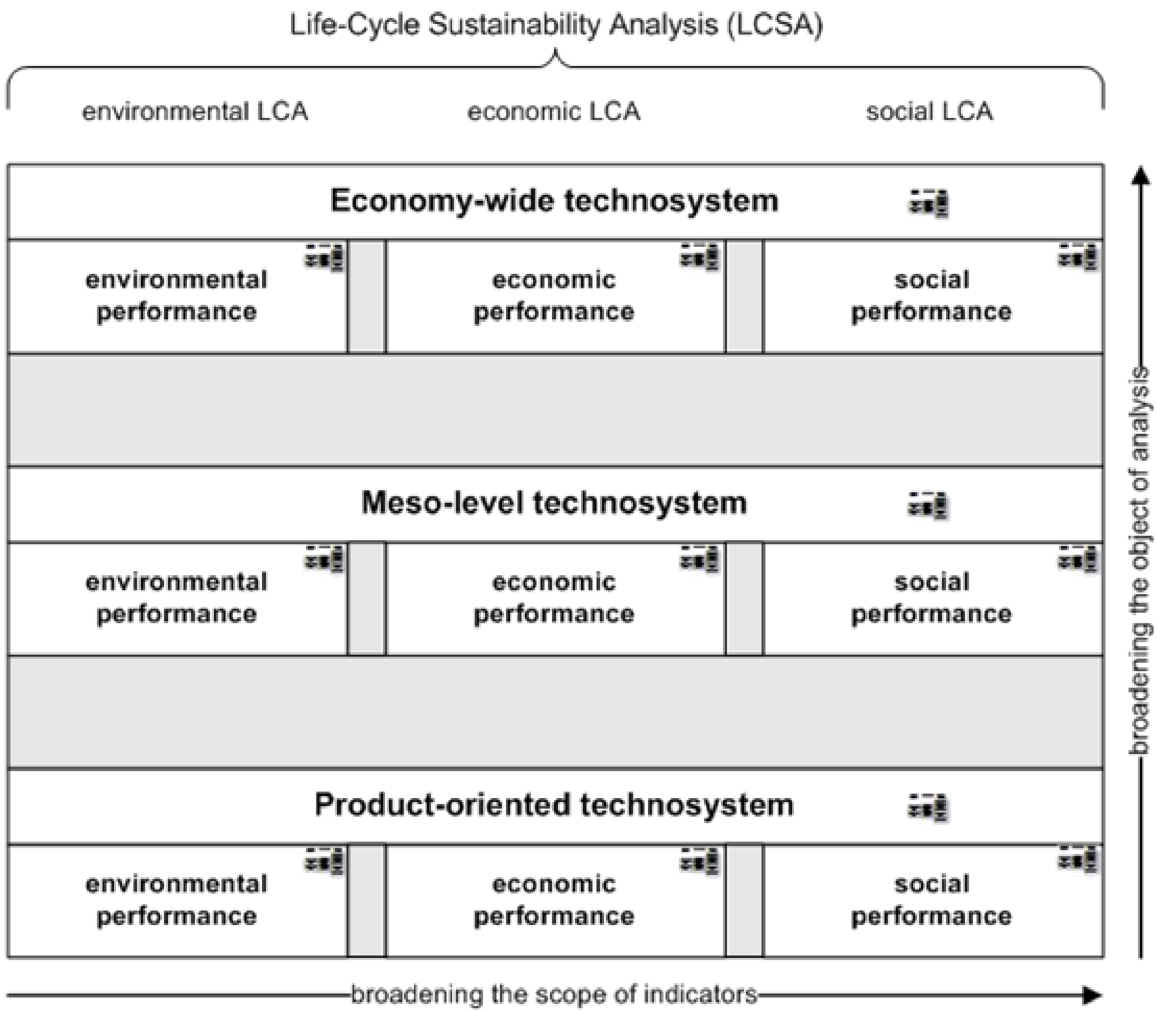


Figure 1: Research strategy for LCSA

Deepening can be done in each box of Figure 1, either a technosystem box or an environmental, economic or social performance box and is indicated by the symbol in each of these boxes. Deepening thus is at right angles to broadening in this Figure. Zooming in on this symbol shows us the structure for deepening as presented in the Blue Paper (D20), which is illustrated in Figure 2.

Most of the broadening and deepening research issues, programmes and projects will be valid for all three levels of questions (product-oriented, meso-level, economy-wide) while they will at the

same time require separate elaboration for each level. On top of this, there will be issues that are cross-cutting the broadening and deepening directions.
We therefore adopt broadening, deepening and cross-cutting research for integration as the main topics of three research programmes with related exemplary projects:

- Programme 1: broadening and deepening the scope of indicators (sustainability indicators for LCSA);
- Programme 2: deepening the scope of mechanisms and particular mechanisms (mechanisms in empirical modelling);
- Programme 3: cross-cutting research for integration.

As broadening and deepening of sustainability indicators can only be disconnected in an artificial and inefficient way, we swapped these two together. Under the headings of these three programmes, all potentially relevant research projects will be listed in the subsequent chapters.
Topics for these projects are formulated independent of levels, i.e. product-oriented, meso-level and economy-wide. A topic thus comprises a subject of research that is important for all three levels. As far as relevant, this implies that a topic might need further elaboration for each level separately while guarding consistency between the elaborations. On top of these level-elaborations, there will be level-independent issues that need to be considered under the heading of a topic.

Within one programme, we will then make a distinction between more application-oriented research (to be funded primarily, e.g., by the EU or national governments) and more science-oriented research (to be funded primarily, e.g., by the ESF or national science organisations). Exemplary projects will be formulated for all identified application-oriented and science-oriented project topics. For most exemplary projects, brief project descriptions (maximum ½-1 page) will be provided. Some exemplary projects will be described more extensively. These more extensive project descriptions could, for example, serve as a stepping stone towards a full ESF White Paper (cf. Pandit et al., 2006). As far as applicable and useful, each exemplary project will be described according to the following format:

1. *Goal and scope*
2. *Activities*
3. *Planning*
4. *Case reference (see section 2.5 for an explanation)*
5. *Expected results.*

These headings will be used explicitly for the more extensively described projects, and implicitly – structuring the project description text – for the more briefly described ones.

On top of this, far reaching co-ordination is needed. The field of LCSA research is so wide that no single discipline can cover all of it (see also Schepelmann et al., 2009). Scientists from various scientific disciplines will be involved. This is needed for getting most up-to-date and relevant knowledge into LCSA, but the attached risk is that of crumbled research with incoherent results for the different LCSA research topics as a consequence. That should be prevented and therefore far-reaching co-ordination is necessary. For this, co-ordination actions for two levels are proposed:

1. within a specific research programme, between the various projects of that programme;
2. within the LCSA strategy as a whole, between the three programmes.

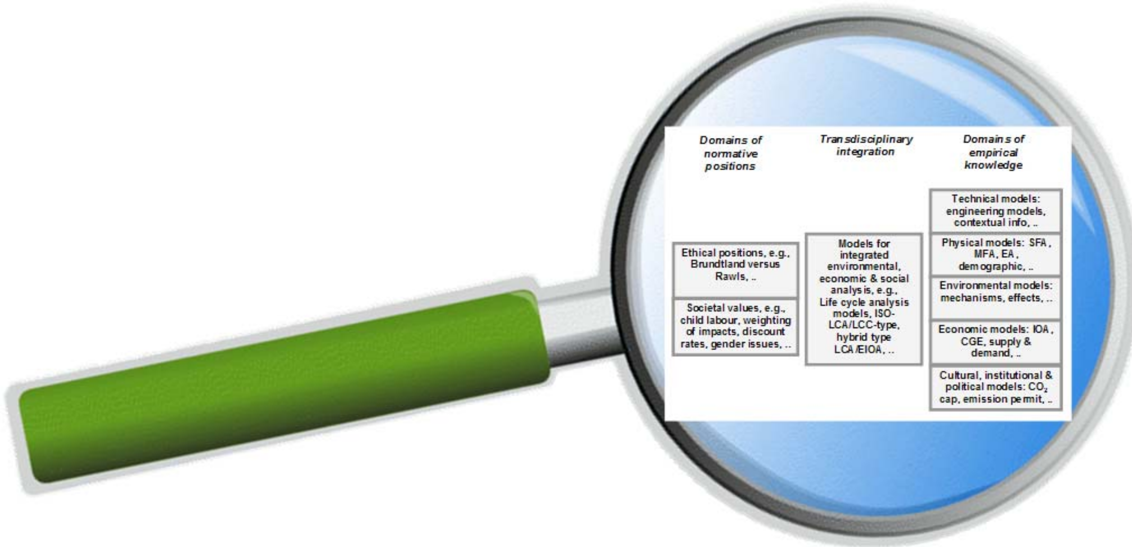


Figure 2: Structure for deepening.

All research projects within programme 1 and 2 will comprise of generic knowledge and techniques (level-independent) and a specific elaboration of the knowledge and techniques for each of the three levels (product-oriented, meso-level, economy-wide). However, consistency between projects in dealing with similar topics like time, space etc. will have to be guarded. For this reason, co-ordination actions are recommended for each of the three programmes. This co-ordination action for each programme may exist of workshops on a common topic for all the research groups involved but will also include active co-ordination and control of projects on criteria determined in advance.

Between research programmes, co-ordination will also be needed on similar topics. All of the research projects will have to fit into the overall LCSA structure. Again, this strategy co-ordination action may exist of workshops on a common topic for all the research projects of the LCSA research strategy, and will also include active co-ordination and control of programmes and projects. On top of that it could also include the responsibility to specify the topics for the next round of FP calls.

How could this two-layered co-ordination work out in practice? Let’s take the research programme “sustainability indicators for LCSA” and the projects “modelling options for economic indicators” and “modelling options for social indicators” as an example. Employment or unemployment can be considered an economic indicator as well as a social indicator. Fine-tuning between these two projects is then necessary. This would be a topic for a type 1 co-ordination action within the research programme “sustainability indicators for LCSA”. Determining how generic issues of handling time (steady-state; dynamic; infinite or 100 years time horizon; etc.) are approached between the various programmes within the LCSA strategy, would be a topic of type 2 co-ordination. Type 1 co-ordination should be established for each of the three programmes; type 2 co-ordination is only one co-ordination activity for the whole LCSA research strategy.

2.4 *Different levels of questions*

In this section we briefly discuss the distinctive characteristics between the three levels of questions: product-oriented, meso-level and economy-wide. We hereby repeat and build on what was already written on this subject in D20.

2.4.1 Level 1: product-oriented questions

Products are defined as in the ISO 14040 Standards (Anonymous, 2006a; Anonymous, 2006b) and comprise any goods or services. *Single products with the same function* are compared. An example could be the comparison of switch grass versus stover ethanol as biofuel. The textbox below provides a non-exhaustive list of further examples.

Examples of product-oriented LCSA questions:

- Choice of biomass for car fuel
- Choice of metals and materials in car construction
- ....

2.4.2 Level 2: meso-level questions

Meso-level refers to a level in between product-oriented and economy-wide. It may include groups of related products and technologies, baskets of commodities (e.g., the product folio of a company), a municipality, a household, etc. An example question for this level might be the introduction of biomass as a major car fuel. Sustainability Assessment of Technologies (SAT) questions generally are meso-level (or economy-wide) LCSA questions. The textbox below provides a non-exhaustive list of further examples.

Examples of meso-level LCSA questions:

- Second generation biomaterials & energy technologies
- Grid electricity based individual transport systems
- Research portfolio for sustainable technology development (also firms)
- Waste management and recycling systems
- Biofuel potential
- Nuclear energy potential
- Nanotechnology
- ....

2.4.3 Level 3: economy-wide questions

Economy-wide refers both to economies of states or other *geographical/political entities* including continents, the EU, the OECD, the ASEAN etc. and eventually the world. An example question for this level might be the comparison of options for technology domains, like for example strategies for phasing out fossil energy. The textbox below provides a non-exhaustive list of further examples.

Examples of economy-wide LCSA questions:
- Biofuel potential
- Nuclear energy potential
- Nanotechnology
- Algae and artificial leaf based materials and energy
- Bio-based economy
- Degrowth by selective constraints on consumption
- ....

2.5 Case study experiences and challenges

Experiences with case studies have shown the various shortcomings of current LCA, e.g. the biofuel examples described in (the annex of) D20. LCSA is intended to address these shortcomings. The research set-out in deliverable 20 (Zamagni et al., 2009b) and in this deliverable 22 is intended to bridge the gaps between current LCA and LCSA. In order to assure that the research strategy for LCSA in the end covers as many problems and issues identified in the various cases as possible, every research project proposed should be linked to one or more case studies for which the core issue of that project is, was or will be relevant. Wherever manageable, the description of projects in this document will already contain 1-2 reference sentences to such case studies.

A non-exhaustive and open listing of possible cases that may be used as a reference includes:
- biofuels for transport;
- second generation biomaterials & energy;
- grid electricity based transport systems;
- nano technology;
- algae and artificial leaf based materials and energy;
- bio-based economy;
- food and agriculture systems;
- etc.

3 Programme 1: sustainability indicators for LCSA

This chapter focuses on deriving a research programme for broadening and deepening the scope of indicators for LCSA (short name: sustainability indicators for LCSA). The topics for this research programme are based on the inventory of research issues that has been made in the Blue paper (D20), and thus in all previous CALCAS deliverables as the Blue Paper builds on the results of these previous deliverables. On top of that, topics have been derived from several open workshops that have been held as part of the CALCAS project, like the Leiden workshop on deliverable D1 and the CALCAS-ESF workshop in Brussels, and from SAT workshops and several projects done as part of the European Platform on LCA (http://lct.jrc.ec.europa.eu/eplca). Below, topics for projects are identified and classified as either predominantly application-oriented or science-oriented. Finally, brief exemplary project descriptions are given for a selection of project topics.

3.1 Topics for projects

This research programme comprises of all topics that can be classified under sustainability indicators for LCSA, including projects that are of general interest for broadening. Note, however, that this programme on sustainability indicators for LCSA also includes deepening of the modelling of environmental mechanisms as these mechanisms are covered when modelling environmental indicators.

The topics identified as part of this research programme are considered important for improving and disseminating the use of the life-cycle sustainability assessment of products and technologies. Project topics are formulated independent of levels, i.e. product-oriented, meso-level and economy-wide. A topic thus comprises a subject of research that is important for all three levels. As far as relevant, this implies that a topic might need further elaboration for each level separately while guarding consistency between the elaborations. On top of these level-elaborations, there will be level-independent issues that need to be considered under the heading of a topic.

Deepening the environmental mechanisms is particularly relevant for environmental indicators for product-oriented LCSA. It is not yet so relevant for meso-level and economy-wide LCSA as we first need to have more clarity on the starting model. For ISO-LCA we have a clear picture of its basic models, something which is still lacking at the meso-level and economy-wide level. Therefore we first need an overview of possible modelling options in general for these levels (see below and section 3.3.1).

This results in the following, preliminary list of project topics for research "Programme 1: sustainability indicators for LCSA":

- Co-ordination action Broadening;
- Framing the questions and a decision tree;
- Governance;
- Options for ethical positions and societal values in LCSA;
- Options for indicators: aligning environmental with economic and social indicators;

- Schools in sustainability analysis of technologies.

3.2 Distinguishing between application-oriented and science-oriented research

The main driver for distinguishing between application-oriented research (to be funded primarily, e.g., by the EU or national governments) and more science-oriented research (to be funded primarily, e.g., by the ESF or national science organisations) is the type of funding (see section 2.3). There will often be grey areas between these two classes of research, topics may be elaborated in a application-oriented and/or in a science-oriented way, and topics for projects may also often comprise of a mixture of application- and science-oriented research. Therefore, a classification of topics to these two classes of research will always be a bit artificial and therefore remain debatable. The classification will thus be based on an assessment of the predominant application- or science-oriented aspects of the research embraced by a project topic, or a topic will be elaborated into an application-oriented and a science-oriented project, which then constitute two different projects.

Bearing the above in mind, the following projects are considered to be predominantly application-oriented:
- Options for indicators: aligning environmental with economic and social indicators;
- Framing the questions and a decision tree;
- Co-ordination action Broadening.

The following projects are considered to be predominantly science-oriented:
- Options for ethical positions and societal values in LCSA;
- Schools in sustainability analysis of technologies;
- Governance.

Below, brief exemplary project descriptions are provided for each of the project topics, distinguished to application-oriented and science-oriented and applying the formats and lengths discussed in section 2.3.

3.3 Exemplary projects for application-oriented research

3.3.1 Options for indicators: aligning environmental with economic and social indicators

In prospective LCSA studies the evaluated effects of the alternatives form one main basis for supporting choices. There is gap between what is available and what is required and possible so is stated in deliverable 19, section 7.2.1 (Rydberg, 2009) to further develop meaningful indicators and metrics to be applicable within LCSA studies on different scales. See D19, section 7.2.2 for several concrete suggestions, to be covered in this project. There are several competing requirements on such indicators for sustainability. They should reflect ethical and normative positions; they should be operational; they should refer to the same empirical modelling; they should be mutually exclusive (non-overlapping); they should be adaptable to specific situations;

they should be easy to understand and communicate. The focus here is on how they can be made operational in a way that they are mutually aligned, i.e. referring to the same decision situation and based on the same empirical relations and assumptions.

For aligning indicators they have to be defined in the same modelling framework. This seems self-evident but is not easy to realise. For example, when analysing different options for biofuels, like switch grass, corn stover and sugar cane, the regional reference differs. Even if analysing environmental effects in the same framework, social and economic aspects will be specified with effect mechanisms in Kazakhstan, the US and Brazil respectively, as such data are available. In reality, there will be a mix of countries involved, partly depending on the volume of shifts to biofuel assumed, with highly differing effect mechanisms involved. In a way, the resulting indicators are country specific, as indicators are defined operationally by the models used. This problem can be resolved either by ever more specific indicators, or by handling differences in some other way, while retaining the comparability of alternatives. Also, questions on specific product options may be placed in a broader meso-level and economy-wide context, for example if some stakeholders feel this to be relevant. At these different levels of questions and models, different indicators may be used. Distributional criteria, regarding income and exposure to environmental hazards, typically are hard to specify at the level of product analysis using functional unit for comparison; they require an analysis of how totals are influenced by the choice at hand. Also, practical analysis may use short cuts avoiding detailed analysis and still giving valid answers. An example is on bio-based economy, an economy-wide question on how a major share of our materials and energy use can be obtained from biomass. Relatively simple scenario analysis reckoning with economic growth (as proposed by J.P Hettelingh at the CALCAS expert meeting in Leiden, 4-5 June 2007), may show that this is possible only when using up all of nature, within decades. The evaluation is clear; nobody will want this, whatever the ethical position taken. Such questions can then be answered and more relevant questions then can be posed on this subject.

Taking the environmental indicators as developed and developing in LCA as a starting point, there is an expansion needed to cover aspects at the meso-level and economy wide level, and an expansion to cover more issues than the environmental ones. The expansion to meso-level and economy wide level should start by connecting as much as possible to the sustainability indicators of European Environment Agency (EEA; http://themes.eea.europa.eu/IMS/CSI), Eurostat (http://epp.eurostat.ec.europa.eu/portal/page/portal/sdi/introduction), Organisation for Economic Co-operation and Development (OECD; http://www.oecd.org/dataoecd/18/55/2713868.doc) and United Nations (UN; http://www.un.org/esa/sustdev/publications/indisd-mg2001.pdf). Building on and in addition to these ongoing international efforts, a discussion on expansion to more issues has been unfolding within product LCA. CALCAS deliverable 7 (Zamagni et al., 2008) and deliverable 13 (Jacob & Rubik, 2009) have reported, for example, on the efforts made to incorporate social aspects into the classic LCA methodology in the past years. Recently, the taskforce "Integration of social aspects in LCA" of the UNEP-SETAC Life Cycle Initiative has published its report "Guidelines for Social Life Cycle Assessment of Products" (Benoît & Mazijn, 2009). The report discusses the state-of-the-art of Social LCA (S-LCA) and, amongst other things, it concludes that there is a fundamental need to develop (inventory) databases and that indicators to assess the various social issues of concern are elaborated (social "impact assessment methodologies are under development and are an open field for future research"). These outcomes are in line with results from the PROSA[1] project (Manhart & Grießhammer, 2006). An empirical study on the social impacts of the production of notebooks (Manhart & Grießhammer, 2006) confirms some of the methodological caveats currently prevailing for the calculation of social aspects in the product chain:

- the restricted availability of unit process data for product related social life-cycle assessment (SLCA)
- the different perception of social issues by different actors, thus making stakeholder involvement a key issue for SLCA.

Furthermore, most of the distributional aspects as indicated by Brundtland cannot be specified at the micro level of unit processes in product LCA. They are macro level characteristics of society, like the inequality of societal income distribution, or, more complex still, the intergenerational distribution of environmental quality and economic welfare.

In a similar way, options have been explored to link LCA to economic evaluation. Assuming that the functional unit represents the value of the product system, the economic aspect is to reduce cost, as in Life Cycle Costing (LCC; cf. Zamagni et al., 2008). LCC then should not cover environmental externalities. However, several LCA studies already specify different values for different options to fulfil a function, requiring a disentangling of cost and value not yet resolved in LCA-type studies. Surely when leaving the realm of functional unit analysis, going for totals as is required in market analysis, the shift is to value creation, as in eco-efficiency (EE) of the type advocated by the UN and the World Business Council for Sustainable Development; see Huppes & Ishikawa (2005) for a survey.

Deepening the economic analysis involves the addition of mechanisms, like market mechanisms and a more encompassing analysis, possibly also for the product level already. Hybrid LCA (see Suh (ed.; 2009) for a survey) can specify the total of the function in society, linking to value added for systematic coverage of different types of cost. The intricate relation between social and economic analysis shows in indicators referring to the same but with a different perspective. Cost is a negative economic aspect, while it is measured in value added which at the same time indicates employment. Income distribution is an economic variable in its specification, but at the same time a major social aspect of sustainability. This complex domain has not been matured yet.

So in current sustainability discourse, a number of problems confuse the discussions on sustainability evaluation: the coverage of indicators and their mutual relations, as with cost and employment, and what is not covered; the place of indicators in causal chains; their time specification; and their spatial differentiation. Climate changing emissions are spread out in time themselves; they exert their climate forcing influence over long time horizons, different per emission, with life times varying between days, decades and millennia; they lead to climate change with a delay; which in turn leads to further effects, with delays. In cost-benefit type of analysis and related approaches like in the Stern Review (Stern, 2006), ultimate climate effects

[1] This project is referred to as just one example, and does not imply an exhaustive listing of relevant projects in the area of sustainability indicators. On-going/completed work in this area is to be analyzed and build upon exhaustively by a potential tenderer in due time as yet and is not fixed here.

are specified in time and discounted. In assessing cost of climate change, these effects lead to feedback loops in society, with economic and social effects resulting *through environmental* mechanisms, as a feed back loop. Each step in modelling leads to a different indicators, though they may be called the same name. In LCA, global warming is used as a midpoint indicator, with time integrated climate forcing usually over 20, 100 or 500 years. So, for climate change, which is indicator is the relevant one, and how can it be aligned with other environmental indicators, and with social and economic indicators of sustainability? To take an example, for toxic effects, LCA-type fate modelling of substances integrates till infinity, with for some substances the contributions taking place over millions of years. We may discuss the best way of modelling specific effect mechanisms and effects, but at the same time keep in mind that ultimately it is the full set of indicators which has to be aligned for adequate decision support.
This mutual alignment of indicators is the core goal of this project.

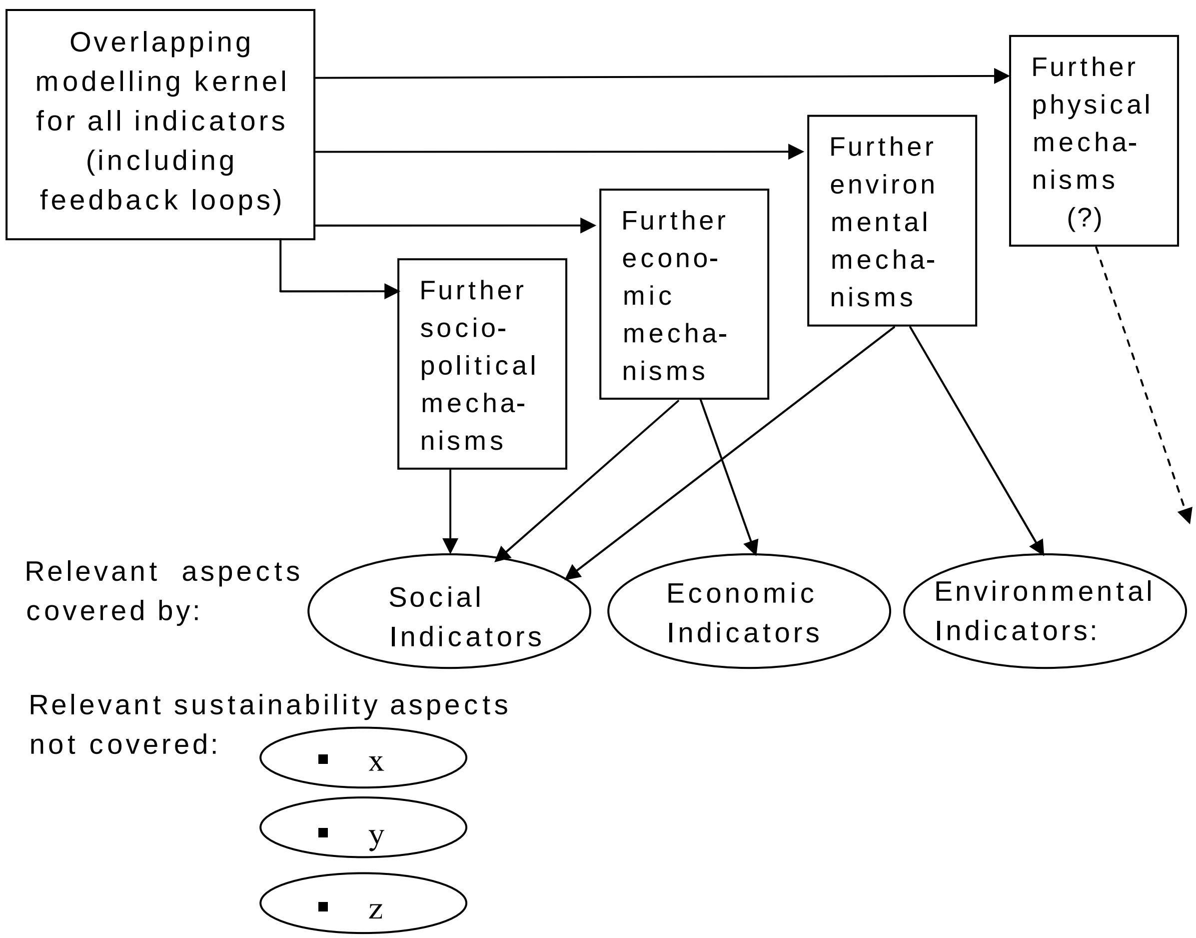


Figure 3: Empirical modelling for specifying sustainability indicators.

Figure 3 depicts the relation between modelling and indicators and draws attention to the fact that even in the most optimal modelling situation, relevant sustainability aspects will remain uncovered. These missing aspects should be specified as good as possible as they are relevant for decision-making, in any governance situation. The independent modelling for specific aspects, like the number of species in nature areas or the extinction of the giant panda, does not have any influence on other indicators, in the operational modelling as present. It also is clear that it is not self-evident how to independence of indicators can be defined, with lines crossing. Also, are there independent physical aspects to be covered by sustainability indicators, or are they relevant only as indirect indicator for the social, economic and environmental ones? Then including them in the base set would lead to double counting. The activities involved in this project relate to the strategic choices on how to evaluate effects of decisions, i.e. which types of indicators may be used for consistent decision support. As the options for modelling, and their active development, have a close relation to the modelling projects in Programme 2, active coordination between these programmes is to be established. The relation to modelling is different for social and economic aspects and for environmental effects, which are in an additional causal chain. The empirical modelling of environmental mechanism is so close at the heart of the consistency subject that it will be treated in this project, as one of the five main issues. So there are four alignment tasks and one task covering all environmental modelling[2]:

1. steps in causal chains covered, and equalisation between indicators;
2. spatial detail of indicators, and integration over space; consistent spatial differentiation for different impact categories for all commonly accepted impact categories but also including geographically differentiated land use and water use impact assessment indicators, consistent with choices in technosystem, economic and social;
3. temporal detail of indicators and integration over time;
4. place in causal chains of different indicators, mutual independence;
5. improved modelling of environmental effect chains, with similar place in causal chains for alternative environmental indicator sets (midpoint, endpoint) and with similar background scenarios (as for climate effects and toxicity effects).

One issue of communication of indicators is their sign. Do we need new metrics, as is suggested in deliverable 19, section 5.2.1? Employment is a positive aspect, while climate change is negative. Only by comparing to a worse alternative can a positive score be created, as when comparing recycling to non-recycling. The underlying indicator then still is negative. This negative formulation of environmental impacts is not an iron law however. Emissions of CO_2 lead to increased speed of growth in agricultural production; climate change makes the tundras more inhabitable. It seems however that environmental engineering focussed on such effects is not what we look for in sustainability analysis of technologies.

Specific projects in the domain of ILCD ((http://lct.jrc.ec.europa.eu/eplca/deliverables/consultation-on-international-reference-life-cycle-data-system-ilcd-handbook), and their results, will be a main input in this project, especially for Task 5. Furthermore, the work in this project will be aligned with ongoing similar work in the PROSUITE[1] project. Furthermore, the results of the MuSA[1] project combining LCA and RA should be considered.

The methods developed shall be demonstrated in real case studies, as on biofuels and nuclear energy, including a comparison with current methods and results.

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[2] All other recommendations from the JRC-IES ILCD Handbook-LCIA project are included in different projects as part of deliverable D14 (Zamagni et al., 2009a) on ISO-research needs (http://lct.jrc.ec.europa.eu/eplca/deliverables/consultation-on-international-reference-life-cycle-data-system-ilcd-handbook).

The planning of this project is in parallel with other projects in this one and the other programmes.

3.3.2 Framing the questions and a decision tree

Framing the question is a very important activity (Heijungs et al., 2007; Zamagni et al., 2009b). An erroneously framed question will get an erroneous answer. Framing the question, amongst other things, means that we ask ourselves in depth what exactly the problem is that we are trying to tackle, what the derived questions are, what the technological options are, what the scale of expected changes is, if a *ceteris paribus* assumption may hold or not, etc. For example, a study on biofuels may lead – and has done so in practice already – to various levels of analysis and the use of various methods and models depending on this question framing. If we pose the question in terms of "to what extent can we supply our global road transport energy needs in a sustainable way with biofuels", we are likely to end up performing the analysis on the level of an economy-wide technosystem with all three sets of performance indicators, running land use models, food models, IO based LCA models, etc. On the other hand, if we pose the question in terms of "is Jatropha-based biodiesel cultivated on set-aside land at a Brasilian farm for local use more sustainable than fossil-based diesel", we might end up performing a product-oriented (ISO)-LCA, possibly replenished with LCC and that is it.

One always has to wonder what the expected impact of the decision at hand is: what the mode of analysis should be (attributional vs. consequential); what the time-frame of the question is (backcasting; assessing the future impact of current technologies; assessing the future impact of future technologies; assessing the short-term and long-term future impact of a transition from current to future technologies; etc.); if the system analyzed is only replacing one other system on a small (local) scale, a product-oriented LCSA might give a sufficiently sensible answer; if it is expected that the technology used in the new system will probably expand to many more applications on a larger scale, the analysis will have to be risen to a higher (meso-level or economy-wide) level.

Question framing intends to unravel the starting sustainability question into questions for, whenever relevant, each of the three different "object of analysis" levels. Sometimes, of course, questions may refer to one level only, but let's suppose we have a starting question that can be transposed into one or more questions for each object of analysis. Questions and object of analysis are then highly interlinked and the models adopted and the deepening strived for together determine the exact technosystem analyzed. The same holds for the performance indicators: question and object of analysis determine which models and which indicators are adopted etc.

The project should frame questions for a selection of specific cases. Based on this, it should identify which methods and tools may already be available (see SWOT results in Schepelmann et al. (2008)) or are (being) developed in ongoing – or just finished - projects (such as NEEDS (http://www.needs-project.org/), EXIOPOL, IMPRO (http://susproc.jrc.ec.europa.eu/activities/IPP/impro.html), PROSUITE[3]). The pros and cons of those methods and tools should then be discussed for addressing the question at stake.

This research should be started up as one of the first activities of the LCSA research strategy.

This project should identify what help science and what help experiences with real (e.g. bio-energy) cases can offer in setting some guidelines for question framing; should result in a set of guidelines and a decision-tree for framing questions and linking them to the appropriate level, broadness and depth of life cycle sustainability analysis; and should further refine the scheme linking question and object of analysis to answers by models/indicators and the working procedure (semantic, syntactic and operational analysis) as first drafted in Deliverable D20 of the EU FP6 CALCAS project.

3.3.3 Co-ordination action Broadening

This co-ordination project should facilitate collaboration and harmonization within research "Programme 1: sustainability indicators for LCSA". This should result in the alignment of the results of the projects within this programme.

The field of LCSA research is so wide that no single discipline can cover all of it (see also Schepelmann et al., 2009). Scientists from various scientific disciplines will be involved. This is needed for getting most up-to-date and relevant knowledge into LCSA, but the attached risk is that of crumbled research with incoherent results for the different LCSA research topics as a consequence. That should be prevented and therefore far-reaching co-ordination is necessary. For this, co-ordination actions for two levels are proposed:

1. within research programmes;
2. within the LCSA strategy as a whole, between the three research programmes.

This project concerns the first type of co-ordination: co-ordination within research "Programme 1: sustainability indicators for LCSA".

How could this two-layered co-ordination work out in practice? Let's take the research "Programme 1: sustainability indicators for LCSA" and the projects "Options for indicators: aligning environmental with economic and social indicators" and "Options for ethical positions and societal values in LCSA" as an example. Employment or unemployment will most likely be elaborated as an economic or social indicator, when (un)employment is considered to be an important societal value. Fine-tuning between these two projects is then necessary. This would be a topic for a type 1 co-ordination action within the research programme "sustainability indicators for LCSA". Determining how generic issues of handling time (steady-state; dynamic; infinite or 100 years time horizon; etc.) are approached between the various programmes within the LCSA strategy, would be a topic of type 2 co-ordination.

[3] These project are referred to as just a few examples. It does not imply an exhaustive listing of relevant projects. On-going/completed work in this area is to be analyzed and build upon exhaustively by a potential tenderer in due time as yet and is not fixed here.

Co-ordination may exist of workshops on a common topic for all the research projects within research "Programme 1: sustainability indicators for LCSA", and will also include active co-ordination and control of projects.

This co-ordination project should start at the same time as the first project of research "Programme 1: sustainability indicators for LCSA" starts and should last until the end of the last activity within this programme.

The expected results of this project are the reinforcement and deepening of cooperation/ coordination within research "Programme 1: sustainability indicators for LCSA", the optimization of research spending, and the maximizing the research outcome of this programme.

3.4 Exemplary projects for science-oriented research

3.4.1 Options for ethical positions and societal values in LCSA

There is widespread agreement on sustainability, as a concept in the Brundtland Report (WCED, 1987), but less broad agreement on how to fill it in. Governance for sustainability ultimately derives its success from creating overall economic progress and alleviating poverty, by productivity increase and income (re)distribution; with improved or at least not deteriorating environmental quality; and with social progress in terms of equity and social standards. Major differences in ethical positions relate to distributional aspects, and to issues as to how acceptable compensation between different aspects may be. Different normative and ethical positions form a starting point for the empirical analysis, see deliverable 15 (Heijungs et al., 2009) and 20, especially sections 2.1.1 and 2.6 (Zamagni et al., 2009b). Though never final and fully agreed by all, consensus is always limited and dynamic, the overall evaluation of different aspects is essential in decision-making. The choice is always between alternatives with effects on all of them. Clarity on the ethical issues supported in LCSA is a prerequisite for its broad application and acceptance. Also, some level of formalised aggregation over specific effects is required to make the evaluation at case level practically feasible. Different effects at different places and at different times would lead to a plethora of individual items to be evaluated. In LCA, only environmental issues came to the fore. In LCSA, the link to social and economic issues is part of the analysis. The central goal of this project is to specify how main ethical positions may be covered in practical indicators and weighting procedures.

The activities in this project first relate to the main ethical position currently present in sustainability discourse and next how these can be linked to the practical level of indicators as then should be made operational in LCSA. These issues are intricately connected with "3.3.1 Options for indicators: aligning environmental with economic and social indicators", and with "3.4.2 Schools in sustainability analysis of technologies".

The distributional issues most clearly differ between Brundtland (WCED, 1987) and Rawls (1971), who has been most dominant in liberal and socio-democratic positions in the last decades. With Brundtland, the poorest, now and in future, should be cared for primarily, while at the same time decreasing the inequality in income and inequality in access to a high quality environment. It is the poor who suffer most from environmental deterioration. Rawls' position agrees on fundamentals but reckons with the practicalities of economic life. Minimum standards are prime, but if the absolute position of the worst off can be improved by allowing greater inequality, that course of action then should or might be taken. Rawls allows a trade off between criteria, while Brundtland does not. Similarly, there are ethical positions on weak sustainability, adhered to by most main stream economist, and strong sustainability, more common in ecological economics and with environmentalists. With strong sustainability, the environment is to be improved virtually disregarding cost. With weak sustainability, deterioration in environmental quality is allowable if compensated for with increasing income, possibly with additional distributional requirements as with Rawls or Brundtland. The justice requirements, to which both Rawls and Brundtland refer, go beyond distribution, linked to human rights, and to requirements regarding environmental quality and resource availability for future generations. Brundtland and Rawls are examples, but philosophers like Sen, Sunstein and Nussbaum have further differing positions, actively linking to the environment debate as well. LCSA has to link to this societal discourse, where possible, if it is to remain in contact with the socio-political reality. Linking to the practical level of sustainability discussions, as by linking to the sustainability indicators of EEA, Eurostat, OECD and UN, is a too practical road, with the number of indicators reaching half a thousand. The GRI (Global Reporting Initiative) has several thousands of indicators specified for the business domain only. Such a proliferation makes decision-making based on their full analysis totally impossible. So LCSA has to link back to fundamentals of the dominant ethical discourse in society, with indicators relevant there. This requires a substantial openness in modelling and criteria development. For example, the nuclear installations, specific variants of them, may differ substantially in the risk of nuclear proliferation, and management technologies for long term storage may differ as to the risk of accidents and misuse. This means that such normative aspects are to be reflected in modelled indicators. Similarly, when analysing biofuels, views on how humans should relate to their natural environment determine what indicators to use, like specifying the space for nature left. General treatment of all practical consequences of importance will not be possible, so a choice is to be made based on what is deemed relatively important. Aspects not developed before starting at a case level will usually be left out of account in studies, and if treated will be treated haphazardly.

The results envisaged in this project are the following:

- a view on how current indicators from the LCA domain link to that discourse;
- a view on indicator domains which are lacking now and could be filled in;
- a view on how different indicators might be combined, either as a lexicographical ordering (first criterion 1 to be satisfied; only then taking nr 2 into account; etc.) versus different weighting procedures, within environmental effect domains and between different domains of sustainability, as mains stream economists do like Stern and Tol;
- an operational set of weighting factors covering the domains of sustainability, conditionally linked to different ethical positions in the sustainability debate.

The planning of this project should be at the start of the programme, as it can give guidance to other projects.

3.4.2 Schools in sustainability analysis of technologies

In different communities there are different ideas on how sustainability questions should be posed and answered (see Heijungs et al., 2009). All of these will come to the fore with open stakeholder procedures and all are present in the sustainability debate. Different scientific communities reflect these attitudes in their method and models.

In many cases, these approaches will lead to assumptions and results, and even to different approaches in terms of questions asked and models used for answering. A clear example is the time specified and time integrated analysis of energy options by main stream economists, including fully monetised weighting, versus the technologists approaches which tend to leave out broader mechanisms, has no feedback loops from environment to unit processes and refrains, uses midpoints in impact assessment and tries to avoid weighting as being too subjective. Scientific approaches may differ in the treatment of many such aspects. They include: openness of methods to using relevant but 'different' knowledge; reckoning with behavioural aspects and motivation; time frames involved in economic activities, including the process of innovation; time frames in environmental mechanisms; locational differences in socio-economic and environmental modelling; the specification of effects to be evaluated as independent effects; dealing with multiple effects; linking micro level actions to macro level sustainability issues; partial or more full uncertainty and validity analysis; how to deal with low chance high impact effects, and several more. These are not just technical issues but also relate to views as can be recognised in different science domains. Resolving such issues hence is not just scientific development of better methods but also a discussion between the schools involved. It constitutes a key issue for broader acceptance of LCSA results.

Linking positions in each of these interconnected issues is not possible in a straightforward manner. In the Figure 4, only three such dimensions in modelling are depicted. The left and upper blog is filled with LCA-type of modelling. The lower right side is how orthodox economists model climate policy. They may refer to the same decision situation, like on the use of biofuels for reducing climate change.

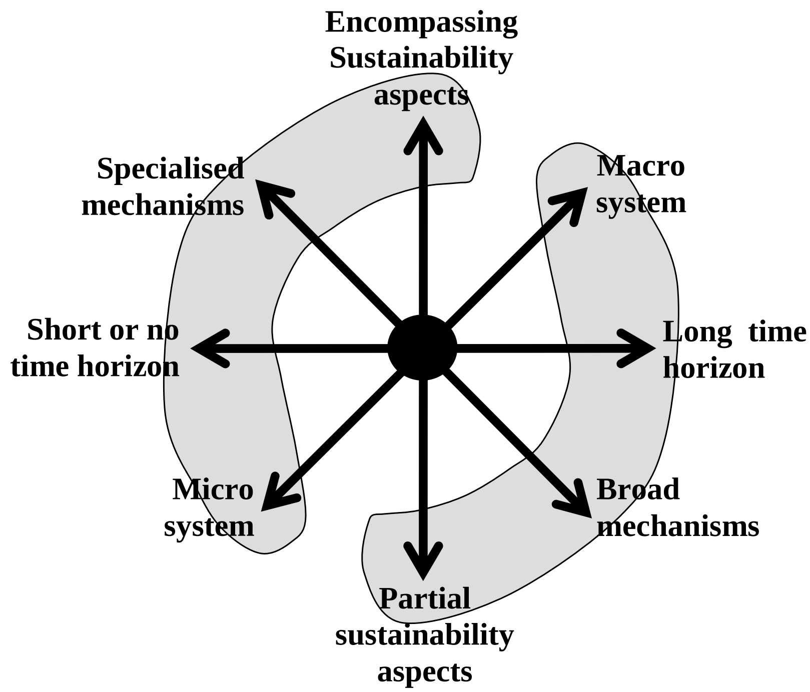

Figure 4: Dimensions in sustainability analysis of technologies

This project will bring together main proponents of these different schools, to analyse their common grounds, their accidental differences and their fundamental differences as are involved in their sustainability analyses of products and technologies. The differences will be highlighted in a number of key case applications, related to bio-energy and nuclear energy options.
Its results will be guiding the development of LCSA. They mirror these basic relations, first by focussing on common grounds where possible; next by avoiding accidental differences; and finally by treating different views explicitly, as in question variants, in options compared, in scenarios applied and in sensitivity analysis.

3.4.3 Governance

Goal and scope
Sustainability oriented decision-making in society is at many levels, from consumers choosing their products to strategy discussions on long term technology development, e.g., for setting up adequate institutional arrangements and policies. Hence when supporting sustainability oriented decision-making, widely diverging governance situations are to be covered in the analysis, and several options for improved decision support exist. This project has a close connection to CALCAS deliverable 8 (Vagt et al., 2008) and 13 (Jacob & Rubik, 2009) on Sustainability Governance.

Ideally, from an analytical point of view, all decisions would refer to the same overall sets of sustainability objectives and the same relevant knowledge, of course defined dynamically and filled in by all participants depending on their cultural and philosophical background. Discourse would centre around the values involved and about the uncertainties in the analysis leading to different views on reality. In practice, the analysis is much more open and not well defined.

Method choices lead to different outcomes; values are hidden behind assumptions; and uncertainties are often treated very partially, for example, by focusing at data uncertainties while leaving out the main uncertainties involved in the limitations of operational modelling, and the limitations on predictability. Even with well-developed LCSA methods and models, this will remain the normal situation. Different choices in the process of making an LCSA will lead to different outcomes. In many situations this means that by making choices selectively, almost any desired outcome can be produced. This is the normal situation in any domain of collective decision-making. To deal with this, we have an open society, with public discourse, with open modes of coordination, and with new governance as horizontal governance, involving stakeholders in the process without dominant hierarchies in decision-making.

The solution to the problem of "producing any outcome" cannot just be in improved methods and data, though of course rules for a balanced analysis are important. The solution is in the process of setting up the analysis and interpreting its results as a collective participatory procedure, involving different persons and organisations with different knowledge backgrounds and different value positions. In such a situation the role of LCSA is not only that as a tool for decision support, giving outcomes as options ordered as to their sustainability scores. LCSA is then also a tool for communication, for ordering the decision-making procedures and the analysis as a process of learning and discourse. In such a process, LCSA results are not final answers but are mainly intermediate inputs in the discussion. Methodological choices in LCSA can be revised to highlight new aspects, as learning through discussion proceeds. Open discussion and communication between independent actors, supported by analysis as is required by them, would lead to consensus. For examples, actors in the value chain, from the beginning of the supply chain with primary producers to the final users of goods and services communicate and agree on most apt ways for sustainability improvement. Research should elaborate strategies on how life cycle approaches in general and LCSA data and results in particular can be communicated better up and down such supply and value chains (Rydberg et al., 2008; Öman et al., 2008). In this business domain, often linked to politics, effective communication for consensus relates also to the general awareness and capability among staff and customers to communicate on sustainability issues and understand LCSA information. This is one main outcome of the analysis in deliverable 19, section 4.2.4 (Rydberg, 2009).

What is the language of discourse required for real dynamics towards the sustainability that we all want, one way or another? Philosophy and knowledge will determine the subjective individual positions to a large extent, next of course to strategic considerations usual with collective goods, like leaving cost to others while having the environmental advantage.

Developing local languages for discourse, with values and methods of analysis differing between domains of analysis, might be possible in principle, as is the option for having dialects within each domain, as full alignment and consensus will never be possible. Sustainability analysis in different domains would then be set up specifically, with specific sustainability goals and domain-specific modelling. Overall, this would increase the cost of communication tremendously. A single language in which to express ourselves would fit into the new governance ideals. A single language is not yet a single position in specific cases. Using the language will be based on specific LCSA studies for specific decision situations. However, discussion mostly are at a more general level, where Life Cycle Thinking can make a core contribution, building on general approaches to analysis and building on the expanding experience of LCSA case studies. This not only holds for public and public-private decision situations but also for purely private ones. What does non-environmental departments and professionals need to include life cycle thinking in their daily operations? Their information needs will differ substantially, not only requiring adapted analysis but may more important different ways of presenting questions, methods and results. Developments of tools and methods to ease life cycle thinking for various groups of professionals, (e.g. by formulation of rules of thumb or inclusion of environmental data in standard software like SAP® or freight management systems), thus giving content to the common language. The purpose here is to spread and use life cycle thinking also outside of the environmental departments, see deliverable 19, section 4.2.3 (Rydberg, 2009).

So what are the requirements on the common language for sustainability discourse? The language would have to be used by a wide array of decision-makers, covering policy domains of all levels, including the international one, non-state actors, and the interactions between all of them. Within this multilevel system, frequently rule making and the implementation falls apart with requirements for coordination across the levels. Within this multi-issue, multi-actor and multi-level framework, the role of tools for assessing decisions, technologies, products, etc. in regards of their sustainability is not self-evident, but a matter of dispute. In such context, there is no single institution, no single actor and 'owner' of evaluation procedures (Jacob & Rubik, 2009). If not having a common language, communication would break down and integrative views could not be developed. This is a key requirement for new governance, as involving several layers of government and supply chains through all sectors of production and consumption.
Moreover, there is no clear view possible on what constitutes a right distribution of burdens, as the right distribution does not depend on single decisions but on the total of outcomes of many small decisions. Also, decisions are not only to be based on expected consequences but may also be judged more directly as being unjust or undue. Getting rid of lead in gasoline is not a matter of individual action, as this would only reduce lead emissions to a limited degree. Accepting individual responsibility might well delay the collective decision-making required here. Creating such an individual responsibility may be unjust, directly, disregarding consequences, putting the burden of responsibility at the wrong shoulders.

On top of these issues, there is the high uncertainty regarding consequences. For example, IPCC has managed to establish a clear view on the most probable outcome of climate change. It might well be the case, however, that the highly uncertain outliers, like the climate runaway due to methane emissions from clathrates, constitute the main reason for action now. Can such highly uncertain predictions of effects be incorporated in LCSA, establishing an operational precautionary principle? This is what is required in many disputed areas, as on biomass for energy and nuclear energy. All such considerations relate to dynamic mechanisms, mostly not covered in LCA now. And when all is said and analysed, the evaluation problem comes up. There is no single answer where all agree, but there is a single decision to be made in most cases. Should coal-fired power plants have carbon capture and sequestration? Is the use of the two-stroke motor to be ended in transport? Even if all relevant facts were established, the relevant facts for all involved, there never will be full agreement in evaluation. Going for specific ways of integration to an overall judgment will always be disputed, but is the essence of decision-making.

Not going for specific outcomes, based unavoidably on some type of weighting, leaves the discussion on weighting unspecified and normative choices unfounded.

So the core question for LCSA in new governance surroundings is how an overlapping view can be developed, which covers considerations deemed important by most. Opinions not covered will of course remain. The core issue in this project is how LCSA can be set up in a way that it can fill in the role also in the participatory process of sustainability oriented decision-making.

There are three key domains which are to be linked for improved sustainability decision-making:
- the set-up of the decision situation;
- the capabilities and knowledge of those involved in the decision-making process;
- the set-up of the life cycle sustainability analysis.

With LCSA established in specific decision situations as a standardised method, as for example in Technology Assessment, the learning process of those involved can be focused and the process itself can be aligned with the requirements of an adequate analysis. With improved knowledge on sustainability analysis in society, the modes of analysis can be more complex, reducing the role of LCSA specialists. With a clear road map for sustainability analysis, and well developed lines of analysis for different situations, the complexity of the decision-making process can be reduced.

These three key domains structure the activities in the project. One strategic aspect for the project relate to practicality. On the one hand, the linking of decisions to their sustainability consequences is to be done as much as possible in an open way, to allow for deviating and dissenting views as are part of participatory processes. On the other hand, this open nature of the analysis should not jeopardise its feasibility and it should not increase the complexity of the results to an unmanageable level, rendering them useless for informed decision-making procedures.

Activities

What are the requirements for a well informed process of decision-making? There is diverging requirements depending on the governance situation, leading to diverging focus and set-up of the analysis. Linking the dimensions of governance to the dimensions of analysis for decision support is the key task in this project, always for a given level of available knowledge and capabilities of those involved. An SME developing a product will need a standardised method with standardised models and data, to select most attractive variants of the product without involving LCSA specialists. The EU making choices on major energy production systems needs specialists both from the energy domains and from the LCSA domain, in a well structured multi-party process of development of alternatives and their strategic assessment.

The process can be refined and well developed only if the analysis and the understanding of the analysis match. The analysis and its presentation is to be moulded towards the capabilities of the participants in the process and, in our knowledge democracy, the participants are to acquire the relevant capabilities to participate in the process adequately. The relation to policies is a double one. LCSA can be integrated into policies, as requiring LCSA as part of the policy preparatory or implementation process. And LCSA can structure policies, leading to more adequate policy processes and broader decision-making processes.

The linking of governance and analysis is to reckon with the variety of decision situations. It takes given decision situations and indicates how the analysis can best be adapted to the process, that is Activity 1. Next, modern governance is much based on institutions already reckoning with several aspects of sustainability, ranging from environmental liability to labour regulations. How to deal with such broader regulatory domains is Activity 2. The intertwining of the analysis and the decision-making process can also be initiated from the analysis side: how can decision processes best take sustainability considerations into account? This is Activity 3. The nature of society as a reflexive organisation is the final link back from governance to analysis. The reflexive nature of society leads to adjustment in behaviour based on the knowledge on current consequences as expected. If we know things to go wrong; we tend to do something about it. This is the subject of Activity 4.

Activity 1 Adapting analysis to the governance process

Dimensions in governance:

- specialist – generalist subject
- specialist – generalist decision-makers
- single decision – series of decisions as a process
- technology decision – technology influencing decision
- applied decisions – strategic decisions
- horizontal coordination – vertical coordination
- single layer – multiple layered decision-making (as in Open Mode of Coordination (OMC) in many domains of the EU)
- institutionalised regulation of sustainability – open situation as to embedding of sustainability in the decision process

Dimensions in analysis for decision support:

- qualitative information, as Life Cycle Thinking – quantitative information, as Life Cycle Sustainability Analysis
- empirical relations, as insight – empirical outcomes, as results
- empirical facts – subjective assessment
- factual information – normative interpretation

The result of this activity is guidelines for diverse set-ups of LCSA and broader life cycle thinking, not only to reflect the nature of the questions asked (as treated in the *road map*) but to reflect the specific processes involved in different decision situations.

Activity 2 Adapting analysis to existing institutional and policy frameworks

One specific issue is how to deal with aspects which are covered by specific policies already, or might be covered by specific policies. One main example is the European Union Greenhouse Gas Emission Trading System (EU ETS), which if working adequately, limits the overall emission level of climate changing substances and creates a market in which emissions have a price. In such a situation, the analysis of specific technologies, like wind power for dairy farms, and policies, like local climate policies, becomes redundant. Choosing the best option from a climate point of view leads to shifts in the total system, with no net effect as long as the ceiling in ETS remains the same. This covers European emissions only. Could climate change fully be left out of the analysis if global carbon dioxide-equivalent emissions trading would be installed? It then is the ceiling decision which determines outcomes, not so much the specific policies to correct market outcomes. If environmental liability would cover dynamic environmental taxes (in economists jargon: Pigouvian taxes filled in as Baumol taxes) the information relevant for economic and environmental decision-making would be covered in prices all over the economy, assuming reasonably working markets. Such polluter-pays taxes are now in discussion in France, Sweden and the EU, and are applied in several countries though at levels not yet influencing behaviour very much. The extreme of direct, physical regulation is not advocated any more as hardly implementable with diffuse global problems like climate change and resource depletion. The other extreme in institutions, fully horizontal governance, would require every person in all of his roles to reckon with all effects of all of his actions based on their expected sustainability consequences. This is fully impossible. In between is reality, with many decentralised decisions but also collective actions, specific policies, institutional arrangements and rearrangements, and cultural developments, all to be viewed from a sustainability perspective. Life cycle thinking is more relevant here than specific LCSA studies. So, specific institutions would lead to very differing requirements on the knowledge of all diverse parties involved.

Getting the role and set-up of analysis clear in relation to institutions is the prime result of this activity.

Activity 3 Adapting decision situations to reflect sustainability considerations

Integration of Life cycle approaches in policies and procedures reverses the focus of analysis. How can a decision situation best be structured to allow for relevant sustainability information to be developed and play its role? A most simple example is the Packaging Covenant in the Netherlands, which specifies technical requirements for environmental performance and then states that deviations from these requirements are possible if LCA shows that alternatives are more attractive environmentally. More broad information and decision support tools such as EIA (Environmental Impact Assessment) and SEA (Strategic Environmental Assessment) are reference approaches in regional planning and for construction projects, etc. However, life cycle approaches are rarely applied in their decision process. Research on modalities and methods appropriate for integrating life cycle approaches in such tools is strongly required, leading to practical recommendations. This is one major conclusion from D19, section 5.2.3.

There not only is a need to express the political will to use LCSA/LCT as well as a need to provide technical support in terms of data, methods, and quality assurance. Requirements for LCSA can be integrated in many more policies, thereby exploiting its full potential and stimulating the demand for the approach. For example, within the agricultural policies, there are few demands for LCA/LCT based approaches, but many potentials can be thought of, e.g. LCSA for agricultural products, for developing trade policies, use of structural funds, establishing Best Available Technologies (as in the Sevilla process), etc. It can be analysed for various policy areas which methods and what data is needed for a meaningful application of LCSA/LCT approaches (paraphrased from CALCAS deliverable 13 (Jacob & Rubik, 2009), p. 12 and see also deliverable 19 (Rydberg, 2009), section 4.2.1).

The prime result of this activity is a specification of options for application of LCSA in public but also private decision-making procedures, and how such applications could actively furthered by supportive measures and institutions.

Activity 4 Reflexive adaptation

When considering the consequences of policies and actions, a feedback mechanism comes in operation to avoid negative consequences and improve positive performance. Reflexivity is a general request – reflexive governance is a key element for sustainable development; see deliverable 13 (Jacob & Rubik, 2009), p. 14 and following. If this reflexive adaptation takes place in the decision process at hand, it is incorporated in the normal ways of decision-making. However, most often the reflexivity will be based on several developments pointing in the same direction, going beyond the decision process at hand.

An example is the green certification of biodiesel based sustainable palm oil production. Increasing the certified production for new applications as in Diesel oil will lead to economic consequences. Market mechanism will lead to expansion of the palm oil production elsewhere, probably in a non-sustainable manner. An example is the expansion of palm oil production in former rainforests of South-East Asia. We now can build into the policy option analysed additional rules to prevent this undesired consequence. We also may assume that separate policies will be developed to prevent this undesirable land use consequence. Or we may expect that such developments towards sustainable policies take place in developing countries. More sustainable land use policies will develop there as economic development takes place, as has been the case in the now industrialised countries. The handling of such feedback mechanisms then either is in the project, or is in adjoining decision processes, or is an option in modelling, especially of cultural, institutional and political mechanisms, see project 4.4.4. Dealing with reflexivity bears the risks of infinite decision-making processes and therefore continuous constraints for legitimation and effective action. Therefore, reflexivity in analysis and action would preferably be embedded in a clear time-schedule and decision-path to avoid undecided situations.

The institutionalisation of reflexivity through LCSA could also be an intermediate strategy between self regulation and hierarchical regulation, in a broader governance respect. Institutionalising LCSA is essential for broad application. Other tools have been elaborated contributing to an improvement of rationality within decision-making process, like Technology Assessment (TA), Impact Assessment or Environmental Impact Assessment (EIA). They came up in the last four decades. It would be interesting to study how their institutionalisation took place; where there were successes and where drawbacks. TA for example has been taken up as core area by parliamentary committees, institutionalised parliamentary scientific consultancies, scientific TA-communities, research institutes dealing with TA, etc. while, conversely, in the US a single political decision finished the very successful Office for Technology Assessment (OTA), showing the vulnerability of specific modes of institutionalisation. In institutionalisation of support for LCSA existing institutions like JRC, Eurostat, and EEA could further be strengthened, or new institutions, like an ombudsman for LCA could be created. Since such ideas of institutionalisation have not been sufficiently covered by existing research yet, research on the applicability of these approaches and to evaluate the achievements and possible shortcomings of existing institutions and their approaches to support LCSA as part of Activity 4.

The result of this activity 4 is an advice on how to deal with reflexivity both in analysis for decision-making processes and in institutionalisation for improved reflexive government.

Planning
The project is to develop in parallel to the major methods developments, giving inputs to the requirements on modelling development and on simplified presentation of results, and taking into account what can reasonably be expected from an adequate analysis. Also, the educational requirements for those involved in different decision-making situations will be specified, depending on their role in the decision-making process informing the development of LCSA learning modules.

Case references
The case references are to cover the divergence in decision situations and procedures, linked to specific technologies. The range goes from in-firm product development to public procedures as on product policy and policies regarding energy technologies. The cases reflect on past decisions and are chosen in a way that they are relevant for future decisions as well.

The in-firm cases could be linked to already well-informed sustainability decisions (like in BASF). A most complex case would be the analysis of possible policies regarding the use of nuclear energy. The ongoing discussions on the role of biomass for materials and energy could cover a broad and complex domain of multiple, interrelated decisions.

Expected results
- Guidelines for sustainability analysis geared to specific types of decision situations, as a process. The intertwining of decision situations with most adequate decision support in all stages of the decision-making process
- Advice on how to incorporate LCSA in specific public decision-making procedures, like Technology Assessment, environmental policy instrumentation, and policy development in general.
- Advice on improved public support for using LCSA in decision-making processes, not only referring to LCSA methods and data, but also as to the linking of methods and data with participatory procedures.
- Advice on how to deal with reflexive feedback mechanisms, which interact between decision processes and their analysis.

4 Programme 2: mechanisms in empirical modelling for LCSA

This chapter focuses on deriving a research programme for deepening the scope of mechanisms and particular mechanisms for LCSA (shortname: mechanisms in empirical modelling for LCSA). The topics for this research programme are based on the inventory of research issues that has been made in the Blue paper (D20), and thus in all previous CALCAS deliverables as the Blue Paper builds on the results of these previous deliverables. On top of that, topics have been derived from several open workshops that have been held as part of the CALCAS project, like the Leiden workshop on deliverable D1 and the CALCAS-ESF workshop in Brussels, and from SAT workshops and several projects done as part of the European Platform on LCA (http://lct.jrc.ec.europa.eu/eplca).
Below, topics for projects are identified and classified as either predominantly application-oriented or science-oriented. Finally, brief exemplary project descriptions are given for a selection of project topics.

4.1 Topics for projects

This research programme comprises of all topics that can be classified under mechanisms in empirical modelling for LCSA. Note that this excludes deepening of the modelling of environmental mechanisms as this is already covered in programme 1, described in chapter 3.
The topics identified as part of this research programme are considered important for improving and disseminating the use of the life-cycle sustainability assessment of products and technologies. Project topics are formulated independent of levels, i.e. product-oriented, meso-level and economy-wide. A topic thus comprises a subject of research that is important for all three levels. As far as relevant, this implies that a topic might need further elaboration for each level separately while guarding consistency between the elaborations. On top of these level-elaborations, there will be level-independent issues that need to be considered under the heading of a topic

Deepening mechanisms is particularly relevant for product-oriented LCSA. It is not yet so relevant for meso-level and economy-wide LCSA as we first need to have more clarity on initial technosystem models for these levels. For ISO-LCA we have a clear picture of its basic models, something which is still lacking at the meso-level and economy-wide level. Therefore we first need an overview of possible modelling options in general for these levels (see below and section 4.4.1).

This results in the following, preliminary list of project topics for research "Programme 2: mechanisms in empirical modelling for LCSA":

- Co-ordination action Deepening;
- Handbook of modelling options;
- Modelling options for meso-level and economy-wide technosystems;
- Options for modelling economic relations for LCSA;
- Options for modelling physical relations for LCSA;

- Options for modelling cultural, institutional and political relations;
- Scenario development for LCSA;
- Uncertainty analysis in LCSA.

4.2 Distinguishing between application-oriented and science-oriented research

The main driver for distinguishing between application-oriented research (to be funded primarily, e.g., by the EU or national governments) and more science-oriented research (to be funded primarily, e.g., by the ESF or national science organisations) is the type of funding (see section 2.3). There will often be grey areas between these two classes of research, topics may be elaborated in a application-oriented and/or in a science-oriented way, and topics for projects may also often comprise of a mixture of application- and science-oriented research. Therefore, a classification of topics to these two classes of research will always be a bit artificial and therefore remain debatable. The classification will thus be based on an assessment of the predominant application- or science-oriented aspects of the research embraced by a project topic, or a topic will be elaborated into an application-oriented and an science-oriented project, which then constitute two different projects.

Bearing the above in mind, the following projects are considered to be predominantly application-oriented:
- Scenario development for LCSA;
- Co-ordination action Deepening.

The following projects are considered to be predominantly science-oriented:
- Modelling options for meso-level and economy-wide technosystems;
- Options for modelling physical relations for LCSA;
- Options for modelling economic relations for LCSA;
- Options for modelling cultural, institutional and political relations;
- Uncertainty analysis in LCSA;
- Handbook of modelling options.

Below, brief exemplary project descriptions are provided for each of the project topics, distinguished to application-oriented and science-oriented and applying the formats and lengths discussed in section 2.3.

4.3 Exemplary projects for application-oriented research

4.3.1 Scenario development for LCSA

For all three levels of questions in LCSA, consequences analysed for decision support may extend into the longer future, especially with meso-level and economy wide questions. The modelling of mechanisms involved may be improved but can never fully reckon with developments in the background. Such developments may substantially determine the outcome of studies. In a scenario where non-fossil energy becomes dominant, energy aspects as leading to climate change loose some of their salience. Such scenarios should be so technology specific that the typical questions in LCA can be covered by them. Currently available scenarios, like the Millennium Scenarios, IPCC scenarios and the Shell energy scenarios, are not technology specific enough to link to LCSA.

According to the SETAC-Europe LCA Working Group on Scenario Development in LCA (Rebitzer & Ekvall, 2004) a scenario in LCA is "a description of a possible future situation relevant for specific LCA applications, based on specific assumptions about the future, and (when relevant) also including the presentation of the development from the present to the future." Backcasting, or time series specification, is integral part of the scenario specification, when time specification is required.

Scenarios may be developed in two different ways. Scenarios developed for a case study require support of the type the SETAC working group has developed, but then extending also to the meso and economy wide level, where requirements are different. Work on case oriented scenarios has focused up till now on product-oriented ISO-LCA. This project will inventory and assess the most appropriate options for scenario analysis for meso-level and economy-wide LCSA. For this, an inventory of options including how scenarios are used in IOA, Integrated Environmental Models (IEMs), etc. should be made and these options should then be assessed on criteria to be developed in order to select the best practicable options for meso-level or economy-wide LCSA. On top of that open questions as identified by the SETAC-Europe LCA Working Group on Scenario Development in LCA for product-oriented scenario-analysis should be investigated. Finally, consistency should be guarded between scenario approaches selected and developed for the three levels of LCSA: product-oriented, meso-level and economy-wide. Involving LCA practitioners in this project part is essential.

The second use of scenarios is that of general background scenarios, relating to optional developments of major technology domains like energy, agriculture, transport, and housing, and also reckoning with economic growth. Such scenarios are case independent, or at least usable for many case studies. In a technical sense, their application can be compared to the variant of Hybrid LCA where environmentally extended input-output analysis (EIOA) used for background data. Another challenge to face in this part of the project is to investigate the balance between endogenously modelling mechanisms or including mechanisms as exogenous scenarios, modelled outside LCA, or filling options in based on assumptions. An example of the latter are the four story lines and World views of the IPCC, making “people” and “profit” issues exogenous instead of endogenously modelled. The use of scenarios for background data is also practically useful for LCSA, diminishing the need of modelling mechanisms within LCSA studies. For example, consequential market-based modelling of biofuel production chains in country X using a partial equilibrium model (as might be based on GTAP or EXIOPOL (http://www.feem-project.net/exiopol/)) would estimate land-use consequences due to this single biofuel production system in country X. It might be more appropriate to run scenario analyses on global (agricultural) land availability for different purposes (food production, bio-material and bio-energy production etc.), and then perform meso-level and product-oriented LCSA studies analyzing what would be the most efficient and effective way to produce bio-energy (including fuels and electricity). This work on constructing quantified scenarios requires specialist input from the scenario makers and from the input-output community. The also political nature of scenario construction requires active involvement of a broad group of stakeholders.

Co-ordination with other projects from the research strategy, particularly those on modelling various mechanisms, will be essential (see also section 4.3.2).

This project has two main results. The first is for development of scenarios in cases, on most appropriate ways to quantitatively develop scenarios for each level of LCSA. It will provide practical tools and guidelines for LCSA practitioners on how to operate scenario analysis and where to get the required input data from. Practical models and tools will be identified and developed, specifically for product-oriented, meso-level and economy-wide LCSA. The techniques behind the models and tools can be level-independent. The scenario techniques identified and developed shall be demonstrated in real case studies, if possible making use of available and published LCA case studies for comparison of results.

The second result is a number of scenarios which can be used as background scenarios in case studies, at all three levels. They are fully quantified and time specified data sets, applied in major cases, including bio-energy and nuclear energy.

This research could be started up as one of the first activities of the LCSA research strategy.

The result of this project should contribute to an increased adequacy of LCSA results for all case studies performed including those on technologies and products analysed at meso-level or economy-wide level.

4.3.2 Co-ordination action Deepening

This co-ordination project should facilitate collaboration and harmonization within research “Programme 2: mechanisms in empirical modelling for LCSA”. This should result in the alignment of the results of the projects within this programme.

The field of LCSA research is so wide that no single discipline can cover all of it (see also Schepelmann et al., 2009). Scientists from various scientific disciplines will be involved. This is needed for getting most up-to-date and relevant knowledge into LCSA, but the attached risk is that of crumbled research with incoherent results for the different LCSA research topics as a consequence. That should be prevented and therefore far-reaching co-ordination is necessary. For this, co-ordination actions for two levels are proposed:

1. within research programmes;
2. within the LCSA strategy as a whole, between the three research programmes.

This project concerns the first type of co-ordination: co-ordination within research “Programme 2: mechanisms in empirical modelling for LCSA”.

How could this two-layered co-ordination work out in practice? Let’s take the research “Programme 1: sustainability indicators for LCSA” and the projects “Options for indicators: aligning environmental with economic and social indicators” and “Options for ethical positions and societal values in LCSA” as an example. Employment or unemployment will most likely be elaborated as an economic or social indicator, when (un)employment is considered to be an important societal value. Fine-tuning between these two projects is then necessary. This would be a topic for a type 1 co-ordination action within the research programme "sustainability indicators for LCSA". Determining how generic issues of handling time (steady-state; dynamic; infinite or 100 years time horizon; etc.) are approached between the various programmes within the LCSA strategy, would be a topic of type 2 co-ordination.

Co-ordination may exist of workshops on a common topic for all the research projects within the programme "Mechanisms in empirical modelling for LCSA", and will also include active co-ordination and control of projects.

This co-ordination project should start at the same time as the first project of research "Programme 2: mechanisms in empirical modelling for LCSA" starts and should last until the end of the last activity within this programme.

The expected results of this project are the reinforcement and deepening of cooperation/ coordination within research "Programme 2: mechanisms in empirical modelling for LCSA", the optimization of research spending, and the maximizing the research outcome of this programme.

4.4 Exemplary projects for science-oriented research

4.4.1 Modelling options for meso-level and economy-wide technosystems

In current ISO-type LCA, the core process delivers the functional unit and all other processes in the product system are linked by technical relations, reflecting principal causalities in the system. Dynamic aspects may be taken into account by specifying the relevant processes, for example the ones expanding due to increasing the amount of product for the functional unit. Questions on biofuels may be treated at this level. However, if the biofuel is produced in a biorefinery, and biofuels are used extensively, effects on staple markets for food and fodder and through these on land use, become essential ingredients for sustainability analysis and evaluation. The question asked then no longer is on comparing biofuels to gasoline and comparing different options for biofuels, but is on the larger scale system choices involved in biomass use for energy and materials. This is a meso-level question which may next jump to an economy wide question when biofuels broaden to bio-energy and are compared to other options for renewable energy. Systems analysis then has to shift in two ways. It has to become a multi-product system, and is has to cover totals of the products involved. A few tons of biofuel will not lead to hunger in the cities of developing countries; a few hundred million tons probably will.

In ISO-type of LCA, technological relations form the central element in modeling the product system, focusing on a functional unit defined as lean as possible to allow for comparison between options. An LCA of TVs would cover the production, use and waste phase. Not all aspects of these are treated equally, however. Most LCAs of a TV would exclude the broadcast issue, while the use of the TV fundamentally requires programmes to be produced and relayed to the TV somehow, by air or cable and combinations. If the purpose of the LCA study is to compare different types of TV, we often assume that these issues are the same for all alternatives, so that we can rightly leave them out, limiting the scope of the case study and restricting the effort needed for such a partial difference analysis. However, it should be kept in mind that we are thus not including the complete use phase of the TV, and hence not the full life cycle of watching TV. If such issues will differ between alternatives, they should be included in the LCSA model. On an economy-wide level, this may be the case. When the market share of wide-screen TVs grew, more and more broadcasting companies switched to recording wide-screen content as well, shifting the all apparatus involved. With the shift made there was no real choice between the existing TV format and the wide screen version it was only a matter of time in phasing the changeover. Such formerly left out elements may play a role in rebound mechanisms, which always are based on behavioural mechanisms. Analyzing high speed internet options may focus on the data transmission, but data transmission is not the activity but use of the PC, mobile etc is. Then reactions like increased working at home and reducing traffic jams become part of the system to be modeled. There then are more relations than technical relations, more functions than a single functional unit, the volumes of them play an independent role, and dynamic aspects become more relevant. For example, when considering carbon capture and sequestration (CCS) to reduce carbon emissions, the material requirements for substantial implementation require an amount of nickel which for years would be higher than current consumption. The speed of introduction of CCS is limited by such physical (and next economic) constraints. This becomes an essential element in modelling for LCSA.

So the question now is how to reckon with multiple functions, in a system with not only technical but also behavioural relations, and with physical options and constraints, and with volumes involved to be specified? In LCA, ISO has standardised the good practice. Before such a standardisation can take place for meso-level and economy-wide questions, the practice is to be developed. The overall structure of empirical modelling, covering what in LCA was called the inventory, is the subject of this project. Details in physical modelling of options and constraints are an essential part of this modelling, requiring a dynamic analysis. For example, the use of rare metals like platinum in renewable energy applications requires a substantial inflow of palladium in a build-up stage, which next can be reduced if adequate recycling schemes can be established, based on economic, cultural, institutional and political mechanisms. With this structure established further details in partial modelling domains (physical; economic; socio-cultural-political) can be detailed, in one project for each of them.

Whereas the ISO-LCA way of modeling technical relations is well-known, such a broader reference model is lacking at the meso-level and economy-wide level. Therefore, this project will survey and evaluate the most appropriate structure for modeling technosystems.

The requirement to be met is that on the basis of meso-level and economy-wide LCSI, it should be possible to better address large-scale societal questions, like for example on the transition to a renewable energy based society, nanotechnology applications as a group, development of national or continental waste management and recycling systems, etc.

As they will rather cause incremental than marginal impacts, non-linearities and feedback loops will be involved requiring the specification of full volumes.

In Figure 5, the right hand side of Figure 2, Structure for deepening, five main modelling domains are discerned. Environmental effects and their modelling are incorporated in programme 1, especially section 3.3.1.

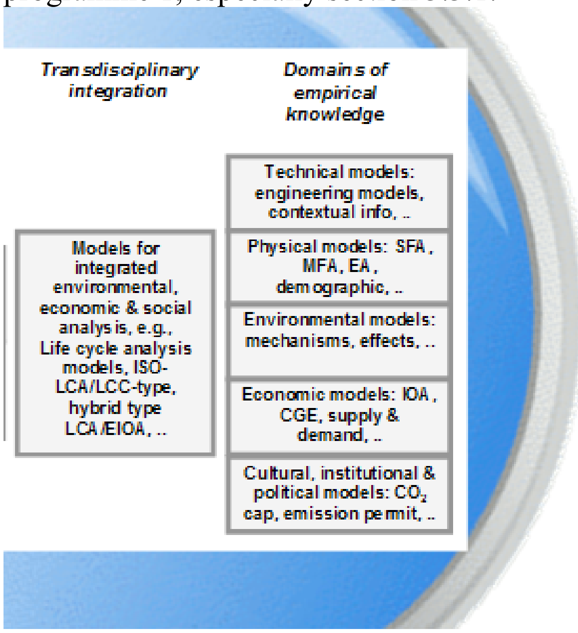

Figure 5: Empirical modelling for deepening.

In this project the interrelations between different modelling domains are the core. If there are constraints on some materials or on available land, these feed back into market models, and they may lead to cultural and institutional adaptations, and combined, may ultimately induce political action to guide the processes involved. Without such an overall structure in mind, filling in the specific modelling domains is not well possible. Reasoned choices require the overall structure first. There is an interrelation of course, as the overall structure is build from modelling blocks as are available or may be made available. So first a survey of partial modelling options will be made, a start of which is present in deliverable 1 (D1; Heijungs et al., 2007). A first step is to specify systems in full, without any allocation or cut off, and covering the economy as a whole.

One first option to investigate is on the possible role of an input-output type of structure, not yet incorporating further behavioural mechanisms, and specified for a reference date or for a time series. See deliverable 18, section 2.5 (Weidema et al., 2009), for a discussion of this subject including research recommendations, but with a broader bearing for higher levels of questions as well. Though often seen as an economic model, the basic fixed ratios input-output scheme is very much comparable to current LCI. It is without any explicit endogenous behavioural mechanisms, as is the case with LCI, but covers the full economy. It could function as the trans-disciplinary integration model. Also, economic models covering the full economy (for example CGE-type) always use a similar input-output framework. How exactly this is done can vary substantially. One may use a thirty sector representation for the full world or one hundred sector presentation with forty linked countries as now developed in the FP6 project EXIOPOL. Such representations might be tailor made for LCSA. Without additional mechanisms, these models will remain attributional in nature, even if applied to higher level questions for decision support, which tend to be consequential questions (see deliverable 18, section 1.6 (Weidema et al., 2009), for a discussion of this subject including research recommendations). They differ from the use of EIOA as specifying background data for functional unit based product LCI as currently being developed, see several papers in Suh (Ed) (2009). Such an IO-type of framework could hold economy-wide accounts for stocks and flows in three sustainability pillars, as advocated in deliverable 19, section 5.2.2 (Rydberg, 2009).

The other options for modelling concern both physical and behavioural mechanisms, the last covering both economic mechanisms and cultural, institutional, and political mechanisms. Modelling of environmental mechanisms, see programme 1, is usually independent from these behavioural mechanisms. Only if a feedback loop is involved, as is now adopted by some economic models for assessing climate measures. This latter option (including feedback loops through the environment) will be considered in the project. Especially for economy wide questions this loop might be relevant.

Technical and engineering models are usual in all production domains. They are not much linked yet to life cycle analysis yet. There is general software available such as Aspen BPS™ which includes optimisation modules. In this respect such models may also function as economic models, maximising some measure on profits. The goal function as specified might even include broader sustainability aspects. There also are more domain specific packages, s for instance SuperPro™, for use in the field of biotechnology. These models are partial models, covering a number of related installations or activities, and mostly assume one decision-making agent. The technical analysis may be included in the economic analysis by transforming it into a supply function. There are widely diverging assumptions possible, as on assuming constant capacity with varying capacity use, with a short time horizon, or on varying capacity with constant capacity use, for longer time horizons. Dynamic models technical and engineering models are possible but not usual. Expanding the use of technical and engineering models in LCSA is a clear goal. It directly links with economic modelling options.

Economic models typically cover the relations between several agents, like in market analysis which in its simplest form has a supplier and buyer of the one product involved. The survey further includes comparative static market models; Partial Equilibrium Models (PEMs), static or dynamic; applied general equilibrium models, again static or dynamic; Integrated Models; etc, see also the analysis in deliverable 1 (D1; Heijungs et al., 2007). Markets for several products tend to be linked. If corn prices rise due to demand for bio-ethanol as a fuel, some demand will shift to other staple foods and fodder, expanding production there, etc. Linked markets can be modelled operationally, as PEMs, to a limited level of complexity only. Linking ten or so markets already leads to substantial computational problems, with high requirements on data quality. Small shifts in supply functions can lead to widely diverging outcomes, as any experienced business man can confirm. Models covering the full economy can cover a limited number of markets only but may include other relations, like on investment, technological progress and growth, all highly important in sustainability evaluation. Economic models with behavioural relations usually are set up as comparative static models, with the time horizon implicit, in the relations. If a domain is well developed, the time paths involved may be worked out, leading to endogenously dynamic models. Such options often are partially implemented, giving some idea on specific dynamic mechanisms but not at all most relevant mechanisms together.

As special class of models dealing with complexity of socio-economic mechanisms with large numbers of different agents, is currently developing. They cover the same domain as economic models but may simplify relations focused at dynamics. Such agent-based models of complex systems can lead to the specification of evolutionary mechanisms. See the survey paper by Grimm et al. (2005) and a recent application by Cao et al. (2009), and the special issue of the Journal of Industrial Ecology on complexity, see Dijkema and Basson (2009).

Next, there are the cultural, institutional, and political mechanisms. These social mechanisms hardly allow for independent quantified modelling as yet. However, they may influence the nature and numbers of other models essentially. Suppose a cap on carbon emissions (as CO_2 equivalent emissions) is institutionalized, as in the EU ETS (European Union Greenhouse Gas Emission Trading System), which effectively reduces carbon emissions (let us say as CO_2 equivalent emissions). The improved carbon performance of specific product-technology system will then have zero effects at a macro level, unless it induces a political reaction, reducing the level of the cap. If climate policy is institutionalised in a different way, by a carbon tax, this same improved technosystem will have a positive net effect for the full economy, reducing total carbon emissions. If internet induces people to shift their consumption to services, this cultural mechanism may well lead to substantial differences in sustainability performance, though the internet connection itself may be a large user of energy and comes out negatively. Such social mechanisms may be implemented in economic models, if developed enough for that purpose.
There is a substantial overlap between empirical models and scenarios, as mechanisms covered in scenarios exogenously should not be incorporated again through behavioural models. This means that co-ordination between this project, the scenario project and with other projects on empirical mechanisms and models is essential (see also section 4.3.2).

It is clear that somehow the different options for empirical modelling require development in depth for each of them, see the next chapters. But using them is to be in an aligned way only, as otherwise the combined results come out of overall modelling in a haphazard way, useless for decision-making if not worse. Developing this framework for aligning assumptions, modelling and scenarios is a central research activity. The framework as now being used for describing this and other projects is a tentative one itself. It is part of the results in project 5.4.1, both content and consensus may be improved, leading to adaptations in research programming.

In a most practical sense, this project should identify and select most appropriate ways to quantitatively model technological relations for each level of LCSA, and it should provide practical tools and guidelines for LCSA practitioners how to operate these models.

Practical models and tools will have to be identified specifically for product-oriented, meso-level and economy-wide LCSA, but the framework behind the models and tools can be level-independent.

This project shall be demonstrated in real case studies, covering the same subject at different levels of questions and different levels of modelling. The linked cases of biofuel; biomass for energy; and the role of biomass in a renewable energy society seem good candidates.

Several overlapping studies have been published on this subject, LCA type studies; partial studies on specific mechanisms as for land use; and framework studies on mechanisms to be taken into account (cf. Zamagni et al., 2009b).

The result of this project should contribute to an increased adequacy of LCSA results for all case studies especially for questions on a meso-level or economy-wide scale. If such options become operationally available, they might also be used for questions at a product level, leading to different views in the role of functional units and allocation.

In terms of planning, this project should be one of the first activities in the LCSA research strategy, guiding the research in the projects for the specific modelling domains.

4.4.2 Options for modelling physical relations for LCSA

Physical relations have a core in natural science, as for example based on the conservation of mass and energy. Furthermore, there are physical parameters which are hardly changeable, from the inflow of solar energy to the earth, to the amounts of mineral resources and fossil resources on earth, and the amounts of land and seas of different types. In nature, ecological mechanisms determining population dynamics of species in the short and medium term and species evolution on the longer term also have their functioning at least partly independent of human interventions. Such physical relations and mainly natural size and developments of stocks and flows are to be reckoned with in analysing potentials and constraints of technologies. A bio-based society with globally high consumption levels of the type we have now, just is not possible within these constraints.

In getting a view on the constraints and potentials of a technology system, there are physical relations and constraints which cannot be ignored (Heijungs et al., 2009). There are limits in a physical sense as involved in the availability of resources and land. For example, supplying soot filters to all cars in the world is not possible within a decade due to limitations in platinum supply. In order to be able to also include available knowledge on such constraints and potentials, MFA and (dynamic) SFA have been identified in the CALCAS SWOT analyses (Schepelmann et al., 2008) to be useful additional tools to the LCSA road map. These tools can be used to assess potential constraints for resources and materials that are important for future technologies. For example, dynamic SFA scenarios demonstrated that platinum could become a constraint for fuel cell technology within one century. For bio-energy studies and scenarios similar information on land-use constraints is essential showing that and biofuels and -energy cannot be introduced unlimitedly. More in general, the challenge here is to bring resource scarcities into LCSA studies through the development of scenarios on scarcity of different resources on, e.g. technological change, economic performance, etc. The latter indicates that co-ordination with other projects on mechanisms may be essential (see also section 4.3.2).

However, economic activities cannot be linked to such mechanisms and constraints in a straightforward manner. Though the ultimate resource of some mineral may be given, the amount that practically can be mined depends on the mining technology and on the allowable cost (e.g., the market price). These are not constant in time. Also, the speed with which the volumes of mining can be increased is limited due to sheer size of the activities involved, requiring substantial investments, but also due to prospecting activities required, political procedures on who receives what, permitting procedures and research and development for the actual mining operations. The purely physical constraint, combined with societal constraints and options determine what is actually possible in terms of dynamics of implementation of specific processes and technologies. As most of these physical constraints are global in nature it is not the requirements of one technosystem which are relevant; it is the sum total of all technosystems, of the technosphere, which have to be taken into account. Nickel used of carbon capture and sequestration cannot be used for the building sector at the same time.

A further complication in the physical analysis is that some mechanisms are irreversible, like the energy in a system always being transformed to a higher level of entropy, while primary materials being used in some installations and products can be used indefinitely in principle, if energy and other materials are available for their collection, separation and remanufacturing or recycling. Some materials degrade in such processes, like aluminium being degraded and ultimately requiring an upgrade similar in requirements to primary production. Gold remains gold in concentrated applications, with only wear and tear diminishing these stocks.

How to set up the physical analysis to support technology decisions is the core subject and goal of this project. The core principles of energy analysis and material flow analysis (MFA) are clear, their application for LCSA is not. In energy analysis, there are competing paradigms, with a natural science type of energy analysis (energy never lost only transformed); on emergy analysis; exergy analysis; and the more economic energy analysis on what energy products we can produce and buy in specific forms. Also empirical data are relevant there and often lacking, as on the potential of geothermal and wave energy.

Most clear materials models are available in the MFA domain. Dynamic analysis of stocks and flows has developed. Scenarios in these stock-flow models are based on general assumptions of economic development; recycling options, very much dependent on specific applications, are detailed, each with their own life time and spreads; and options for primary production are specified. This dynamic specification requires a methodology and requires data to as on mining options for specific materials at specific prices, and links to assumptions on technology development in the sectors and products involved. For major materials, this analysis is to be set up in a case independent way. Such general data bases are to be developed, very similar to the data bases which form the backbone for LCA applications. Without them, case studies in LCSA of more complex questions will remain too slow and expensive.

As with LCI, not all information can be in general data bases. At a case level, the methodology can be used for specific materials relevant there.

This project will result in a specification of most appropriate ways to quantitatively model these physical constraints; it will provide practical tools and guidelines for LCSA practitioners how to operate these models; and a number of exemplary MFAs of core materials. These models and tools will be developed specifically for product-oriented, meso-level and economy-wide LCSA, though the general principles behind them can be level-independent.

The models identified and/or developed will be demonstrated in real case studies, preferably using already published LCA case studies for which additional modelling of physical constraints is performed.
This project could start after some major issues have been resolved in project 4.4.1 on the empirical modelling strategy and 5.4.1 on the LCSA research strategy, around the second year after programme start.

The result of this project should contribute to an increased adequacy of LCSA results for all case studies performed including technology questions at a meso-level or economy-wide level.

4.4.3 Options for modelling economic relations for LCSA

Current ISO-type LCA reckons with economic mechanisms exogenously only, as in the choice of processes relevant when expanding the production of a specific variant for the functional unit. It does not take into account specific economic relations as based on supply and demand functions (Heijungs et al., 2009). However, a number of proposals and case studies have been published in which some micro-economic aspects are part of the analysis. For instance, some authors have included shifts in market structure as part of the LCA inventory and others have discussed the inclusion of rebound effects. Inclusion of meso- and macro-economic models (modelling in terms of labour, capital, economic growth, spending etc.) has not yet received attention in relation to LCA.

Market effects on food prices and the induced clearing of rain forests have become relevant effects in the sustainability discussion of biofuels and bio-energy and rebound effects have surfaced as a consequence of, for example, the introduction of new information technologies. Rebound mechanisms now are lumped together in terms of the mechanisms involved. They may have a cultural background, as in adapting working behaviour or looking for new lighting options when light becomes less energy intensive. There also are normal market mechanisms, and one key element is on how income is spent which becomes available when goods and services become cheaper, which is the case with most innovations. How to link such relevant mechanisms in a consistent, not haphazard way is one key question here, linking to knowledge in the economic domain and also aligning with knowledge in the cultural and institutional domains. This research will contribute to a more sophisticated way of handling these economic mechanisms as part of life cycle sustainability decision-making. Also for this project, it will be important to co-ordinate with projects on other mechanisms. Such mechanisms form a key element for answering consequential question, for decision support, with adequate consequential modelling; see section 4.4.1 and also section 4.3.2.

This project will survey available approaches in economic modelling, (building on the surveys in deliverable 1 (Heijungs et al., 2007) and deliverable 19, section 5.2.4 (Rydberg, 2009); it will develop most appropriate ways to quantitatively model economic mechanisms for LCSA; and it will develop ways to use the outcomes of such modelling in a consistent way in the overall LCSA strategy at different levels of questions.

Some part of this analysis will be general in nature, as on the globally interlinked markets for staple food and fodder. Such analysis may then be integrated in the general scenarios for LCSA at meso and economy-wide level. The project will also provide practical tools and guidelines for LCSA practitioners how to operate these models at a case level, including support on availability of data. All results will differentiate as to the three main levels of question discerned. The biomass for energy subject seems a most appropriate one for case study, as was shown in the Blue Paper (Zamagni 2009b, annex 2).

Currently available models hardly are specific on distributional effects, which are key subject in sustainability, both within and between generations. Such information refers to totals in society, in a way to be specified in Programme 1. The IO type of framework may be used for bringing together information on distributional effects, after this information has been generated in behavioural models. There is not much experience here, but see Duchin (2005) and Duchin & Levine (2008) for some good starting points. Substantial development work is required. The disaggregation needed for distributional analysis (Jacob & Rubik, 2009), may lead to additional requirement on the trans-disciplinary integration framework. For intergenerational distribution longer time series are required, while economic mechanisms for analysing such longer term developments hardly do exist now. Also CGE models might be developed to incorporate some information on income distribution, though also their aggregation level might not be appropriate for this purpose. It seems that specific distributional modelling modules are to be developed in the economic modelling domain to cover these sustainability indicators. Such models are to be aligned with the normative analysis in distributional aspects, see project 3.3.1 and 3.4.1. They will have tentative results.

This project could start after some major issues have been resolved in project 4.4.1 on the empirical modelling strategy and 5.4.1 on the LCSA research strategy, around the second year after programme start.

4.4.4 Options for modelling cultural, institutional and political relations

In a broad social science sense, culture as the sum-total of knowledge and values, drives political and institutional development, the tree together driving economic processes. These in turn, in their material aspects, as the technosphere, have their influence on the environment as through extractions and emissions. Modern economic growth is based on institutions of learning, on intellectual property rights and on well developed rules for ownership, and on adequate infra structure for economic development. This of course is not a unidirectional development. There are feed back loops at all levels, within each functional element and between them. In LCSA, we are not concerned with the full social and environmental system as ultimately guided by cultural development and reflexive government, but in one of the many feedback loops: how will society and environment be different due to decisions on products and technologies? In a governance sense it is the policy process which is correcting the autonomous development of the system. From a technology evaluation point of view a choice is required on what is relevant to include as mechanisms. First, there are primarily physical feed back loops as treated in project 4.4.2, from the green environment to the black-and-blue technosphere and economy, see Figure 6. Next, there are feedback loops within the economy. If biofuels are added to the market, the energy market grows, with other activities influenced, growing, diminishing and possibly changing. There always is a close correspondence between economy and technosphere, with production and consumption having utility, at the society side, and having physical requirements and effects at the environmental side. This is the core of the technical analysis and of the economic analysis, see project 4.4.3.

The environment exerts its influence in a second way, not in a physical sense but in a perception sense, as a reflexive mechanism also including expected developments. This may be the driver of much of sustainability policies and measures, but such empirical effect mechanisms through politics are not included in the analysis of specific technology decisions as to their sustainability performance. As far as these perceptions guide economic activities, however, it seems they belong to the analysis. Perceived scarcity of oil in the future guides economic actions now already and should be taken into account. This feedback loop is through the culture of society. The culture itself has no sustainability effects. These occur through its influence on the economy and from there on the technosphere. The most difficult role to specify is that of the polity. Effects of governance based decisions at a case level would be part of the analysis, as defining the specifics of the case. The expected further reactions, by the same governance group, are not part of the effect mechanisms, as it is these decisions which are analysed. However, other reactions to choices on technologies should in principle be included. If Brazil is setting up effective land use policies, urged by the speed of deforestation due also to large scale biofuel production, this reflexive element should be part of the analysis. Again, the polity itself does not have direct sustainability influences. Only the effect on economy and technosphere (including distributional effects of taxes, etc) determine sustainability performance.

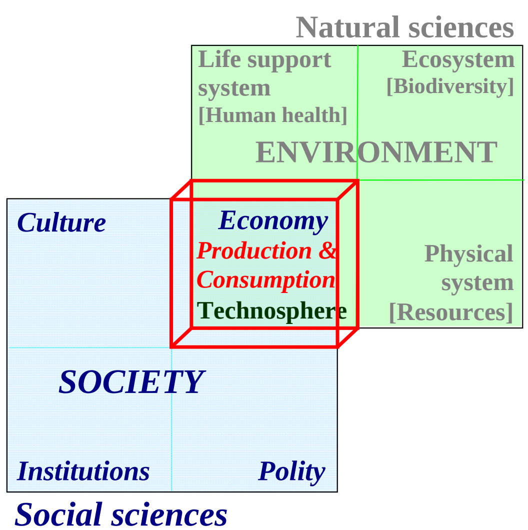

Figure 6: The role of social sciences in establishing sustainability effect mechanisms.

The institutions of society are the major creator of stability and dynamics in society, but there is no independent institutions manager. Institutions develop trough cultural mechanisms, in a fluid way, and they are created through the political process. Current discussions on protecting intellectual property rights, in the US, determine the power of large corporations versus small inventors, with a sure influence on many technologies to come. Such background developments help specify how specific technologies can come into existence in the economy.

Overall, the role of the social sciences is to help determine how the economic activities will develop. Their modelling is not independent but goes only through their influence on economic activities. How these social mechanisms can be fed into different types of modelling consistently and systematically is a very open subject, requiring close cooperation of very different types of social scientists, as Tamborra (2002) noted in great detail. For all longer term types of analysis these social mechanisms will determine a major part of the quantitative outcomes.

Since there are no independent social mechanisms towards sustainability effect to be analysed, the cases covered should not be chosen independently, it is the cases used in economic analysis which should be enriched by the social analysis.

This project should contribute to a more sophisticated way of handling social mechanisms as part of life cycle sustainability analysis. Especially for this project, it will be important to co-ordinate with the other projects other mechanisms in section 4.4. At a most practical level it will produce guidelines for LCSA practitioners how to gather and use the social science information in modelling for LCSA. This research could be started up as one of the first activities of the LCSA research strategy.

4.4.5 Uncertainty analysis in LCSA

Indicating effects of choices has basic limitations. These relate to:

- the not fully determined nature of our future, as covered in the use of scenarios;
- the set-up of the modelling of mechanisms; and to
- the parameters used in that modelling.

Parameters refer both to quantified estimations of empirical relations like elasticity of demand, and to data like emissions of specific power plants. Core question for this project is how these uncertainties involved in the analysis can be specified and quantified, as input into decision-making processes using LCSA.

LCSA studies may, depending on the goal and scope, comprise many methods, models, assumptions, choices and data. The robustness of methods applied have to be assessed and/or guaranteed, in order to provide sound and scientific based information, thus systems and solutions aimed at identifying and/or reducing uncertainties are necessary. Currently, uncertainty analysis is limited to LC(S)A studies that evaluate small (marginal) system changes. Some databases with inventory data and characterisation factors contain information (standard deviations, several alternative values, etc.) that can be used for uncertainty analysis. And some software for LCA contains routines for carrying out simple uncertainty analyses (Monte Carlo, etc.). The analysis still requires a large effort from the side of the LCA practitioner, that is one reason that many reported LCA studies do not address uncertainty, or only superficially. Moreover, uncertainty analyses yields answers that are not easily understood by a decision-maker: confidence intervals, t-values etc. A more encompassing analysis of robustness, including an uncertainty reduction strategy, requires definitely more, in the sense of method development, data availability, software implementation, communication and visualization, and training of LCA practitioners. At the same time, we must acknowledge that in order to let uncertainty analysis become a routine task, it must be simple to apply.

Therefore the field of advanced uncertainty analysis techniques is an important area of research, in particular on the following issues: simplification of the routine analysis of LCAs, development of assessment methods for the uncertainty in LCAs that evaluate large system changes, easy and yet meaningful way to present the uncertainty information.

A distinction can be made between parameter, model and scenario uncertainty and for each of these three specific types of uncertainty research needs have been identified. E.g., it would be useful to provide guidance on which specific technique for parameter uncertainty analysis is better to use in which context (e.g., for which governance or decisions situation; cf. 3.4.3), and to identify methods for assessing the appropriateness of distributions taking into account interdependencies between parameters as sophisticated as possible; there is a need for methods organizing the analysis and identifying significant sources of uncertainties; scenario uncertainty analysis should become routine practice due to the influence of choices to the final results, but feasible methods are still needed for dealing quantitatively with these choices.

Practical methods and tools for handling these three types of uncertainties will have to be elaborated specifically for product-oriented, meso-level and economy-wide LCSA, but the techniques behind the tools can be level-independent.

As this project may depend on the results of various other projects, the planning of this project can be shifted towards the second part of this research programme.

The result of the project is an encompassing though practical uncertainty analysis methodology for LCSA, allowing for a better basis for interpreting results of studies. This insight can improve the quality of results, by focussing on the most relevant uncertainties in intermediate stages of a project.

4.4.6 Handbook of modelling options

In this project, a summary overview is given of the results modelling different mechanisms as described in sections 3.4.1, 3.3.1, and 4.4.1 until 4.4.4, and an integration of models and data is made where possible.

The Handbook should summarize the results of the preceding projects focusing on one group of mechanisms, in an orderly and convenient way. This means that easy-to-use guidelines are provided to practitioners on how to handle and apply the various models. On top of that is should integrate these results, i.e. where methodologies or data requirements for modelling of different mechanisms overlap, integrated guidelines should be provided. The various model identified and selected in the preceding projects each require specific data. One main challenge here is to combine all this knowledge in a coherent framework. Efforts should be spent on analysing possible connections among the different methods and models, and particularly their input data.
Results from the project on framing questions (see section 3.3.2) should also be integrated, i.e. by providing guidance on determining the important mechanisms for a given sustainability question and relating that to modelling options. Finally, the Handbook should be illustrated with numerous, expressive examples and the scientific foundations of product-oriented, meso-level

and economy-wide LCSA and all possible modes of deepening and broadening should be documented in a separate scientific background document to the Handbook.

The work on this project can start after the last one of the preceding projects focusing on one group of mechanisms, has finished.

The resulting Handbook and scientific background document should summarize and justify the preferred modelling options, provide detailed guidance and - where possible – links to practical models and data for the different levels of technosystems and for sustainability criteria for that level from all the preceding projects focusing on one group of mechanisms.

5 Programme 3: cross-cutting research for integration

This research programme comprises of all topics that cannot be classified under one of the previous two programmes (chapters 3 and 4) because they concern cross-cutting LCSA research. The topics for this research programme are based on the inventory of research issues that has been made in the Blue paper (D20), and thus in all previous CALCAS deliverables as the Blue Paper builds on the results of these previous deliverables. On top of that, topics have been derived from several open workshops that have been held as part of the CALCAS project, like the Leiden workshop on deliverable D1 and the CALCAS-ESF workshop in Brussels, and from SAT workshops and several projects done as part of the European Platform on LCA (http://lct.jrc.ec.europa.eu/eplca).

Below, topics for projects are identified and classified as either predominantly application-oriented or science-oriented. Finally, brief exemplary project descriptions are given for a selection of project topics.

5.1 Topics for projects

This research programme comprises of all topics that can be classified under cross-cutting research for integration. The topics identified as part of this research programme are considered important for improving and disseminating the use of the life-cycle sustainability assessment of products and technologies.

This results in the following, preliminary list of project topics for research “Programme 3: cross-cutting research for integration”:

- Aligning time frames in life cycle sustainability modelling;
- Answering sustainability questions;
- Connections between different levels of questions and modelling;
- Co-ordination action Cross-cutting;
- Heterogeneous models aligned;
- Integrating dynamics of socio-economic and environmental modelling;
- Modelling framework and roadmap for LCSA;
- New ILCD Handbook for LCSA;
- New ISO-standards for LCSA;
- Participatory approaches;
- Simplified LCSA;
- Standardization of LCSA for policy;
- Sustainability oriented decision-making methodology.

5.2 Distinguishing between application-oriented and science-oriented research

The main driver for distinguishing between application-oriented research (to be funded primarily, e.g., by the EU or national governments) and more science-oriented research (to be funded primarily, e.g., by the ESF or national science organisations) is the type of funding (see section 2.3). There will often be grey areas between these two classes of research, topics may be elaborated in a application-oriented and/or in a science-oriented way, and topics for projects may also often comprise of a mixture of application- and science-oriented research. Therefore, a classification of topics to these two classes of research will always be a bit artificial and therefore remain debatable. The classification will thus be based on an assessment of the predominant application- or science-oriented aspects of the research embraced by a project topic, or a topic will be elaborated into an application-oriented and a science-oriented project, which then constitute two different projects.

Bearing the above in mind, the following projects are considered to be predominantly application-oriented:

- New ISO-standards for LCSA;
- New ILCD Handbook for LCSA;
- Simplified LCSA;
- Answering sustainability questions;
- Sustainability oriented decision-making methodology;
- Standardization of LCSA for policy;
- Participatory approaches;
- Co-ordination action Cross-cutting.

The following projects are considered to be predominantly science-oriented:

- Modelling framework and roadmap for LCSA;
- Heterogeneous models aligned;
- Connections between different levels of questions and modelling;
- Aligning time frames in life cycle sustainability modelling;
- Integrating dynamics of socio-economic and environmental modelling.

Below, brief exemplary project descriptions are provided for each of the project topics, distinguished to application-oriented and science-oriented and applying the formats and lengths discussed in section 2.3.

5.3 Exemplary projects for application-oriented research

5.3.1 New ISO-standards for LCSA

Building on the results of the LCSA research strategy, new ISO-standards for LCSA should be drafted. Integrated – or separate for each level – standards should be developed for all levels of LCSA (product-oriented, meso-level and economy-wide).

As this is no EU or ESF activity but something that ISO will have to initiate and lead once the LCSA research strategy has delivered its final (operational) results, a further description of activities, planning etc. is refrained from here.

5.3.2 New ILCD Handbook for LCSA

Building on the results of the LCSA research strategy and the new ISO-standards for LCSA, an updated version of the International Reference Life Cycle Data System (ILCD) (http://lct.jrc.ec.europa.eu/eplca/deliverables/consultation-on-international-reference-life-cycle-data-system-ilcd-handbook) Handbook from the European Platform on LCA should be drafted: the Handbook for Sustainability Analysis of Products and Technologies[4].

An integrated – or separate for each level – Handbook should be developed for all levels of LCSA (product-oriented, meso-level and economy-wide). The Handbook to be drafted should be a series of technical guidance documents inline with the new ISO-standard, following the same structure as the previous Handbook of the European Platform on LCA, and developed through peer review and public consultation.

The activities described above can start right after the activities of the LCSA research strategy have finished.

5.3.3 Simplified LCSA

In the project described in section 3.4.3 a distinction was made between simplified LCSA models or methods, and simplified presentation of LCSA results. the latter is part of the project described in section 5.3.4. The project described in this section deals with simplified LCSA models and methods.

In the FP7-ENV-2010 Work Programme 2010 - Environment (including climate change) (http://cordis.europa.eu/fp7/dc/index.cfm?fuseaction=UserSite.FP7DetailsCallPage&call_id=267#infopack) activities are announced addressing the development of simplified LCA methodologies and tools for different industrial sectors and the development of methodologies for expressing the somewhat complex results of LCA studies into easily understandable terms for public and private decision-makers. A similar activity for LCSA is foreseen. LCSA will in some aspects be more advanced that ISO-LCA. Barriers reducing its implementation should, however, preferably not be increased, especially for SMEs (high data intensity, costs, expertise required to run the LCSA studies, etc). Moreover, simplification is crucial to make LCSA operational and applied in practice (Zamagni et al., 2008; Rydberg, 2009; Schepelmann et al., 2009). Therefore, simplification should actually be integrated into all projects making LCSA more sophisticated, and it should be derived from the sophisticated method; see for example the OMNIITOX proposal for a simplified toxicity impact assessment model (Guinée et al., 2004)). The latter should safeguard the validity and credibility of simplified approaches (Rydberg et al., 2008; Öman et al., 2008).

Sector-specific eco-design approaches, working with Key Environmental Performance Indicators (KEPI) that do not require the designer to have LCA knowledge, could be a way forward. The objective of this research topic is to contribute overcoming some of these barriers through the

[4] This new ILCD Handbook for LCSA is different from the Handbook of modeling options (section 4.4.6). Whereas the Handbook of modeling options is rather a catalogue of modeling, the new ILCD Handbook for LCSA is a much more complex and demanding document, describing LCSA in logical and coherent steps, guidelines and methods and models. With respect to methods and models, fine-tuning of both Handbooks is a prerequisite

development of simplified operative methods and tools to be used by SMEs working in a number of industrial sectors.

To ensure consistency and compatibility with related tools in policy and industry context, the methods and tools developed will have to build upon the new International Reference Life Cycle Data System (ILCD) Handbook on LCSA, and therefore this activity can only be started after the work on the new ILCD Handbook on LCSA has finished. Web-based training courses on their application should also be developed by the project

A computer open source tool with a simple interface could facilitate cheap and quick LCAs, and increase the use of LCA significantly. It should be designed in a way that it could use already existing databases in a flexible and cost efficient way. Innovative technologies (e.g. semantic web) could be explored and implemented if feasible.

The sector-specific methods and tools developed shall be demonstrated in real case studies (at least one for each industrial sector tackled), involving SMEs acting at different levels of the value chain.

The Life Cycle Inventory (LCI) data sets resulting from the case studies implemented within the funded project(s) will have to be made available for free by the applicants as one component of the ILCD Data Network database. This topic is relevant for SMEs.

5.3.4 Answering sustainability questions

Not only question framing is important in performing and LCSA study, but also answering the sustainability question at stake properly is a profession in itself. Part of answering a question is interpreting the vast amount of results that an LCSA study can produce, particularly for giving insight in major mechanisms and when sensitivity, uncertainty and scenario analyses are performed. All of these useful and sensible analyses together may cause headaches to a practitioner when trying to interpret them. Up till now, practitioners often interpret the results of such analyses one by one and not in an integrated way. With improved analysis, in a technical sense, the interpretation of answers becomes increasingly complex. This problem of communication not only exists for final results. In all participatory processes involved, intermediate results should be presented adequately, adapted to the needs of different stakeholders. Based on discussion, these intermediate results should lead to improved consecutive analysis, with new and more final results.

The goal of this project is to design operative methods and tools for visualizing and interpreting the pallet of results of LCSA studies, e.g. by graphically presenting a sort of probability distribution of combining all possible results from performed sensitivity, uncertainty and scenario analyses, conditional dominance analysis, excluding combinations of mutually exclusive results, etc.

The methods and tools developed will have to be elaborated specifically for product-oriented, meso-level and economy-wide LCSA but the techniques behind them (e.g. data mining techniques) can be level-independent. The related cases on biofuels and biomass for materials and energy seem most appropriate to use as for developing methods and tools in a most practical sense.

As this project depends on the results of various other modelling projects, the planning of this project should be set around two years after programme start.

The result of this project should contribute to a better interpretation of results for all cases including the analyses mentioned above, and including the presentation of intermediate answers in participatory processes.

5.3.5 Sustainability oriented decision-making methodology

Decisions are framed, in an analytical and a social process. This framing may lead to specific questions and specific answers, In LCSA already possibly to be covered in a multiple way. Participatory procedures in LCSA, for example, may easily lead to combinations of levels of questions. For some, it is a product oriented question. For others, the LCSA question may better be analysed at the meso-level placing the product system in its broader context, and by some again, the analysis is better at the economy-wide level, to see it as part of overall societal development of technologies. In principle, this is not the end of framing questions in a more general way. Relevant reasoning could indicate that even with substantially improved technologies, the volume of the activities involved places a too heavy burden on the environment; may lead to social exclusion of substantial groups; or may contribute to instability in developing countries. The life cycle technology question then becomes linked to developments regarding consumption patterns, growth mechanisms, and ultimately to cultural developments as related to sufficiency and social cohesion. All such levels of embedding of decisions and questions are fully admissible in an open society.

The consequence is that decision-making cannot just refer to the case level analysed, as there can hardly be societal agreement on what constitutes the case. Broader and diverging contexts inevitably are involved. See on this subject concisely deliverable 13 (Jacob & Rubik, 2009), especially the sections on “Challenges of sustainability governance” and on “Reflexivity”. A most simple example may show the decision-making complexity. This complexity is somehow is to be resolved to avoid both paralysed inaction and haphazard choices, which may already result from broad stakeholder procedures at a case level. The capacity of the political system to deal with complex questions is limited. If we focus at renewable energy systems and squeezing the inflow of fossil resources, we may do so at a technical level, with many specific cases to be analysed and decided upon, by different decision-makers and different stakeholder groups, or we may go for the overarching policy of Kyoto and Post-Kyoto/Copenhagen, or less encompassing but more effectively towards a regionalised cap-and-trade system like the European Union Greenhouse Gas Emission Trading System (EU ETS) with main trade partners joining the system. If focussing on the last policy options, multi-stakeholder actions on specific technologies will recede from public attention and in a way they become less important, with participatory processes shifting to different subjects. In such a policy context, then the corrected market can do its work, in this climate respect at least. Cultural questions on consumption and growth then form a second large chunk for societal development, requiring the spirit and actions of dominant groups in society. Ethical-political positions also may lead to divergent framing of decision situations. In the discussion on lead free petrol, some see it as very wrong to leave such decisions to individuals in society. Lead in petrol should be abolished by a collective decision, not by private decisions of those wanting to improve environmental quality. Lead in petrol must not be a private decision-making issue, or one by green firms; that is fundamentally wrong. Looking at technology choices from these higher order strategic levels may reduce the salience of decision-making and may lead to different views and choices on what "the case" is. If such issues of broader embedding are not resolved, the danger is that LCSA becomes a minority issue, ignored in broader domains of decision-making in society. So, the goal of this project is to help place LCSA in its broader decision-making contexts in society, by developing a sustainability oriented decision-making methodology as a framework for specific LCSA supported decisions.

The tasks involved first involve to charting of these embedding mechanism in society based on historical cases.. On the one hand these involve 'wicked problems', that is problems where there is no agreement on relevant value domains and values, nor on key facts. Main examples to be covered are the nuclear energy discussion; the discussions on genetically modified crops; and possibly the discussions on nanotechnology. On the other hand, there are success stories, where the 'wicked problem' situation might have occurred but has been resolved, leading to adequate decisions and actions. The second part relates to what we can learn from the analysis in terms of how to frame the case analysis of LCSA into the broader decision-making procedures in society.
The result of this project is based on the analysis of the second task: advice on how to embed the technology subject at hand in a broader social fabric, giving guidance to the question framing discussion and guidance on whom to involve and how in participatory procedures, ultimately supporting a methodology of decision-making which reckons with this embedding subject in a most adequate way.

This project will need a substantial input from social sciences and has to link to all other projects in Programme 3. It can start right at the beginning of the implementation of the research strategy.

5.3.6 Standardization of LCSA for policy

The current standardisation of LCA for policy is supported by JRC-IES, as resulting in the ILCD Handbook. The focus in this project is supplementary, covering new elements coming up in LCSA as deepened and broadened LCA and also covering unresolved issues in LCA, as for example on the now divergent allocation procedures and on the consistent treatment of time in impact assessment. Within the allocation subject, there is for example the treatment of biogenic carbon and CO_2 emissions, now differently standardised in different policy contexts. Also, the relation of functional unit based LCA (or product-oriented LCSA) to meso-level questions is to be clarified, as allocation just does not play a role at this meso-level. Full systems are compared there, using different criteria for comparison. So the broader scope of LCSA leads to several additional issues in standardisation, and possibly to solutions to current problems in standardisation. At the product level for example, requirements on EPDs might be formulated differently based on meso-level insights. At the meso-level, requirements on LCSA, especially in terms of the road map, are to be aligned or even integrated with the requirements on Technology Assessment as formulated by the EU and several countries. All such issues either go beyond the current ILCD, or should become part of new versions of ILCD. This last choice is a fundamental institutional choice to be made in practical standardisation.

For clarification, let us focus on one specific issue: CO_2 emissions by a product system. Several national governments, national bodies, EPD schemes etc. have adopted or are adopting so-called life-cycle based carbon or broader Greenhouse Gases (GHG) indicators for measuring the carbon footprint of bio-based fuels and various other consumer products. The European Commission is also working on the implementation of ways to determine the carbon footprint (greenhouse gas balance) from (bio)fuel chains. From a policy alignment point of view it is important to bring the EU calculation methods in line with the calculation methods developed by the individual Member States, for example the German Product Carbon Footprint and the UK PAS (Publicly Available Specification) 2050, and possibly also with international standardization work such as upcoming ISO 14067 on the quantification and communication of carbon footprints for products, and the development of a GHG Protocol for products and Scope 3 by the World Business Council for Sustainable Development (WBCSD) and World Resources Institute (WRI); see for a nice overview of initiatives: http://www.lcacenter.org/LCA9/special/Carbon-footprint.html. Life-cycle based biofuel studies persistently have problems with the handling of biogenic carbon balances and with the treatment of co-products and recycling. Particularly the combination of these two issues can lead to flawed results (Guinée et al., 2009). Member States have formulated various ways of solving the allocation issue in particular: on the basis of mass, energy, economic value of co-products, avoided burdens, etc. The ILCD Handbook - General guidance document for Life Cycle Assessment (LCA) also still gives room for application of various allocation method, see page 136 of the ILCD Handbook - General guidance document for Life Cycle Assessment (LCA): http://lct.jrc.ec.europa.eu/lca-files/ILCD-Handbook-General-guidance-document-for-LCA-data-and-studies-Draft-for-public-consultation-clean.pdf. For some policy applications this guidance may not go far enough. As the GHG indicator may constitute the basis for granting subsidies to stimulate the use of bio-energy, for example, and as many Member State methods provide no guidelines on the handling of biogenic CO_2 and guidelines for allocation issues that still leave room for various choices, current methods are not yet sufficiently robust for these policy purposes.

Summarising:

- Different allocation methods for CO_2 are now applied within and between systems, leading to widely diverging outcomes.
- The link of allocation to broader modelling issues for LCSA is poorly established.
- A prospective formulation of the question or questions to be answered is lacking.
- In several societal domains practical solutions with poor theoretical status are being formulated for decision support, leading to a spread of haphazard methods which cannot be communicated.

If such routes towards solutions are formulated - in the directions indicated above or in different directions - there is a clear need for standardisation for policy. The aim of this project is to define how this standardisation might be approached, both detailed, as with CO_2 related issues, and broader, as with relations to Technology Assessment, and involving the different levels of questions in the road map for LCSA.

The case of carbon footprint will be used as an example to show the diversity and inconsistency of methods now developed, and to see how more generic solutions might be formulated based on the deepened and broadened analysis of LCSA.

The results of the project will include:

- a proposal on how to embed LCSA standardisation for policy in an institutional sense, linking to other standardisation domains;
- a proposal on how to resolve major issues in current standardisation, in the new road map of LCSA, reckoning with different levels of questions, as on carbon foot printing;
- specific proposals on how to deal with current subjects of contention.

The project will involve an advisory board with specialists in standardisation for public policy, from the different applied domains where issues now arise in public policy.

The project can start at the beginning of the Programme.

5.3.7 Participatory approaches

In the broader governance situations, which are customary in modern decision-making and especially in sustainability oriented decision-making, the process of decision-making and the process of analysis for decision support are intricately intertwined. The general relations of governance and LCSA are the subject of the project on Governance, described in section 3.4.3. In this project, the focus is on how to deal with the multitude of participants involved in decisions at a case level, especially larger decisions. The learning-and-discourse processes involved can follow the general structure of LCSA (see Zamagni et al., 2009b; sections 2.3 and 2.4), see Figure 1, and more specifically can use the road map at a project level in the goal and scope stage of the project. However, there is no generally accepted working method on how to involve stakeholders and for which issues to involve them. In the Dutch Handbook on LCA (Guinée et al., 2002) procedural guidelines are provided for six decision situations. Other tools identified in deliverable 4 (D4; Schepelmann et al., 2007) as part of the CALCAS SWOT analyses of approaches, methods and tools assessed in deliverable 10 (D10; Schepelmann et al., 2008), provide additional examples of reflexive and participatory approaches. They include Sustainability Assessment (SA), Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA), and Eco-Design (EE).

However, there is no clear-cut rules on whom to involve in the participatory process and how to organise this process, nor are there established methods for decision procedures, though in some obligatory processes like IA and EIA there exist rules for consultation and participation. There is a number of roles in the participatory process, which are to be filled in adequately, giving indications on whom to involve. These relate to the domain knowledge, the general policy context, the LCSA knowledge as required and, most diffusely, to the normative positions included in the project. In a practical sense, the latter involve the choice of sustainability indicators and their prioritisation and weighting. Some may value the welfare of future generations highly and will therefore want to see the cumulative storage cost of nuclear energy specified, if going for nuclear energy in a broad way, while others are content with the net present value of such costs now. In the first position, the question on a specific building project or technology design shifts from the project level to the sector-level, while with the second position the LCSA can remain at the product level.

How the LCSA process is to be managed directly relates to how the decision situation is structured. In a consensus decision procedure, the consensus is required in the LCSA as well, leading to a participatory process between equals. With deviating positions and views, this can be complex and lengthy process. In a more hierarchical situation, there is a core participant who can structure decisions or can decide on the set-up of the analysis and the conclusions drawn from them. Then other participants shift from a participatory to a consultative role, with all shades of grey in between. In this situation, the acceptance of LCSA outcomes and the decisions which are supported will be smaller, leading to a more limited legitimacy and support. Also in a more practical sense, participation might help to overcome problems of hidden normative values within LCA and increase the results' quality and robustness as well as their acceptability within the political discourse, see the outcomes of deliverable 13 (Jacob & Rubik, 2009), especially p. 14 and following. This acceptability also extends to those not participating in the process, up and down supply and value chains, ultimately to users of products involved; see, for example, deliverable 19 sections 4.2.4 and 6.2.1 (Rydberg, 2009).

So the central goal of this project is to develop a general participatory framework which allows for a consensus oriented LCSA, of highest feasible quality, as a basis for well supported decisions.

A core issue involved is how to keep the LCSA process manageable in terms of cost and duration, and how to get to adequate results for decision-making, the most adequate feasible.
The issues in content relate to level of questions and the indicators involved, with other main choices, as on options to compare, depth of analysis, the number of iterations, and the extension of the group of participants following. If indeed the question is brought to the meso-level do we still maintain the analysis at the product oriented level as well? If some want to see the analysis extended to the economy wide level, how can we accommodate such further expansions? How to deal with strategic behaviour, of some wanting to postpone a decision they don't want? What if the pluralistic processes are hijacked by powerful interest groups with ample resources? Can such minorities be overruled or should at least an outline of "their" analysis be included in the LCSA? Do we expand the specialist LCSA support team with scenario specialists? Is any LCSA not going to be a major endeavour with substantial cost and duration, limiting its broad applicability and hence usefulness? Pluralistic processes

Aligning to these diverging requirements is possible if clear routes for participatory analysis are developed, for typical decision situations. Experience in different domains of sustainability analysis for decision support forms an empirical basis. Most detailed examples include the British Big Public Inquiry, as has for example been used for decision support on nuclear waste management and genetically modified crops. One key outcome is that in such a process, low-chance-high-impact effects tend to become more dominant in the overall evaluation, especially if evocative indicators and examples are developed. Ongoing project which might serve as a well developed example is the FP7 SPRing project on nuclear energy analysis. At a more general level, results from other EU projects like Sustainability A-Test, MATISSE, or FORESCENE are to be taken into account.

The results envisaged in this project are on the set-up of main stakeholder procedures and how to use the road map of LCSA in them. As the knowledge on such procedures resides primarily with LCSA practitioners, they should be involved to assess the practicality of the guidelines and to set them up in a way that they can help organise the participatory process most adequately. The practical guidelines for dealing with participatory approaches in LCSA will have to be developed specifically for product-oriented, meso-level and economy-wide LCSA, and for combinations where required. The general line of reasoning can be level-independent. A final element is how these participatory processes may be institutionalised both in the public and the private domain.

5.3.8 Co-ordination action Cross-cutting

This co-ordination project should facilitate collaboration and harmonization within research "Programme 3: cross-cutting research for integration". This should result in the alignment of the results of the projects within this programme.

The field of LCSA research is so wide that no single discipline can cover all of it (see also Schepelmann et al., 2009). Scientists from various scientific disciplines will be involved. This is needed for getting most up-to-date and relevant knowledge into LCSA, but the attached risk is that of crumbled research with incoherent results for the different LCSA research topics as a consequence. That should be prevented and therefore far-reaching co-ordination is necessary. For this, co-ordination actions for two levels are proposed:

1. within research programmes;
2. within the LCSA strategy as a whole, between the three research programmes.

This project concerns the first type of co-ordination: co-ordination within research "Programme 3: cross-cutting research for integration".

How could this two-layered co-ordination work out in practice? Let's take the research "Programme 1: sustainability indicators for LCSA" and the projects "Options for indicators: aligning environmental with economic and social indicators" and "Options for ethical positions and societal values in LCSA" as an example. Employment or unemployment will most likely be elaborated as an economic or social indicator, when (un)employment is considered to be an important societal value. Fine-tuning between these two projects is then necessary. This would be a topic for a type 1 co-ordination action within the research programme "sustainability indicators for LCSA". Determining how generic issues of handling time (steady-state; dynamic; infinite or 100 years time horizon; etc.) are approached between the various programmes within the LCSA strategy, would be a topic of type 2 co-ordination.

Co-ordination may exist of workshops on a common topic for all the research projects within research "Programme 3: cross-cutting research for integration", and will also include active co-ordination and control of projects.

This co-ordination project should start at the same time as the first project of research "Programme 3: cross-cutting research for integration" starts and should last until the end of the last activity within this programme.

The expected results of this project are the reinforcement and deepening of cooperation/ coordination within research "Programme 3: cross-cutting research for integration", the optimization of research spending, and maximizing the research outcome of this programme.

5.4 Exemplary projects for science-oriented research

5.4.1 Modelling framework and roadmap for LCSA

The road map for LCSA developed in the Blue Paper (D20) including the procedural framework for LCSA and the structure for deepening can be further improved, elaborated in steps and details with respect to choices and options. Moreover, the proposed road map, framework and structure should preferably be submitted to a more elaborate consensus process, allowing more time to the LCA community to react upon these proposals and also allowing other communities, e.g. the Technology Assessment (TA) community, to participate in this process. Comments already provided during the open consultation of the Blue Paper (see the CALCAS website: http://fr1.estis.net/sites/calcas/), which could not be handled yet as part of the CALCAS project, will be included and debated as part of this consensus process, including topics as:

- The relation between ISO standards and the development of LCSA: what is already mature for the standardisation; which existing methods can be combined with ISO LCA for more complex applications in the meantime; what shall be in between the research on LCSA and standardisation process; etc.?
- How do the three levels of LCSA analysis (product, meso, economy wide) differ from other classification, e.g. the ILCD Handbook, should these be aligned or are ther good reasons for these differences, and what are the criteria for selecting a product-oriented, a meso-level or an economy-wide analysis (type of question; object of analysis; expected impact of the decision; etc.).

The consensus building will require active participatory procedures as applied in earlier concerted actions such as LCANET and CHAINET[5].

In addition and parallel to this consensus process the road map, framework and structure should be applied and tested in pilot case-studies. These studies should address varying levels of questions, determine in more detail what the precise driver is for differentiating between different levels, and identify mechanism models useful for that case study on the basis of, for example, the results of the CALCAS SWOT analyses (Schepelmann et al., 2008). The exercise with case-studies should learn how LCSA relates in more detail with individual methods and models like LCA, Material Flow Accounting (MFA), Substance Flow Analysis (SFA), Input-Output Analysis (IOA), Computable General Equilibrium Models (CGEM) etc. Is LCSA only an integration framework of these methods and models for answering life cycle sustainability question or is it more than that?

Another outcome of the pilot case-studies should be a further specification of steps that are necessary to perform the work within the procedural phases Goal and scope definition, Modelling and Interpretation. Starting point for these steps are the elements and items as defined

[5] CHAINET was a concerted action in the EU Environment and Climate programme (ENV4-CT97-0477). Similar to its predecessor LCANET, it was a European network which sought broad participation. CHAINET addressed the use of a variety of environmental tools. The Concerted Action commenced in December 1997 and ran for 2 years.

by ISO 14044 for each phase (where Modelling is an integration of the ISO phases Inventory analysis and Impact Assessment). Furthermore, special attention should be focused on a unified terminology. Results of the case study exercises should be submitted to the consensus process. This small-scale preparatory consensus project should begin right from the start of the LCSA research strategy. Case studies should not be performed as full LCA studies but merely as Goal and Scope exercises.

The results for this project are a refined and consensus-based road map, procedural framework and deepening structure for Life Cycle Sustainability Assessment (LCSA). The project results will be supportive in formulating more final programmes and projects, already before commissioning them, and may reckon with the different options towards funding as now indicated in chapter 7, and by then maybe other ones as well.

5.4.2 Heterogeneous models aligned

Current models cover a broad and divergent domain of mathematical descriptions. These are partly based on differences in variables covered, partly based on different assumptions, and partly based on different interpretations of the mathematics involved.

To give an example of the last: the now usual description of a product system in LCA in matrix form may be interpreted as a steady state model, as an average over the system life time, or as a time slice covering one year of operations for the functional unit. In behavioural modelling in economics, the usual approach is to first specify major relations and implement these in a comparative static model. Only when major mechanisms have adequately been modelled are they put into a dynamic model. The comparative static model, however, already has an underlying time frame assumed. Simple elements like the price elasticity of supply are very much time dependent. Econometric models as sophisticated extrapolations reflect economic reality in a different way from production function and demand function related analysis, while the same subjects may be covered in agent based models in a totally different way again.

Macro-economic models may be based on a neo-Keynesian type of monetary relations, effectively quantifying monetary policy. Specific technological measures may be placed in that context, mixing sustainability policies with monetary policies, which however have overlapping time horizons only in exceptional cases. Optimisation models use empirical modelling parts with enough degrees of freedom to change variables so as to maximize a goal function. This goal function may reflect reality or it may reflect good intentions. Formulations and outcomes are the same, but the allowable interpretations differ widely.

These diverging mathematical formulations and allowable interpretations not only exist in the domain of economic activities with their environmental interventions, but also in the domains of technical modelling, physical modelling and environmental modelling. Modelling green house gas emissions based on global warming potentials is based on a background scenario of emissions with one pulse of emission at a certain time, the climate forcing induced by this pulse and next the time integration of this climate forcing over a period of time: usually 20, 50, 100 or 500 years. Putting these GWP-based data back into a dynamic model creates chaos. Time specified effects are not possible on this basis, while the assumptions of the case based model conflict with the general GWP model. It is hardly possible to interpret results coming out of such a mixed exercise.

The goal of this project is survey the different modelling approaches with their assumptions as are now relevant and possible applied in the contexts of LCSA.
The project would require a specialist in applied mathematics in its core, and a number of domain modellers to link to the often underspecified practice.

The application to the different levels of questions related to biomass, as developed in other projects, seems most sensible here to keep the feet on the ground

The results relate to two types of outcomes: the restructuring of models to bring them partly or fully on the same mathematical formulations and assumptions, and a systematic guide to allowable interpretations.

5.4.3 Connections between different levels of questions and modelling

In the road map, levels of questions are discerned, with modelling requirements for each of them, to be further developed in the project described in section 5.4.1. LCSA now distinguishes three levels of analysis: product-oriented, meso-level and economy-wide. For these levels options for deepened modelling of the technosystem will be developed. There is, however, a grey area between these three levels In terms of modelling, options and consistent combinations have been formulated as a subject for research in the project described in section 4.4.1. In the projects described in section 3.4.3 on “Governance” and in section 5.3.7 on “Participatory approaches”, it has been indicated that specific cases will require treatment at several of the levels of question, at the same time. This leads to the subject of this project: what is the relation in terms of outcomes of analysis between the three levels discerned? This question is not just of analytical importance but also at a practical level: are outcomes basically consistent when going to higher level questions, or do they reflect diverging views on reality, and diverging options for evaluation, leading to irresolvable problems in interpretation of outcomes of multi-level studies? It would be very important if the three levels, and possibly intermediate options, could be structured so as have them most clearly aligned, with additional knowledge added in a consistent way to already available knowledge at the product level. So the analytical goal of this project is to analyse the information content of models at each level in their mutual relations, and the synthetic goal is to formulate a strategy for aligning the information content of different levels of analysis so as to avoid conflicting empirical content. Of course, the more simple modelling levels do not cover what more encompassing levels do; this project is about information elements present in several layers, both in their empirical reference and in terms of the mechanisms involved.

One most clear example relates to the micro-macro distinction. Sustainability analysis on the one hand links to the micro level of specific actions of individuals and organisations, with their environmental, social and economic consequences, and on the other hand to the aggregate or macro level at which most sustainability issues in society reside. The macro level analysis may fully take into account the micro-level information, adding further mechanisms, or it might be set up independently, then almost certainly making assumptions at variance with micro level analysis.

This project will dissect a number of cases as treated in other project and will specify the information content at each level discerned, possibly specifying intermediate sub-levels. The biofuel case is one example to be included. An example is the biofuel case where product-level decisions on the promotion and blending of biofuels with gasoline have resulted in macro consequences on food prices and cutting of rainforests. This unravelling of information elements is input in the second stage, where strategies to consistently link the levels will be formulated.

The result will be a detailing of the road map for LCSA, giving guidance in modelling choices at all levels to keep these levels of analysis consistently connected.
The project needs to be spread out in time, giving inputs to other projects and receiving inputs from other projects, hence needs a close link to the overall coordination the project described in section 6.1.

5.4.4 Aligning time frames in life cycle sustainability modelling

When considering the consequences of choices on products and technologies, the prospective, consequential nature of the questions asked inherently involves time. In all empirical modelling, this time element somehow is resolved, by dynamic modelling or specification in time, by averaging a system over years, by steady state modelling, by time speciation with time integration, or whatever option there may be, see deliverable 1 (Heijungs et al., 2007), section 3.4. Next, in evaluation of effects there is a time element involved as well, of a different nature. Effects in a million years of time will be judged differently from the same amount of effects over a decade from now. In economic analysis this is done by discounting valued effects, in global warming potentials by a cut-off of this effect after 20, 50 or 100 years, and integrating by addition over the period covered. Discounting in stead of cut-off would lead to very different outcomes. Optimization models would require a consistent treatment of time both in modelling and evaluation.

In the ILCD consultation Brussels, June 2009, it was asked to avoid discounting in the inventory as it was seen as a value choice that doesn't belong in the inventory. Similar could be said for the empirical modelling in the environment, making the value choices as independent as possible from empirical modelling there as well. In impact assessment methods now used in LCA we see fate models for toxicity analysis implicitly covering millions of years, as for long lasting heavy metals, while global warming is cut off usually after fifty or one hundred years, not for empirical reasons but because later climate forcing effects are seen as less important. Within specific options, there also is divergence in treatment of normative aspects, as with the number of years taken into account in GWPs, and as with the method of discounting in economic analysis and the discount rates chosen. In all models practically available now, these diverging options of treating time have been filled in differently, both empirically and normatively.

We can set up a mental picture of the time frames involved, of course also depending on the decision and the question at hand. It may be back casting an interesting future; assessing the future impact of current technologies; assessing the future impact of future technologies; assessing the short-term and long-term future impact of a transition from current to future technologies; etc. These time frames may also be relevant for product-level questions, though of course some questions have really short time horizons and limited system consequences, like the choice of a detergent or the use of plastic cups versus paper cups. Let us take a meso-level question as on non-fossil based road transport systems. Typically, the route to full market penetration requires research and development and broader system adaptations, together requiring in the order of at thirty five years after the basic decision to develop such a route has been made (see Huppes et al, 2008). Next, the system will usually function for a few decades at least (see Figure 7). While functioning, it creates value, has social impacts and creates environmental interventions. Focussing on the last, first on midpoint mechanisms, there is substantial difference between them, in reality. POCP is disappearing mainly within a year while toxics may stay around for a very long time. But also within each of them such differences exist. Some climate gases have half times of thousands of years. Treating them like we do with fate modelling of toxic substances - as the full effect over the life time of these substances after emission - would reduce the influence of CO_2 extremely. For example, current sulphur hexafluoride emissions then might become more important for climate change than CO_2. Next, further effects in the causal chains involved take their time as well. Climate change leads to sea level rise with a delay in the order of a century. Species extinction is forever, be it through land use shifts, effects of toxic chemicals, nutrification or climate change. Biodiversity loss will recover through evolutionary processes, but at a time scale going into the millions of years. If we would make a tentative curve combining all effects relevant for evaluation, typically a skewed distribution would result. The graph would be skewed towards a later period, after the main use stage of the technologies and products involved may already have ended. This delay of environmental effects also occurs with systems which may function on shorter notice. See a survey of this time issue in Huppes & Ishikawa (2009; p. 1690 and following).

Some models build in a next round of mechanisms, through economic effects induced by environmental impacts, especially around IPCC studies. Climate change will create deserts in former agricultural areas, while agriculture can expand in current tundras. Such broader effects are real and can sensibly be modelled. A survey of a few dozens of such studies is in Tol (2008). The marginal contribution of the product-technology system studied to the climate change as effects modelled could well be specified.

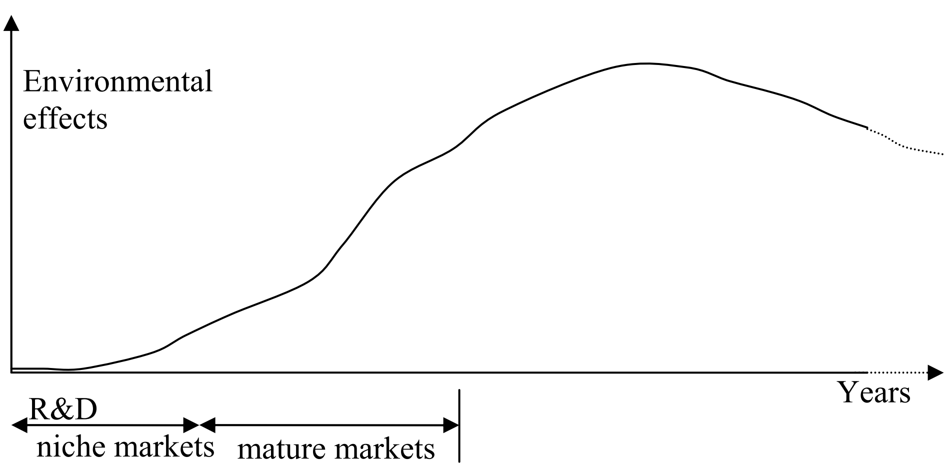

Figure 7: Level of environmental effects in time (some type of weighting implied)

There is a clear wish to move LCSA in a direction which more explicitly takes into account time frames involved, in order to make it more proactive, see deliverable 19, section 5.2.5 (Rydberg, 2009).
The tasks involved relate to basic strategic choices in LCA modelling and evaluation, and to creating consistency in treatment of time between the sub-models used, both empirically and for evaluation.

The solutions may be different for different levels of questions. For the product-oriented level, consistency would focus on condensing effects in time to an average over the system or to steady state situation, both allowing for the usual linear relations as now used in ISO-LCA, and with impact assessment models roughly fit the time frames involved. The other option is to have an time series specified explicitly, as is usual in managerial life cycle analysis, and in cost-benefit analysis and in many economic models. For the meso-level and economy wide questions, the time specification seems unavoidable, either filled in by dynamic models (in the strict sense) with core mechanisms endogenised, or through time specification of activities and effects based on several external models, or through steady state scenarios representing some future situation. Such time specified models might be developed in a way that they could be used as a background for product-level questions and analysis, similar to hybrid LCA using EIOA as a background. The most general scenarios, at the economy wide level, could be used for framing the modelling of meso-level questions.

When executing LCSAs, the time flattened and the time specified options may both be relevant in one case, as when stakeholder procedures require a shift from product level to meso-level questions and analysis. For all larger scale changes induced, non-linearities involved in reality require full system quantification. In the example of biofuels, the analysis as specified in time can show land use mechanisms adequately only if reckoning with other developments leading to land use changes. A growing and more affluent global population eating more and eating more meat will compete in land use with biofuels, and with the requirements for at least a basic level of nature remaining. In the case of nuclear energy, the time specified analysis may show the importance of developing techniques to reduce the storage time of nuclear waste.
Dynamic specification of such background mechanisms cannot be developed at a case level. Very similar to data bases of current processes, such background scenarios are to be developed in coordinated way, for repeated use at a case level.

The treatment of time seems a fundamental issue in deepening the analysis in LCSA. The planning of this fundamental project is to be early in the programme, guiding choices for modelling at many levels, and with implications for governance and participatory projects as well.

5.4.5 Integrating dynamics of socio-economic and environmental modelling

When improving on the coverage of specific mechanisms, the question of their mutual relations is a key issue. Markets can be analysed, quite well. But markets are linked. Increasing maize production for energy, squeezes out maize for feed and fodder. Next other agricultural staple markets are involved, and next all land markets. Somewhere along these chains, the combination of linked models becomes incomputable. CGEM, Computable General Equilibrium Models are computable by reducing mechanism numbers through aggregation. Then they don't differentiate any more between the technology-options, mostly. This is linking problem 1, similar in all modelling domains, and treated in the respective projects. Next, there are the relations between different modelling domains. A socio-political adaptation to nature deterioration, as through introduction and more effective implementation of land use regulations, will have effects on the economic mechanisms. The latter then become more constrained, and that has effects on environmental impacts, both positive, through increased hectarage of nature and negatively through increased intensity of agricultural activities. More generally, virtually all ecological mechanisms feed back into economic mechanisms, and vice versa. Coupled dynamics of socio-economic and ecological systems is the subject of this project. Development of integrated scalable dynamic models is the core goal.

This quite abstract subject will be worked out based on a number of case studies. The use of renewable energy sources, based on wind, sun and biofuels, for example, is rapidly increasing. Especially the production of biofuels is actively promoted by governments. Biofuels provide a reduction in waste and (greenhouse gas) emissions; are in principle inexhaustible; and can be used as decentralized energy sources. They may provide developing countries with great opportunities for economic growth. However, there are also dangers involved in a large-scale production of such fuels, since they compete for scarce resources with other human and non-human needs. In particular, their production requires much space, and therefore has large consequences for land use. This creates a trade off with other economic uses of land, as for food production, production of other natural resources, such as wood, game and fish, recreation, and housing. Space is also needed for supporting biogeochemical cycles and hosting nature. Switching policies to such energy sources may have unintended negative effects, that will affect biodiversity as well as assimilation capacity of ecosystems. Though this state of affairs is recognised, it has not been modelled in its coupled dynamics.

In this project we will study such effects, through development of scalable dynamic models for the interaction between socio-economic systems and ecosystems. With such models, thought experiments can be performed on the effect of different energy policy scenarios. Real experiments are either too risky or impossible to perform empirically; hence mathematical models are indispensable for rational policy choices. The models are unique, because they will be fully dynamic, with equal economic and ecological detail. This allows us to study effects of time lags of the system in reaction to (unexpected) changes, and a-synchronicity in ecosystem and socio-economic system dynamics. We will also study effects of lack of full information for making strategic decisions on system dynamics. None of these aspects of human-environment system dynamics have been studied before.

The ultimate goal of the project is to identify factors that are risky for sustainability of such systems, and provide guidelines for technology evaluation, on how to keep the system away from risky states. These general outcomes may lead to higher order level indicators and can guide the specific modelling at a case level as well.

6 Coordinating the implementation of the research strategy

As argued in section 2.3, strategy-wide and far-reaching co-ordination is needed. This chapter focuses on the co-ordination within the LCSA strategy as a whole, between the various research projects of the three programmes. The co-ordination activity needed is formulated as an integration project according to the general format for project descriptions adopted in this document (see section 2.3).

6.1 Coordinating the implementation of the research strategy

This coordination project should facilitate collaboration and harmonization between three LCSA research programmes, which should result in the alignment of the results of these three programmes.

The field of LCSA research is so wide that no single discipline can cover all of it (see also Schepelmann et al., 2009). Scientists from various scientific disciplines will be involved. This is needed for getting most up-to-date and relevant knowledge into LCSA, but the attached risk is that of crumbled research with incoherent results for the different LCSA research topics as a consequence. That should be prevented and therefore far-reaching co-ordination is necessary. For this, co-ordination actions for two levels are proposed:

1. within research programmes;
2. within the LCSA strategy as a whole, between the three research programmes.

This project concerns the latter: co-ordination of the LCSA strategy as a whole, i.e. between the three research programmes.

How could this two-layered co-ordination work out in practice? Let’s take the research programme “sustainability indicators for LCSA” and the projects “modelling options for economic indicators” and “modelling options for social indicators” as an example. Employment or unemployment can be considered an economic indicator as well as a social indicator. Fine-tuning between these two projects is then necessary. This would be a topic for a type 1 co-ordination action within the research programme “sustainability indicators for LCSA”. Determining how generic issues of handling time (steady-state; dynamic; infinite or 100 years time horizon; etc.) are approached between the various programmes within the LCSA strategy, would be a topic of type 2 co-ordination.

Co-ordination may exist of workshops on a common topic for all the research projects of the LCSA research strategy, and will also include active co-ordination and control of projects. On top of that it could also include the responsibility to specify the topics for the next round of FP calls.

This project should start at the same time as the first of three programmes starts and should last until the end of these three programmes.

The expected results of this project are the reinforcement and deepening of cooperation/ coordination of research programmes on LCSA, the optimization of research spending, and the maximizing the research outcome to address the LCSA research strategy.

This co-ordination project concerns application-oriented research.

7 Coordinating the implementation of the Research Strategy for LCSA in EU and (inter) national research programmes

7.1 Introduction

The trans-disciplinary research for LCSA requires a level of coordination which is quite unprecedented. Scenario analysis for sustainability, for comparison, is complex already as involving beta-gamma integration and several assumptions to guide their development. For LCSA, the added complexity is that a link back to several kinds of decisions is to be established, with very specific requirements on the reasoning and the modelling involved. An example is the treatment of time which now is different in different modelling domains. Aligning partial models in this respect to allow for comparability and possibly linking will lead to substantial changes in the practice of modelling in different domains. For example, the impact assessment models for LCA and the externality modelling in economics cover the same subjects in a mutually inconsistent manner. Solving this inconsistency will probably require an extensive revision in the framework of LCA as currently used. Economic modelling of externalities is poor regarding many environmental mechanisms. It could take in the LCA knowledge, which in turn is based on specialist models as for fate modelling of toxic substances and the toxic effects resulting. Resolving such issues in a way that these domains can adequately communicate requires more than two separate projects. For the twenty two projects and three coordination projects envisaged, their mutual alignment is a major task as such, both intellectually and organisationally. The subject of internal organisation and coordination is detailed in chapter 6.

Implementation of the trans-disciplinary research programmes will not easily fit into one funding organisation. Some projects and some elements of projects have an applied nature, making their funding through ESF, national research councils and the European Research Council (ERC) not well possible. Other projects and parts of them have a more abstract and scientific nature, which makes their inclusion in the EU Framework Programme and by DGs and national governments a complicated issue. The projects now have been labelled as application-oriented or as science-oriented research, to indicate most appropriate funding organisations. This distinction of course is not hard. All projects contain elements of both types of research, while the programmes as a whole combine both elements by necessity. So it seems most appropriate to have funders of both types of research involved in overall programming. This subject of organising the funding of trans-disciplinary research is detailed in section 7.2.

As funding will not be from one organisation, there is the coordination between funding organisations, see section 7.3. They will have to agree on contributing elements which are in their domain of responsibility, together leading to the full programming of the LCSA research road map.

This endeavour not only involves research but also a broader dissemination, creating alignment and support. This can be organised in educational programmes and in focused exchanges, see section 7.4. Overall recommendations are in chapter 8.

7.2 Organising the funding of trans-disciplinary research

Not only do research organisations differ as the nature of research funded, they also have very different traditions in specifying content in advance and in active coordination in content during the execution of projects. Also, how to deal with influence on content by third parties, essential in participatory projects, is unusual in science-oriented academic research. Public-private partnerships in research are developing, but hardly funded by ERC or through ESF routes. Combined funding by different research funding organisations is unusual. Involving them in trans-disciplinary research as set up here in the three programmes for the road map for LCSA thus has its additional hurdles to take. Moreover, issues on scope of content cannot be decided in advance. Deciding how the integrated knowledge generation for sustainability decision-making will evolve is not just an analytic affair within funding constraints. It has an overall design element, with degrees of freedom, and it has a participatory element, for serving decision-makers throughout society. This input needs to be organised as well, in relation to what research funders deem relevant and allowable. One existing example of this mixed type of coordination is public-private research management as for example has developed in the Netherlands in domains like biotechnology. The boards involved there have a mixed background from business, policy and science, with a prime role for the national science foundation in a procedural sense and in terms of quality assurance. Such public-private partnership structures seem most adequate for trans-disciplinary research.

Detailing this aspect of the management structure now would be too early. It would involve the experience of several funding organisations potentially involved. However, one option to ease the stress on the coordination task in a programme sense is to work with larger institutes, with their own internal modes of coordination. This might for example be done by setting up a pan-European virtual institute, with a real board and director, and with real power over specific funding of activities.

One further issue at this level is how to deal with non-European researchers, and research funders who are interested to join. Influence and guidance from beyond Europe seems a prerequisite for broader international application of results, which is highly desirable. Such multilateral research programming is quite usual but adds a new layer of preparatory activities.

Conclusion for now is that the internal organisation of the Research Strategy (see sections 3.3.3, 4.3.2, 5.3.8 and 6.1):

- should reflect the alignment in content of the different projects;
- should reflect the developing views of the funding organisations; and
- has a participatory and communicative role towards major decision-making groups and organisations which are to use the results of the LCSA projects, also outside the EU.

This management organisation is part of the trajectory towards funding.

7.3 Roles of different funding organisations

The embedding of a larger programme seems beyond a single funder, not only for budgetary reasons - framework programmes could easily incorporate the budgets involved - but for reasons of alignment, embedding, broadening and acceptance. However, it is clear that the framework programmes of Directorate-General (DG) Research play a key role in European trans-disciplinary research already. Below we make an inventory of main research funders who might be involved in the *Research Strategy for LCSA* (for which a more evocative name might be developed).

As all research funding organisations have their own preparatory procedures, not mutually aligned, combining their efforts will require some deviations from current procedures. Let us first summarise the roles of the different funding organisations which might be involved.

Framework Programmes of DG Research
FP7 programming, and following framework programmes, have the option of directly focusing on trans-disciplinary research for sustainability decision-making, including policy development. Life cycle approaches may well be linked to related subjects like the more general Impact Assessment and Environmental Impact Assessment of technology related policies. Framework programme projects can be grouped in order to further their alignment. This is a weak form of coordination, after the start of the projects. Ideas on more active coordination within the Framework Programmes are developing.

European Research Council (ERC)
The ERC has a prime responsibility to further most advanced and specialised results with less focus on trans-disciplinary research. However, a number of subjects can be filled in by top specialists, if working adequately in the overall programming and alignment. ERC has no control over the content of research, only on quality control.

ESF with National Science Foundations
ESF can bring together research programmers interested in this subject, with a role in stimulating aligned funding in the member states involved. However, ESF always works through national science foundations, combining and aligning their efforts.

National Science Foundations
National Science Foundations and similar organisations like Academies of Science play a key role in research programming at a national level. Trans-disciplinary research seems always a special issue, as excellence in disciplinary research is key strategy element. There is a recognised need for supporting trans-disciplinary research. Involving them might be a good opportunity to fill in this role. This can be done trough ESF but might also go trough national programming as part of the Research Strategy for LCSA. Active coordination after start-up of projects is difficult, apart from quality control.

Directorates General of EU
DGs tend to have a relatively long time horizon in policy development, allowing for views on longer term policy development. In such a role, they could contribute actively. there is experience in executing programmes and in co-programming the Framework Programmes.

National governments and Ministries
Specific interest is in support for policy development regarding products and technologies. Funding usually involves practical results to be used by government. There is some experience in funding programmes of aligned projects.

Firms
Some larger firms have set up research programmes and even research institutes, like BP. Shell plays a role in long term scenario development. It seems that their role could be to help guide the development work towards relevant applicability, i.e. safeguarding the trans-disciplinary nature of the research outcomes.

Foundations
Major foundations might be interested in co-funding. A survey on such options cannot now be made.

Resource-for-knowledge funds
Proceeds from mining of depletable resources are used in funds to develop knowledge. Most clear examples are the funds in the Netherlands and Norway based on the state proceeds of natural gas extraction. They are used for transforming natural capital in human capital and knowledge. Substantial amounts of money are involved. The subject of sustainability seems most apt for funding by such funds. They don't have authority in guiding research.

Surveying this field, it seems that all of the organisations can be involved in funding, requiring an active role in programme development for the LCSA Research Strategy, and in the scope development which is required during implementation. The lead for such implementation routes can most aptly be initiated by DG-Research and ESF. ERC seems less apt for this role, but may play a role in implementation of parts.

7.4 Academic curricula

7.4.1 Research and education

As part of the CALCAS project, a survey has been done on the current development of life cycle thinking in European educational programs, research institutions and Business Schools. The results of this survey have been reported in deliverable 12 (D12; Valdivia et al., 2009a). The results of D12 have been included and built upon in deliverable 19 (D19; Rydberg, 2009) dealing with the "Demand for science in sustainability decision support - identification of user needs".

The D12 survey showed that life cycle topics are incorporated in more than 50 different educational and research programs across Europe. Of these programs, 75% focuses on basic level topics[6]. All the programs use different tools and training materials. None of them could evidence publicly available material, although out of six studied programs, three are already sharing information through a network (either existing or in construction). All programs use software tools for the application of life cycle thinking into practice: most programs use Excel, and 4 out of 6 programs also use (or have used) commercial software. All the programs studied would be interested in moving further in the incorporation of life cycle topics in their organization.

[6] Within "Basic level" (in contrast to "Advanced level") a general understanding of LCA and ISO 14040 series and standard applications in business, for example, is provided. This type of level is most suitable for business schools, some postgraduate educational programs and also for consultants' training (Valdivia et al., 2009a).

For advancing the current, predominantly basic level of life cycle thinking in European educational programs, research institutions and Business Schools, there is a need for assistance and guidance. For this, D12 proposes a training plan promoting the dissemination of life cycle thinking and more advanced levels of life cycle training and research. The training plan aims to achieve the above-mentioned goals, by sharing knowledge and experience between institutions, schools and academia and by exploiting the cooperation opportunities between them.
Key actions proposed in this training plan include[7]:

- improvement of education and training materials and tools;
    - converting methodologies and life cycle thinking into practice;
    - cooperation between educational programs;
- sharing information and knowledge;
- organization of workshops and conferences;
- mobility of researchers and practitioners.

Below, each of the needs are briefly described on the basis of deliverable 12 (Valdivia et al., 2009a) and 19 (Rydberg, 2009). The first three needs are described jointly under the heading of improvement of education and training materials and tools, as the D12 proposals for converting methodologies and life cycle thinking into practice and for cooperation between educational programs smoothly connect to developing dedicated education and training materials and tools.

Together, these actions constitute the CALCAS training implementation plan on life cycle topics for educational organizations in Europe. CALCAS expects that this training implementation plan will promote life cycle thinking in educational and research institutions, reinforce and deepen relationships between all parties involved, and provide new developments in life cycle theory and practice. This action can be further developed outside of the European continent, by extending the plan to countries in other five UN regions (Latin America and the Caribbean, Africa, Asia Pacific, West Asia and North America), and potentially to any organization over the world interested in starting or broadening the implementation of life cycle topics in educational programs or research activities.

7.4.1.1 Improvement of education and training materials and tools

What is proposed here is development of training modules to advance the use and understanding of life cycle thinking for different groups of professionals. This may be relevant both for professionals in public administration and for professionals in business (e.g. managers, purchasers etc). As there is, generally speaking, less experience on applying Life cycle thinking in policy making and policy development, this seems to be the more urgent activity.

Textbooks are often too difficult to access for the inexperienced reader. The universities end up creating their own materials. There is a need for reference/ guidance documents, and maybe a general textbook designed specifically for education purposes, explaining life cycle thinking (this is also an opportunity for cooperation between teachers/ researchers).

[7] Source: slightly adapted from D12 and D19.

Such reference documents and possibly a general textbook should also focus on making methodologies and life cycle thinking practical. This could be done by making materials and tools publicly available (preferably for free or a low price) for students and non-experts, providing advice on the use of methodologies and on the steps to be followed, and discuss the challenges and expectations of businesses.

In addition it is proposed to explore the possibilities of further cooperation between institutions involved in life cycle education and training. This enhanced cooperation can be promoted through existing research structures such as the EU FP7 Marie Curie People Programme (http://cordis.europa.eu/fp7/people/home_en.html), the Erasmus Mundus Programme (http://ec.europa.eu/education/external-relation-programmes/doc72_en.htm), etc. These structures are existing and helpful but the above actions would really be supported if they would also include dedicated life cycle themes/topics in future.

7.4.1.2 Sharing information and knowledge

It is proposed to collect examples of life cycle assessment case studies in, ideally, an on-line accessible database format with the possibility to download reports. This would help avoiding double work, learning from good performances and from mistakes, building up experience, and also in improving and developing LCSA further. It is important that these examples represent the diversity of countries and LCSA work performed across Europe. An open-source registry could be created, allowing partners to upload life cycle studies with or without peer review.

Not only case study reports can be collected and disseminated through this on-line tool, but also PowerPoint documents, training course materials, articles, videos/ audio, etc. This should give enhanced opportunities for improving education and training materials and tools and for cooperation between institutions as described above in section 7.4.1.1.

The resulting database should list all downloadable life cycle materials together with information on, e.g., their accessibility, language, and areas covered, since this would allow practitioners, researchers and teachers to search for subjects of their interest, to adapt content to their own context and to actively participate in knowledge-building.

7.4.1.3 Organization of workshops and conferences

Life cycle thinking in itself, even at a basic level, needs still to be promoted. This could be done by workshops for teachers but also by conferences with students, to broaden the understanding of life cycle topics. Another option is to organize workshops where practitioners in industry and public administration meet and share experiences on life cycle education and training. Master degree programs, national networks (see section 7.4.2 and D16) and the UNEP/SETAC Life Cycle Initiative could promote these ideas and this work in all European countries, and specifically in those that have less access to information on the subject.

7.4.1.4 Mobility of researchers and practitioners

Another interesting manner to share information is through staff or students exchanges, in collaboration within and between universities, public administration and business. This could concern teachers giving a specific lecture, or students wanting to write a thesis related to life cycle thinking but not having this possibility at their home university, for instance. This would also encourage the dissemination of knowledge and the discussion of new ideas.

The mobility of life cycle researchers and practitioners can again be promoted through existing research structures such as the EU FP7 Marie Curie People Programme (http://cordis.europa.eu/fp7/people/home_en.html), the Erasmus Mundus Programme (http://ec.europa.eu/education/external-relation-programmes/doc72_en.htm), etc. These structures are existing and helpful but, also in this case, increased mobility would really be supported if they would also include dedicated life cycle themes/topics in future.

7.4.2 Expanding European networking activities for LCSA

The results of a survey on the current state of (inter)national networks on life cycle topics within Europe, have been reported in CALCAS deliverable 16 (D16; Valdivia et al., 2009b). This survey also included a self-assessment of the national implementation level of life cycle topics. These levels were ranked from 0 to 4:
0: no life cycle experience or regulation;
1: limited experience and no regulation;
2: some research experience and foundations of life cycle based regulation;
3: some good practices and limited regulation;
4: advanced life cycle practices and developed regulation.

Based on this survey, Valdivia et al. drew the following general conclusions:

- ten out of fourteen countries have identified one or more national networks;
- fourteen networks have been identified throughout these countries;
- one is an international network;
- five are national networks;
- eight are sector-specific networks;
- nine of these networks are either run or have been started by an university or research centre;
- seven out of fourteen countries have identified an existing and effective national database (public or private);
- twelve out of the fourteen countries surveyed have been assessed as level "3" or beyond.

The survey also learned that various countries have intentions to move towards level 4 "advanced life cycle practices and developed regulation".

To strengthen these intentions, Valdivia et al. (2009b) propose that efforts be undertaken in the following three fields:

1. to facilitate data collection, as this has crucial implications for life cycle research and applications at national and European level. The availability and understanding of life cycle data, through local data, and an international database registry, will allow greater participation in the development of life cycle networks, regulations, and applications.

2. to promote and interlink networks. Increased communication between sector-specific networks, but also between expert networks and practitioners' networks, will allow developing the understanding and interest in life cycle topics.
3. to expand the networking activities beyond the countries that have taken the lead, to the countries that have not reached level 3 yet, including countries in Eastern Europe and perhaps even developing countries worldwide. There is also a clear need to link these expert activities to concrete business applications.

With respect to the first field ("data"), the EU has launched the European Platform on LCA (EP_LCA) supporting the development of recommended international approaches, indicators, reference data, and pilot studies to facilitate life cycle thinking in business and public administrations.

With respect to the second and third fields on networks and considering the advancement already achieved here, there are possibilities for cooperation at European and even inter-continental level. This would demand efforts in terms of translation and adaptation of materials to local context, but also in terms of follow-up for management and enhancement of the activities. Other sustainability related networks could contribute to strengthen the level of networking within Europe and outside, starting with the EP_LCA and the UNEP/SETAC Life Cycle Initiative. The UNEP/SETAC Life Cycle Initiative can participate as a platform for exchange and communication between networks, providing online information and contact, as well as publicly available training materials.

Networks for by life cycle researchers and practitioners are also already promoted through existing research structures such as the EU FP7 Marie Curie People Programme (http://cordis.europa.eu/fp7/people/home_en.html), the Erasmus Mundus Programme (http://ec.europa.eu/education/external-relation-programmes/doc72_en.htm), etc. These structures are existing and helpful but, also in this case, increased networking would really be supported if they would also include dedicated life cycle themes/topics in future.

8 Final notes

Three research programmes with twenty-two related topical and four coordination projects have been defined to bridge the gaps between current LCA and future LCSA. This reflects the huge research effort that will be needed to achieve a well developed and practical LCSA methodology, but it also stresses that timing and concerted budget-allocation of this substantial effort is necessary. In the process some prioritisation by different funding organisations will take place, while the overall concept and results should remain intact.

Timing of some projects is crucial. There is a special place for the project on “Modelling framework and roadmap for LCSA” described in section 5.4.1. It further defines the scope of the whole project, it can create broader support, and it can be a tool in aligning funding organizations for this endeavour. Therefore, this project should be started up first.
Next there is some logic in timing of the three sets of projects as a whole. First in line are the following projects then:

- project 3.3.1 on “Options for indicators: aligning environmental with economic and social indicators”,
- project 3.3.2 on “Framing the questions and a decision tree” and
- project 4.4.1 on “Modelling options for meso-level and economy-wide technosystems”

should start – together with the four coordination projects - as their results will, for example, be the reference basis of:

- projects 3.4.1 on “Options for ethical positions and societal values in LCSA”,
- project 4.4.2 on “Options for modelling physical relations for LCSA”,
- project 4.4.3 on “Options for modelling economic relations for LCSA”,
- project 4.4.4 on “Options for modelling cultural, institutional and political relations”, etc.

Budget-allocation can’t be done yet in any credible way right now. For that, the various brief project descriptions should be further elaborated and detailed and the results of the project on “Modelling framework and roadmap for LCSA” described in section 5.4.1 should be known. However, it is clear now already that a very substantial amount of research is involved. If the size of the projects is on average around two million Euros, the research strategy would require around fifty million Euros. With duration of around seven years, this would require a budget of around seven million Euros per year, a bit less at start up and a bit more at the final stages of the programmes involved.

It seems sensible to elaborate a scheme for timing and budget-allocation only after the research strategy, the programmes and the projects proposed in this report have been further evaluated by the EU and other potential funders. Table 1 on the next page could be used as a format for this.

Programme 1: sustainability indicators for LCSA	Timing	Indicative budget (€ million)
3.3.1 Options for indicators: aligning environmental with economic and social indicators 3.3.2 Framing the questions and a decision tree 3.3.3 Co-ordination action Broadening 3.4.1 Options for ethical positions and societal values in LCSA 3.4.2 Schools in sustainability analysis of technologies 3.4.3 Governance		
Programme 2: mechanisms in empirical modelling for LCSA		
4.3.1 Scenario development for LCSA 4.3.2 Co-ordination action Deepening 4.4.1 Modelling options for meso-level and economy-wide technosystems 4.4.2 Options for modelling physical relations for LCSA 4.4.3 Options for modelling economic relations for LCSA 4.4.4 Options for modelling cultural, institutional and political relations 4.4.5 Uncertainty analysis in LCSA 4.4.6 Handbook of modelling options		
Programme 3: cross-cutting research for integration		
5.3.1 New ISO-standards for LCSA 5.3.2 New ILCD Handbook for LCSA 5.3.3 Simplified LCSA 5.3.4 Answering sustainability questions 5.3.5 Sustainability oriented decision-making methodology 5.3.6 Standardization of LCSA for policy 5.3.7 Participatory approaches 5.3.8 Co-ordination action Cross-cutting 5.4.1 Modelling framework and roadmap for LCSA 5.4.2 Heterogeneous models aligned 5.4.3 Connections between different levels of questions and modelling 5.4.4 Aligning time frames in life cycle sustainability modelling 5.4.5 Integrating dynamics of socio-economic and environmental modelling		
Coordinating the implementation of the research strategy		
6.1 Coordinating the implementation of the research strategy		

Table 1: Timing and budget-allocation of the projects proposed in this report

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Appendix A: Terms & abbreviations

ASEAN	the Association of Southeast Asian Nations
BASF	Badische Anilin- und Soda-Fabrik
BP	British Petroleum
CALCAS	Co-ordination Action for innovation in Life-Cycle Analysis for Sustainability
CBA	Cost-Benefit Analysis
CGEM	Computable General Equilibrium Models
DG	Directorate-General
DoW	Description of Work
EC	European Commission
EE	Eco-Design
EE	Eco-Efficiency
EEA	European Environment Agency
EIA	Environmental Impact Assessment
EIOA	Environmentally extended Input-Output Analysis
EP_LCA	European Platform on LCA
EPD	Environmental Product Declaration
ERC	European Research Council
ESF	European Science Foundation
EU	European Union
EU ETS	European Union Greenhouse Gas Emission Trading System
EXIOPOL	a new environmental accounting framework using Externality data and Input-Output tools for POLicy analysis
FORESCENE	Development of a Forecasting Framework and Scenarios to Support the EU Sustainable Development Strategy
FP	Framework Programme
GHG	GreenHouse Gases
GRI	Global Reporting Initiative
GTAP	Global Trade Analysis Project
GWP	Global Warming Potential
IA	Impact Assessment
IEM	Integrated Environmental Models
ILCD	International Reference Life Cycle Data System
IO	Input-Output
IOA	Input-Output Analysis
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
ISO-LCA	LCA according to ISO 14040:2006 (E) and ISO 14044:2006 (E) Standards
ITN	Initial Training Network
JRC	Joint Research Centre
JRC-IES	Joint Research Centre - Institute for Environment and Sustainability
KEPI	Key Environmental Performance Indicators
LCA	Life Cycle Assessment

LCC	Life Cycle Costing
LCIA	Life Cycle Impact Assessment
LCM	Life Cycle Management
LCSA	Life Cycle Sustainability Analysis
LCT	Life Cycle Thinking
MATISSE	Methods and Tools for Integrated Sustainability Assessment (http://www.matisse-project.net/projectcomm/)
MCA	Multi-Criteria Analysis
MFA	Material Flow Accounting
MIPS	Material Input Per unit of Service
MuSA	Integrating Multiple Scale Impact Assessment on Ecosystems for Contaminated Land Management (http://www.bio.vu.nl/do/research/ecotoxicology/musa.htm)
OECD	Organisation for Economic Co-operation and Development
OMC	Open Mode of Coordination
OTA	Office for Technology Assessment
PAS 2050	Publicly Available Specification 2050 - Specification for the assessment of the life cycle greenhouse gas emissions of goods and services
PEM	Partial Equilibrium Models
PROSA	Product Sustainability Assessment (http://www.prosa.org/index.php?id=249)
PROSUITE	Development and application of a standardized methodology for the PROspective SUstaInability assessment of TEchnologies
R&D	Research & Development
RA	Risk Assessment
SA	Sustainability Assessment
SAT	Sustainability Assessment of Technologies
SEA	Strategic Environmental Assessment
SETAC	Society for Environmental Toxicology and Chemistry
SFA	Substance Flow Analysis
S-LCA	Social LCA
SME	Small and Medium Enterprise
SPRing	Sustainability Assessment of Nuclear Power: An Integrated Approach (http://www.springsustainability.org/)
SWOT	Strengths, Weaknesses, Opportunities, Threats
TA	Technology Assessment
TC	Technical Committee
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Programme
UNEP-SETAC	United Nations Environment Programme - Society for Environmental Toxicology and Chemistry
WBCSD	World Business Council for Sustainable Development
WCED	World Commission on Environment and Development
WP	Work Package
WRI	World Resources Institute