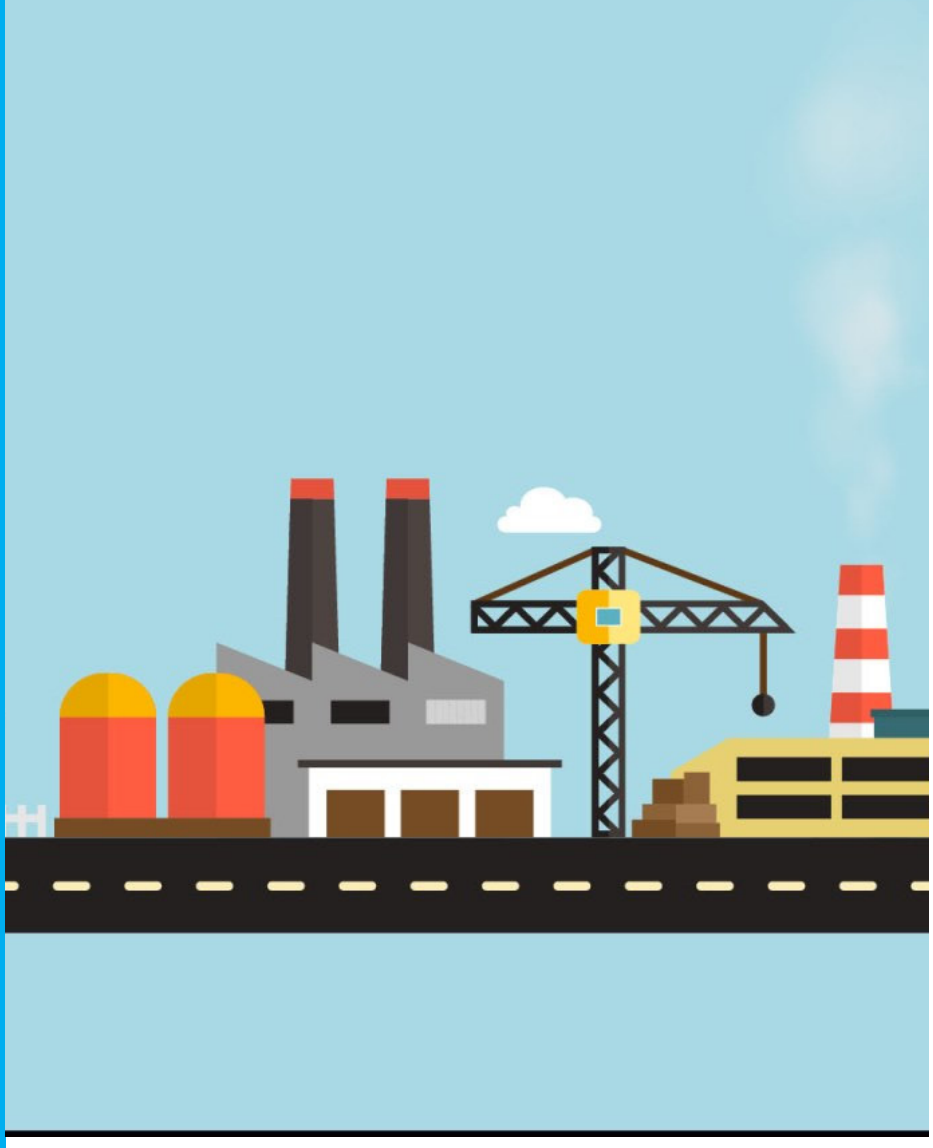

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Conclusions and recommendations from the SAMT project

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Preface

Resource efficiency and reducing greenhouse gas emissions are among strategic policy priorities in Europe and globally. The second priority objective of the 7th European Environment Action plan (2003) is “to turn the Union into a resource-efficient, green and competitive low-carbon economy” (European Parliament and the Council of the European Union 2003). Resource efficiency does not only mean using resources efficiently (doing more from less), but reducing the overall environmental burden related to society’s resource use.

Total resource use in Europe has declined by 19% since 2007 and improvements in waste management have occurred. Greenhouse gas emissions have decreased by 19% since 1995, even though a 45% increase in economic output has occurred simultaneously. However, it is uncertain whether these positive short-term trends will lead to overall positive development in the long term. For example, the projected greenhouse gas emission reductions are currently insufficient to meet the 2050 target of reducing emissions by 80–95%. In addition, Europe is facing growing pressures due to several global megatrends that include, among others, growing population, changing consumption habits, increasing competition for resources, growing pressures on ecosystems, increasingly severe impacts from climate change and increasing environmental pollution. (EEA 2016a)

While some positive developments in resource efficiency indicators at European level have been observed (EEA 2016b), European consumption remains very resource intensive. In addition, global use of material resources has increased ten-fold since 1900 and is set to double again by 2030. Since European economy is structurally dependent on imports, this trend is a major concern for Europe (EEA 2016a). As a consequence, it is expected that resource scarcity and climate change mitigation continue to be among the long term drivers promoting the adoption of sustainability assessment methods in different contexts.

Contents

1. Introduction

1.1 Sustainability assessment to support decision-making in the process industries

Sustainability assessment methods are needed for various industrial sectors to support sustainable technology development and to evaluate the impacts of existing solutions, products and technologies. Ideally, sustainability assessment methods should address the environmental, economic and social aspects of technologies and cover the whole life cycle of the solutions. The assessment methods should provide robust knowledge to support decision-making, and allow comparability of the results. However, addressing all those aspects within one assessment method or tool is challenging, or even impossible.

At the moment, several assessment methods, indicators and tools exist, but they differ in their goal and scope and are intended for different kinds of uses within companies, by consumers or by authorities to support policy planning and evaluation. Additionally, different methods and tools are focused on different levels of assessment: product, company, industry or society. Thorough understanding of the underlying mechanisms and calculation principles incorporated in the method or tool in question is often required to make a trustworthy assessment.

The SPIRE Public–Private Partnership (PPP) brings together several sectors of the process industry: cement, ceramics, chemicals, engineering, minerals and ores, non-ferrous metals, and water.[1] The acronym SPIRE stands for Sustainable Process Industry through Resource and Energy Efficiency. All SPIRE sectors can be considered as resource and energy intensive and thus improving resource and energy efficiency are urgent issues for improving the sustainability and competitiveness of the sectors.

This report summarises some of the main conclusions and findings of the SAMT 'Sustainability assessment methods and tools to support decision-making in the process industries' project. SAMT was developed as a response to a call under the SPIRE work programme titled: Methodologies, tools and indicators for cross-sectorial sustainability assessment of energy- and resource-efficient solutions in the process industry (SPIRE 4-2014). The aim of the SAMT project was to bring together representatives of different process industry sectors, and to

[1] For more information about the SPIRE PPP, see: www.spire2030.eu.

promote cross-sectorial learning and uptake of the most promising methods and tools related to sustainability assessment. Project activities included literature studies and reviews, expert interviews, case studies, open workshops and roadmap building. The SAMT project approach is visualised in Figure 1.

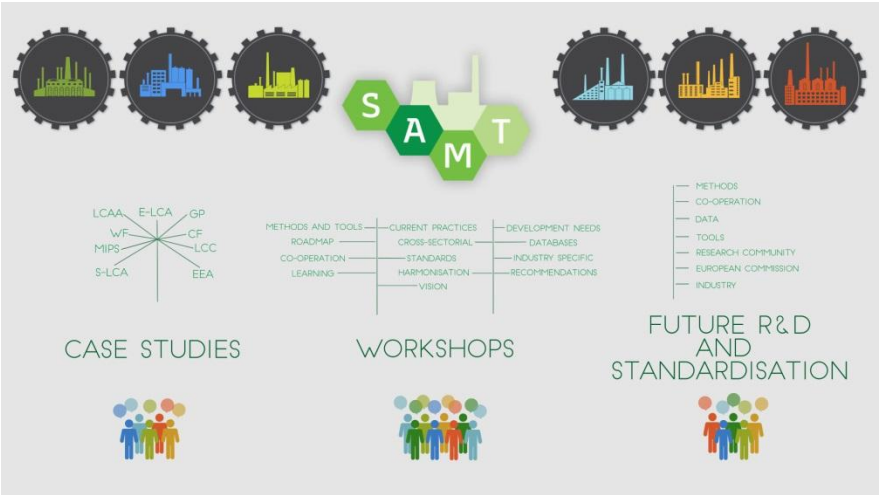

Figure 1 SAMT project approach and main elements.

SAMT was a coordination and support action that was on-going during the years 2015–2016. Project partners were VTT Technical Research Centre of Finland Ltd (coordinator), Tecnalia Research and Innovation (Spain), Wuppertal Institute for Climate, Environment and Energy (Germany), BASF SE (Germany), BAYER AG (Germany), SUEZ (France), Hydro (Norway), CEMEX (Switzerland), Neste Corporation (Finland) and AENOR (Spain). SAMT received funding from the EU Framework Programme for Research and Innovation, Horizon 2020, under grant agreement no. 636727. The work was supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 15.006.

The outcome of the project is based on a series of studies, workshops and discussions with project partners and many stakeholders who contributed and commented on the results on different occasions. Contributions of these persons are acknowledged on pages 33–34.

1.2 Contents of the report

This summary report presents some of the main conclusions and recommendations from the SAMT project. Chapter 2 discusses current practices and motivations for sustainability assessment in different process industry sectors, based on experiences of the industrial actors who participated in the study. The characteristics of available methods and tools for sustainability assessment are

discussed, based on the conclusions from a series of tasks that included a review, an evaluation and implementation of selected sustainability assessment methods using a case study approach. Additionally, identified future research needs and needs for future standardisation activities are presented.

Chapter 3 presents a vision, a roadmap and an implementation plan, focusing on recommended future actions for mainstreaming the use of sustainability assessment methods as part of industrial decision-making, and proposing a comprehensive set of actions regarding methods, tools, data and cooperation between actors. Chapter 4 concludes the findings of the project and presents recommendations targeted at industrial actors, European Commission and policy makers and the LCA research community.

Appendix A presents details of identified topics for future research needs and Appendix B provides a comprehensive description of proposed future activities and responsible actors.

The results included in this report have been previously presented and discussed in the SAMT project deliverables. All deliverables and project results are available at the project website: www.spire2030.eu/samt. References to original project deliverables are given in each chapter.

1.3 Important definitions

Discussions related to sustainability or sustainability assessment can sometimes be confusing due to a variety of terms and definitions applied. While there are several defintions that are commonly applied, their exact meaning and content may vary depening on the context. An example of a term for which many different interpretations and definitions have been presented is *sustainability assessment* (see e.g. Morrison-Sounders & Pope 2012). In a broad sense, sustainability assessment can be defined as “any process that directs decision-making towards sustainability” (Hacking & Guthrie 2008).

Within the SAMT project, it was acknowledged that within the participating process industry companies, sustainability assessment means many different things and includes both quantitative and qualitative methods and evaluations. It may be focused mainly on environmental issues, but often includes also social and economic aspects of sustainability.

The focus of the SAMT project was within quantitative assessment methods and related tools that have a life cycle perspective, would be applicable within the process industries, and are designed for evaluating sustainability either in a broad sense or focusing on relevant aspects for resource or energy efficiency.

Within the literature related to sustainability assessment, the terms *method* and *tool* are used in different meanings but also as synonyms for each other. Within the SAMT project, a distinction between a *method* and a *tool* was made in order to ease the classification and evaluation of available methods and tools, and to focus the activities on a reasonable amount of methods and tools. The definitions applied within the project were:

- *Method:* set of instructions describing how to calculate a set of indicators and how to assess them. Methods include official standards.
- *Tool:* working and calculation platform that assists with the implementation of a method. A tool is usually software but it could also be, for example, a paper-based check-list.

Another important term to define in this context is *indicator*, for which the following definition was applied:

- *Indicator:* a quantitative or qualitative proxy that informs on performance, result, impact, etc., without actually directly measuring it. For example, a low-carbon footprint indicates a low environmental impact for the category climate change, but it does not measure the impact, it refers to greenhouse gas emissions, i.e. environmental pressure.

However, these terms are used differently by many stakeholders in the scientific community, in policy and in industry. For example, a carbon footprint can be described as both a standardised life cycle-based method, and as one of the indicators calculated as part of life cycle assessment. For more information about the definitions applied, please see SAMT D1.1 (Saurat et al. 2015a).

2. Sustainability assessment in the process industry

This chapter describes the current state of sustainability assessment within process industries, and describes existing methods and tools for life cycle-based sustainability assessment. Current bottlenecks hindering the implementation of the methods as part of daily decision-making are discussed, and proposals for future research and development and standardisation activities are made. The results presented in this chapter are based on studies conducted and discussions held during the SAMT project. The findings of these studies were used as a starting point and background material for the SAMT roadmap which is presented in the following Chapter 3.

2.1 Current industry practice

In order to understand current practices related to sustainability assessment at the process industries, interviews with industrial sustainability experts were conducted. Altogether twelve interviews with seventeen people from seven companies were held during May and June 2015. The interviewed companies represented the cement, metal, oil, water, waste, chemical and forest industries. All interviewed companies are currently active in the field of sustainability assessment, and many of them can be considered as forerunners in developing and implementing sustainability assessment. Additionally, data was collected in an open expert workshop organised in June 2015 in Wuppertal, Germany.[2]

The findings of the study indicate that sustainability assessment and sustainability thinking are integrated within the daily work of the interviewed companies. Different assessment methods and tools are applied for different purposes that include product and process development, supply chain management, investment decisions, marketing and responding to stakeholder requests. Assessments are commonly conducted and reported at different levels, such as product, site, company, corporation or a region. As described by one of our interviewees:

[2] Interviewed persons and participants of the workshop are mentioned on pages 33–34.

"We do the assessments simultaneously at different levels: product level, mill level and corporate level, depending on the purpose. And we need all of them."

According to our interviews, the methods most commonly applied are carbon footprint and life cycle assessment (LCA). Carbon footprint is a method that is applied frequently, while the use of full LCA is more rare. The water footprint is a new and recently standardised method which has been of significant interest. By the time of the study (summer 2015), the water footprint method had been preliminarily tested by most of the companies, using varying methods and approaches. Life cycle-based economic and social methods were not commonly applied.

The definition of sustainability assessment is at the moment broad, and implies the utilisation of many methods and tools. Besides quantitative assessment methods, several qualitative assessment methods, checklists and different kinds of internal methods are applied in different contexts. In addition to specific assessment methods, companies make ordinary use of a number of instruments for business to consumer (B2C) and business to business (B2B) communication, including certification schemes, management standards, ecolabels and ratings, all of which might have slightly different approaches and demands. As a consequence, a commonly stated challenge related to sustainability assessment was the existence of so many methods and tools. Keeping track of all available methods and tools, and finding a combination that would be accepted by internal and external stakeholders was one of the challenges currently faced by the industrial experts.

In addition to publicly available methods and tools, all the interviewed companies had developed their own methods, tools or approaches for assessing sustainability. Development of tailored approaches was due to the need to find tools that would be easily adaptable to specific activities and cababilities to respond to specific demands related to data collection, decision-making and reporting. Adaptability and flexibility of methods and related tools was one of the to topics that emerged in different contexts throughout the project.

Another important point highlighted by the industrial experts was the need to focus on essential issues. To motivate the use of (sometimes very laborious) life cycle-based sustainability assessment methods, it would be important to show that the results can generate additional input and value for decision-making. In other words, the information generated from the results should be able to answer to the "so what?" question. Value is not only to be understood as direct business value (sales increase, cost reduction, etc.), since non-financial "values" such as reputation, relationships with suppliers and customers are also important. Results of the assessments should always be presented at a level of complexity and specificity adapted to the recipient's expertise and needs.

The need to focus on essential issues is a strong driver behind the need for developing simplified assessment methods. Simplified methods are required since it is not possible or even reasonable to conduct very detailed assessments in every situation. However, it is commonly acknowledged that simplified methods

alone would not be sufficient. Thus, in best case, more extensive methods and the simplified methods complement each other, having different purposes but providing important input for overall sustainability work and decision-making within the company. For example, a limited number of in-depth successful case studies and/or a larger number of working examples based on streamlined, less-laborious versions of a method can often be used as a kind of compass for identifying the most important aspects or indictors on which to focus.[3] Using the words of one of our interviewees:

"I think it is also about building capacity and competence in companies. We need to start easy to trigger the interest, and to demonstrate the usability and the benefits of using these methods. And then we might create interest and market for looking into more advanced methods."

Data collection was often mentioned as one of the most laborious but also as among the most important phases of the assessment. Using as much primary data as possible was considered as a good practice and very important for ensuring the quality of the results. This is essential espcially when the results are used directly for decision-making purposes. A recommended good practice for implementing data-intensive methods such as LCA, was to apply a staged-approach when introducing the methods in practice. Data collection should first start with well-known and accepted topics, such as energy and material consumption. Alternatively, data collection could also be coupled with existing reporting schemes such as economic figures, as well as social data gathered by the HR department, or any other data collected for GRI-type corporate reporting. When these kinds of procedures are in place, data collection for more comprehensive assessments requires less effort.

A comprehensive description of the outcomes of the interviews can be found in SAMT deliverable 1.2 (Saurat et al. 2015b).

2.2 Available methods and tools

On top of the interviews with industry experts, the first task of the SAMT project was to systematically review the existing sustainability assessment methods and tools. This allowed development of an understanding of the characteristics of existing methods and tools and their applicability for different decision-making contexts.

The web-based search conducted at the beginning of the SAMT project resulted in over 100 methods and tools for sustainability assessment. Out of this number, 51 methods and 38 tools were included in the review. Selected methods and tools had a life cycle perspective and were considered applicable for the purposes of the process industries. Reviewed methods and tools were clustered and their characteristics were evaluated on a general level based on available

[3] A practice usually referred to as 'hotspots analysis'.

information from the literature. The applied method and tool clusters and their main characteristics are presented in Table 1.

Table 1 Description of reviewed methods and tools (Saurat et al. 2015a).

Method and tool clusters	Description
Life cycle methods	LCA, subsets or derivatives of LCA, and life cycle methods beyond environmental assessment
Hybrid methods	Fusion of existing methods (the limit between methods becomes blurred) in order to increase the scope of each individual method.
Integrated methods	Juxtaposition of well-delimited methods ("Russian dolls" construct) to support decision-making. Usually includes a weighting scheme to aggregate sub-indicators into one or a small number of indicators.
Full LCA tools	Implementation of ISO-conform LCA and possibly other life cycle methods
Simplified LCA tools	Implementation of streamlined LCA and possibly other life cycle methods
Integrated tools	Interestingly, available integrated tools do not implement the integrated methods described above but provide their own combinations of methods

The findings of the review pointed out that a large number of tools seem to implement a rather small amount of methods.[4] The method most frequently implemented was life cycle assessment (LCA). LCA method appeared in 19 tools and in nine methods. Interactive visualisations presenting reviewed methods and tools, their interconnectedness and evaluated sustainability aspects can be found from the project website (see www.spire2030.eu/samt).

A subset of the reviewed methods was selected for further examination according to their ability to meet the needs of the process industry in terms of (1) the sustainability dimensions considered; (2) the life cycle stages covered, and; (3) the availability of tools. In total 14 methods were selected for further examination. These 14 life cycle-based methods were subsequently assessed using a set of criteria inspired by the RACER approach[5]. The evaluated methods are listed in Table 2.

[4] Definitions of a method and a tool are presented in Chapter 1.3.

[5] The RACER-method was originally developed for assessing value of scientific tools in supporting policy making (EC 2009). Under the SAMT implementation, the RACER includes criteria for five key components that stand for:

- **R**elevance: Life cycle orientation, cross-sectoral, consideration of resource and energy efficiency aspects.
- **A**cceptance: (use)fulness, recognition by the industry and the administration.
- **C**redibility: ambiguity, transparency, standardisation.

Table 2 Evaluated life cycle-based methods (López et al. 2015).

Short name	Method	Description
LCA	Life Cycle Assessment	Life cycle method
MIPS	Material Input Per Service	Life cycle method, focus on resources
CED	Cumulative Energy Demand	Life cycle method, focus on energy
E-LCA	Exergetic Life Cycle Assessment, Exergy analysis	Life cycle method
CF	Carbon Footprint	Life cycle method, focus on GHG emissions
WF	Water Footprint	Life cycle method, focus on water
LCA/PEM	Hybrid LCA + partial equilibrium model	Hybrid method
LCAA	Life Cycle Activity Analysis	Life cycle method
EEA	Eco-Efficiency Analysis	Integrated method
SEEBALANCE®	Socio-Eco-Efficiency Analysis	Integrated method
PROSA	Product Sustainability Assessment	Life cycle method
LInX	Life cycle iNdeX	Integrated method
SustV	Sustainable Value	Integrated method
EcoD	Ecodesign, Design for Environment	Life cycle method

The findings from the RACER evaluation showed that for the moment there is no single method that would achieve high scores in all the evaluated criteria. In general terms, gains in versatility and multidimensionality often imply less acceptance, credibility and, particularly, simplicity and user-friendliness of methods.

According to the evaluation four of the evaluated methods (out of 14), namely SEEBALANCE, PROSA, LInX and SustV, cover the three dismensions of sustainability (environmental, economic and social). However, it seems that these methods have some deficiencies in terms of practical implementation, and they are not yet sufficiently known or valued among the industry. Similarly, few of the methods focus specifically on energy-related aspects (such as carbon footprint and cumulative energy demand) and a few on resource aspects (Water footprint and MIPS).

Exergetic-LCA (E-LCA) is a method that has been developed to assess the qualitative degradation of resources, and can be considered as a very relevant method from this perspective. However, in order to become more adaptable from an industrial point of view, the E-LCA approach seems to face some development needs. These include dealing with complexity of the inventory phase (due to need

- **E**ase: availability of tools and data, automatisation.
- **R**obustness: responsiveness, comparability, reliability. (López et al. 2015)

.

for transforming all inputs and outputs into exergy units) and need for further standardisation and practical guidelines for the assessment, to improve robustness and comparability of results. Consequently, all of the evaluated methods include aspects that provide relevant information for assessing resource and energy efficiency, but for a comprehensive assessment a combination of methods is likely needed.

A conclusion that can be drawn from the RACER-evaluation is that for the moment a combination of different assessment methods seems to be the most informative solution, especially when resource and energy efficiency assessments are considered. In an ideal situation, especially when entering new areas of study, triangulation of methods (or indicators calculated using different methods) would be recommended. Credibility, robustness and ease of implementation are aspects that would require further development to enhance industrial use, when all the evaluated methods are considered.

However, since all of the evaluated methods have potential in supporting decision-making, and in practice there is often a need to operate with limited resources, starting from implementation of one life cycle-based method may be a relevant solution. Although it might not provide a comprehensive understanding of all relevant issues, it usually increases understanding of potentially relevant questions, and of the data needs and other requirements for successful implementation. This understanding can be deepened by adding further indicators or methods upon needs and available resources. In any case, in addition to data availability, an important criterion for selecting a method would be the goal and purpose of the assessment. (Lopez et al. 2015; Tapia et al. 2016)

Finally, eight methods were either fully implemented or simulated in an industrial context using a case study approach. Methods tested within the case studies were selected based on the joint interests of project partners, with the overall aim of responding to current needs and interests of the industrial actors. Methods tested within the case studies included: Life Cycle Assessment (LCA), Material Input per Service (MIPS – Material Footprint), Life Cycle Costing (LCC) , Eco-Efficiency Analysis (EEA), Green Productivity (GP), Social Life Cycle Assessment (S-LCA), Water Footprint (WF), Carbon Footprint (CF), Exegetic Life Cycle Assessment (E-LCA) and Life Cycle Activity Analysis (LCAA).

The review of methods and tools is described in detail in SAMT project deliverable 1.1 (Saurat et al. 2015a). A description of the modified RACER evaluation criteria, together with the method descriptions and evaluation results are presented in SAMT project deliverable D2.1 (López et al. 2015). Results from the case studies are presented in SAMT project deliverable 2.2 (Tapia et al. 2016) and related annexes.

2.3 Challenges and bottlenecks for implementation

Bottlenecks are issues or factors that currently hinder the use of life cycle-based assessment methods as part of daily activities. A brief summary of the bottlenecks

identified during the project can be found in Table 3, while a more thorough discussion can be found in project deliverables D1.2 (Saurat et al. 2015b) and D3.3 (Pihkola et al. 2017).

Table 3 Bottlenecks hindering the implementation of sustainability assessment as part of daily activities (Pihkola et al. 2017, based on findings of previous SAMT project deliverables).

Lack of market demand & consumer uptake
Companies and sectors are in different situations regarding stakeholder demands. Some sectors are facing regular and diverse stakeholder inquiries, while on many occasions companies themselves are the main driving force behind the assessments. Environmental/sustainability information is not yet widely requested by stakeholders, business partners or end consumers.
Cost & resource demands
LCA methods are often time intensive and laborious to apply. Furthermore results need to be interpreted by experts, since final conclusions are often not easy to generate. This restricts their use as part of daily decision-making.
Complex landscape of methods, tools and indicators
Sustainability assessment would need to answer to varying needs from internal and external stakeholders. One method or tool is usually not capable of addressing all needs. It is not easy to find a suitable and adjustable combination of methods, taking into account all needs & available resources (time and money). In general, the environmental and economic methods are the most mature ones. In turn, the social methods are still in their infancy in terms of well-established methodological approaches, harmonised data and availability of tools. Methods are applied and results are communicated in many different ways, both within and outside companies.
Data
Data collection and handling are laborious processes. Good quality primary data is needed especially for the upstream processes. Uncertainty related to both data and results is not easy to address.

Many of these bottlenecks are not new. For example, in 1999, a study prepared by the United Nations Environmental Programme (UNEP) assessed progress in life cycle implementation worldwide (Clark & De Leeuw 1999). The study identified several barriers that were considered to constrain the potential of LCA results to support decision-making. Respondents included LCA experts working in different parts of the world, and use of LCA within industry was one of the topics

considered within the study. The main barriers were costs of LCA, methodological issues and communication. (Clark & De Leeuw 1999)

Within the study, data quality and availability were mentioned as major practical bottlenecks in LCA studies. Additionally, lack of one agreed manner to carry out an LCA was mentioned, stating that the ISO standardisation did not solve this problem. Another barrier within this category was that it was not always clear how LCA "fits in" as related to other available environmental management tools. (Clark & de Leeuw 1999)

Even though a lot of method and tool development has taken place during the last 15–20 years, the use of LCA has matured (see e.g. Guinee et al. 2011), and the European policy framework is strongly in favour of promoting life cycle thinking (EC 2008; EC 2003), the findings discussed throughout the SAMT deliverables indicate that many of the barriers identified more than 15 years ago are still topical. On the other hand, due to the complexity of current sustainability challenges, and also due to increased understanding of the complex interlinkages between the environmental, economic and social spheres of sustainability, it is likely that also the demands posed for the applied sustainability assessment methods have increased during the years.

2.4 Future research and development needs

Identifying future research needs related to sustainability assessment was one of the main goals of the SAMT project. In order to promote the integration of life cycle-based assessment methods as part of daily activities of the process industries, the following topics for future research and development activities were identified during the project:

- Simplified LCA-based methods and tools for regular use within companies
- Comprehensive assessments integrating different aspects of sustainability to support decision-making
- Hybrid methods and tools for cross-sectorial and sectorial assessments
- Methods and tools for addressing circular concepts and regional or local impacts
- Assessing and communicating positive aspects within the LCA framework
- Support for method and tool selection in different decision-making contexts

Despite that many of these issues are already well-known by the LCA-community, they are still valid and important. For example, time and resource demands related to life cycle-based assessments have been acknowledged regularly in the LCA-related literature. A proposal for defining different levels for LCA methodologies, and for developing a simplified LCA method was made, for example, by UNEP

already in 1999, based on a study in which means for improving adoption of LCA worldwide were proposed (Clark & de Leeuw 1999).

The need to extend the scope of environmental life cycle assessment towards life cycle sustainability assessment (LCSA) that would include environmental, economic and social aspects has been discussed in several studies (see e.g. Guinee et al. 2011; Sala et al. 2013; Finkbeiner et al. 2014). The importance of further development of the LCSA methodology was highlighted also by the MEASURE project, which focused on life cycle sustainability and resource efficiency aspects as applied by the European process industry (Kralisch et al. 2016). Development needs especially regarding the social life cycle assessment methods and related tools and databases have been highlighted by all three SPIRE-4 projects, namely SAMT, STYLE and MEASURE.[6]

Previously, the CALCAS project (Co-ordination Action for innovation in Life Cycle Analysis for Sustainability), which was funded as part of the 6th Framework Programme, concluded that substantial research is needed for making the LCSA framework operational for today's LCA practitioners. The CALCAS project highlighted the need to develop LCSA as an interdisciplinary framework that could help answering questions at different levels (products, sectors, economies) and address environmental, economic and social aspects, and ideally also the interlinkages between them (Guinee et al. 2011). The findings of the SAMT project are in line with these previous recommendations. However, the findings from the SAMT project point out that in order to enable the implementation of the comprehensive LCSA methods in industry, a lot of work remains to be done in harmonising and simplifying the implementation, modelling and interpretation phases.

To achieve an understanding of a potential contribution of an individual product on the assessed sector or economy, some form of economic modelling, or hybrid methods combining LCA with economic models and/or environmentally and socially extended input-output tables would be required. The interviews and discussions held during the project indicate that hybrid models do not seem like realistic or implementable methods for the industry at the moment. Currently, implementation of these methods requires a lot of work and might be possible only in the context of large-scale research projects, when there is a chance for both extensive data gathering and tool building. However, these hybrid approaches are considered promising, especially for assessing the circular economy objectives and resource use or recycling on a larger scale, and for the purposes of policy planning and evaluation. (See also SAMT D3.1 [Pihkola et al. 2016a]; SAMT D1.1 [Saurat et al. 2015a].)

The need to evaluate and communicate positive aspects was highlighted in several occasions throughout the project. This could be an important motivator for implementing sustainability assessment methods, as highlighting positive impacts could be an effective means for motivating people to get engaged with

[6] For more information about the STYLE and MEASURE projects, please see: www.spire2030.eu/style and www.spire2030.eu/measure.

sustainability questions. However, it was emphasised that harmonised approaches and generally accepted guidelines and means of verification would be required, in order to avoid any attempts for greenwashing. The extension of sustainability assessment towards multidimensional assessment that includes social and economic aspects creates even more need for including positive aspects to the assessment, such as societal value and well-being (see also Sala et al. 2013). Handprint is a new concept that has been proposed as a means to describe positive aspects using life cycle-based assessment methods, but currently, no agreement exists on how to measure it.

One of the challenges faced during the evaluation of the methods was that since sustainability assessment methods are applied for many different purposes, it is difficult to find a method that would cover all needs. A challenge pointed out by the industrial experts was that it is difficult to find enough information about available methods and tools. Thus, there is a need for easily accessible and up-to-date information on methods and tools available and suitable for different purposes, and also information about the requirements for implementing them in practice (e.g. data needs and available tools).

When considering the ability to evaluate resource and energy efficiency, which are among the priorities of the SPIRE PPP, the findings from the SAMT project pointed out that almost all of the evaluated 14 life cycle-based methods are capable of providing relevant information for assessing resource efficiency, but a method for comprehensive assessment of resource efficiency is still lacking. Current methods are able to increase understanding of different aspects and impacts related to resource use, but in order to have a comprehensive view a combination of different methods is required (SAMT D2.1, López et al. 2015). Similarly, the MEASURE project concluded that several gaps and challenges in sustainability and resource efficiency assessment still exist. These include, for example, how resources are defined, and how to define the ratio between benefits and impacts from resource use. Further confusion relates to the fact that some methods consider only abiotic resources, while others consider both abiotic and biotic resources. (Kralisch et al. 2016; Finkbeiner et al. 2014)

In the future, further discussion on harmonised principles for resource efficiency assessment are needed to clarify the situation. The diversity between approaches and definitions used in different methods for assessing resource use and resource efficiency was acknowledged by the industrial experts participating in our study. To be able to follow the latest developments and understand the differences between different assessment methods and their underlying assumptions, support for selecting the most suitable assessment method for each purpose is required. This need for support and un-biased, up-to-date information concerns resource efficiency aspects and other sustainability aspects alike.

In addition to the more specific topics listed above, an overarching theme essential for successful implementation of sustainability assessment methods is visualisation and communication as enablers for accurate interpretation of the results. To be able to support decision-making, results from sustainability assessments have to be communicated to several persons and different

stakeholder groups that might not be experts in sustainability assessments. Visualisation of the results was considered crucial for making the results understandable and more easily interpreted. This is a topic that needs to be constantly considered and improved, alongside method and tool development.

Another topic, not directly addressed within the project, relates to considering future development needs from the point of view of small- and medium-sized enterprises (SME's). Improving overall sustainability of different process industry sectors requires methods and tools that are adaptable also for the SME's that operate in various roles in different parts of the value chains. Developing harmonised guidelines for simplified methods, developing tools that would simplify the data collection process and providing support for method and tool selection are topics that would benefit also the SME's and hopefully lower the barriers for implementing the methods in the future.

A table with more detailed descriptions of the research needs and related subtopics, together with examples of recent developments is presented in Appendix A of this report. A more thorough discussion of the research needs is presented SAMT deliverable D3.2 (Pihkola et al. 2016b).

2.5 Needs for standardisation

Standards are technical documents that set out requirements for a specific item, material, component, system or service, or describe in detail a particular method, procedure or best practice. Standardisation is a voluntary cooperation among industry, consumers, public authorities, researchers and other interested parties for the development of technical specifications based on consensus. Standardisation is one of the means to enhance harmonisation within the field of sustainability assessment methods and sustainability communication. Identifying potential topics for future standardisation activities was one of the outcomes of the SAMT project.

As part of the project, existing standards related to sustainability assessment were reviewed at the beginning and at the end of the project (during spring 2015 and autumn 2016). The findings of the reviews, together with the list of relevant standards are presented in SAMT project deliverables D1.1 (Saurat et al. 2015) and D3.2 (Pihkola et al. 2016b), and only the main conclusions and proposals for future standardisation are presented here.

Currently, there are several standards related to sustainability and sustainability assessment. Many of the existing life cycle-based methods are standardised, but the standards most used are those related to life cycle assessment and carbon footprint. In addition, a big amount of non-standardised 'self-made' tools and applications, tailored for companies' specific needs, are in use. Although some of them might follow principles of available standards, this variety causes difficulties in obtaining repeatable, compatible and comparable results. In order to overcome this problem, harmonisation of methodologies, processes, approaches and tools would benefit all sectors and stakeholders.

From the point of view of standardisation, the environmental pillar is the most evolved one, and the traditional efforts on standardisation have focused on this topic. Examples include ISO14000 series which is dedicated to environmental management and includes the guidance standards for LCA, carbon footprint and water footprint. In the future, there is a necessity to promote standardisation works addressing especially the social questions related to social life cycle assessment. Until now, available standards related to social aspects have mostly focused on supply chain management and health- and safety-related issues. Interesting new initiatives with links to economic assessment are ongoing under ISO Technical Committee (TC) 207, dealing with monetisation of environmental impacts.

Based on the analysis of existing standards and identified future research and development needs, proposals for potential future standards development and reviews of existing standards related to sustainability assessment methods were prepared. These proposals are presented in Table 4.

Table 4 Proposed future standardisation activities (source Pihkola et al. 2016b).

Guidelines for streamlined/simplified LCA
Guidelines for simplified LCA would be required in order to harmonise existing approaches. There is a need for a lighter assessment process that could be integrated within daily decision-making, and used for internal communication purposes. - a new working item proposal under ISO TC 207 including guidance for simplified LCA is recommended The guidelines should include : - principles for preparing a simplified assessment based on existing knowledge and previous studies - instructions for handling uncertainty - guidance for communicating about the results
Data documentation and exchange formats
The experiences from the SAMT case studies (SAMT D2.2) showed that sharing inventory or impact data across different software platforms and database versions is currently challenging, since different software tools are not entirely compatible with the exchange formats available. This finding is in line with the conclusions reported by the Joint Research Centre (JRC), stating that existing LCI datasets are mismatched at different levels, representing a major limitation to the combined use of LCI datasets from different sources, and electronic data exchange among practitioners and tools. The situation hampers a clear and unambiguous understanding of LCA studies and their efficient review (EC 2013). - The findings from the SAMT project underline the importance of improving the interoperability among ELCD/ILCD DN and existing LCA software packages, and support further development activities related to development of the ILCD format as a global standard format, as proposed by EC (2013) - ISO/TS 14048:2002 Environmental management -- Life cycle assessment -- Data documentation, has been the starting point for the creation of the ILCD format

- A review of the ISO/TS 14048:2002, considering the possibility to improve interoperability of different datasets and software packages is proposed. The document was last reviewed in 2013

Towards an LCSA standard: Harmonisation of approaches for economic and social assessments within the LCA framework

The definition of relevant standards for the economic and social LCAs entails developing consensus on aspects like:

- The selection of a functional unit that is equally relevant for the social and economic spheres
- The establishment of consistent – but flexible – system boundaries for the economic and social spheres that is nonetheless compatible with the one defined for the environmental dimension
- The access, collection, handling, managing and exchanging of economic and social data
- The establishment of specific allocation criteria
- The definition of stable impact categories and subcategories
- The definition of consistent characterisation models, including the definition of normalisation and weighting criteria, rules and methods

The economic, social and environmental spheres of sustainability should be integrated within a consistent LCA framework. On top of the abovementioned aspects, addressing the integration challenge will entail finding consensus on:

- The relevance and convenience of producing synthetic scores that inform simultaneously on the three sustainability spheres
- The generation of guidance regarding the provision of meaningful visualisation products
- The definition of agreed mechanisms to communicate – and implicitly to deal with – trade-offs between the three spheres

Relevant TC: ISO/TC 207 Environmental management, SC5 Life cycle management

Circular economy aspects

Current standards lack guidance on specific aspects of circular economy like renewability and circularity.

- ISO 14040-44 and related standards should be improved and updated to provide a clear methodological approach for handling questions relevant for "closing the loop" models
- Relevant questions include for example circularity, re-use and utilisation of waste streams

3. A path for future development

One of the aims of the SAMT project was to create a roadmap and an implementation strategy for developing and implementing a consistent set of sustainability assessment methods for the process industry by 2030. The SAMT vision, roadmap and implementation plan were created using the roadmapping methodology.

Roadmapping is commonly applied in foresight studies to support strategic planning and vision building. It is a flexible technique that is widely used within industry to support strategic and long-term planning. Roadmapping provides a structured means for exploring and communicating the relationships between evolving and developing markets, products and technologies over time. A particular feature of technology roadmapping is a time-based structure. (Phaal et al. 2004)

3.1 Vision 2030

Figure 2 SAMT Vision statement – Sustainability assessment by 2030.

SAMT vision was created based on findings of group discussions that were held as part of the second open SAMT workshop on February 2016 in Bilbao. Altogether 27 participants representing 19 different organisations from industry and research organisations participated in the workshop[7]. The aim of the vision-building exercise was to draft a picture of a desired future state for sustainability assessment: – *What should sustainability assessment look like by 2030*? Thus, the vision was considered to represent a long-term strategic target, reaching until 2030. The outcome of the exercise is presented in Figure 2.

In addition to the actual vision, the discussions at the workshop addressed desired elements of sustainability assessment. A consensus on the following characteristics was found among the participants:

- Sustainability assessment includes environmental, economic and social aspects and covers the whole life cycle.
- It should be capable of highlighting both positive and negative aspects related to products, services or organisations.
- Sustainability assessment is increasingly requested by customers, society and stakeholders, becoming a usual market-driven practice.

[7] Participants of the workshop are mentioned on pages 33–34.

A description of the vision building process, together with the roadmapping process is presented in SAMT project deliverable D3.3 (Pihkola et al. 2017).

3.2 Roadmap for sustainability assessment in the process industries

The main building blocks of the SAMT roadmap are divided to Drivers, Bottlenecks, Industrial needs and Solutions. These are considered as central elements that should be thought about to increase the uptake of sustainability assessment methods and to strive for increased harmonisation of the assessments across sectors. Important societal drivers include mitigating climate change and coping with resource scarcity, while micro-scale developments are concrete development needs related to life cycle-based sustainability assessment. Potential solutions include specific activities related to Methods, Tools, Data and Cooperation between different actors.

The visualised roadmap of the SAMT project is presented in Figure 3. It aims to highlight the most important elements and development paths for promoting the use and harmonisation of sustainability assessment methods within the process industries, and reaching towards the vision. The roadmap brings together and illustrates the main findings of the SAMT project. The building blocks included within the roadmap are based on the studies conducted during the SAMT project, on the feedback received and discussions held with project partners and stakeholders during years 2015–2016.

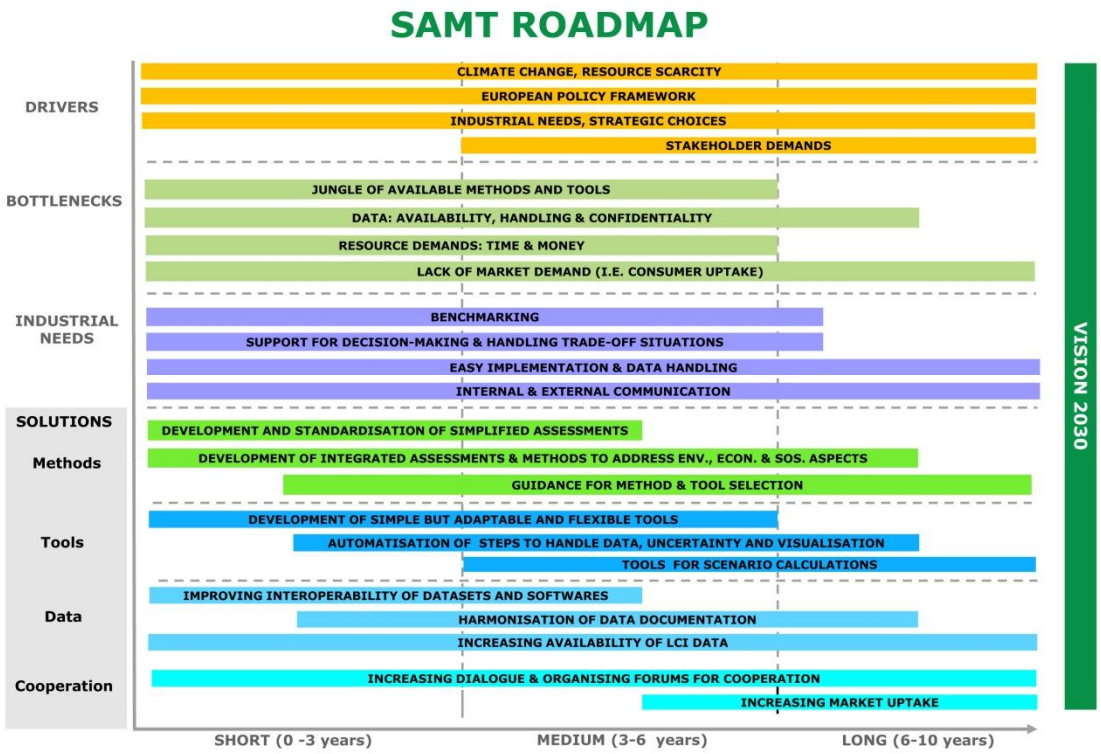

Figure 3 Visualisation of the SAMT roadmap (source: Pihkola et al. 2017).

A preliminary version of the roadmap was presented at the SAMT and STYLE final workshop on October 6th 2016, and a more detailed description of the roadmap can be found in SAMT project deliverable 3.3 (Pihkola et al. 2017).

3.3 Proposed future actions and their implementation

The aim of the implementation plan is to propose concrete actions that should be done in order to mainstream the use of sustainability assessment within process industries and to increase harmonisation. Within the implementation plan, actions proposed as part of the roadmap are clustered as short-term proposed activities (0–3 years) and medium-term (3–6 years) and long-term (6–10 years) strategic considerations. Proposed timing is indicative, and many of the proposed actions are interlinked. An overview of the main elements and actions of the implementation strategy according to proposed timing is illustrated in Figure 3.

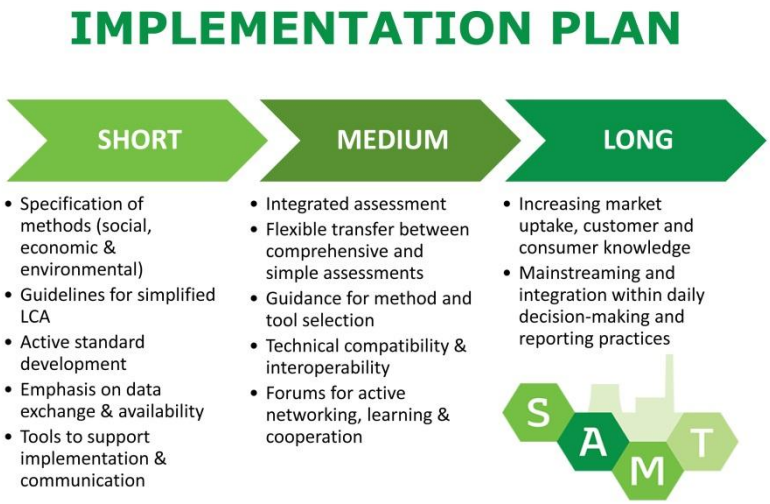

Figure 4 SAMT Implementation plan in a nutshell.

According to the findings of the project, in the short term, the development activities should be focused on further development and standardisation of the environmental, economic and social assessment methods and related tools. Further efforts are needed also for increasing the robustness of the methods and considering possibilities to ease the implementation phase with new tools and automatisation. In addition, emphasis should be given to different possibilities for increasing data availability, through joint efforts and finding ways to overcome current technical challenges related to interoperability and incompatibility. In

general, cooperation and knowledge exchange are considered useful for increasing harmonisation and consensus building.

In the medium term, the focus of the activities should be targeted at actions that are required in order to enable flexible integration and implementation of different methods and tools. This is important for applying sustainability assessment methods in different decision-making contexts and addressing the needs of different stakeholders. It would also support creating comprehensive understanding of relevant sustainability aspects. In the long term, the main goal and focus should be on mainstreaming the use of methods as part of regular reporting systems and activities, and on increasing the general awareness among all value chain actors, including customers and consumers, about relevant sustainability aspects in different contexts.

It is important to note that since sustainability assessment should be able to respond to continuously evolving needs arising from the interactions of society and the natural environment, it is an area which will most likely never become totally ready. Comparison of our findings with some of the earlier studies (see e.g. Clark & de Leeuw 1999; Finkbeiner et al. 2014) showed that many of the development needs have been recognised already years ago. And still, they remain as challenges for the future.

A detailed list of proposed actions and their potential timing is presented in Appendix B of this report. A more thorough discussion can be found in SAMT project deliverable D3.3 (Pihkola et al. 2017).

4. Conclusions and recommendations

The findings of our studies pointed out that life cycle-based sustainability assessment methods and life cycle thinking are implemented in many kinds of activities within the different process industry sectors. However, there is room for further improvement and mainstreaming the use of the methods, and especially in integrating the methods in different processes where information is produced for decision-support on a daily basis. For this purpose, applied methods need to be flexible, adaptable and capable of taking into account different decision-making contexts and local characteristics. Another important feature would be to allow different levels of assessment, from simplified to comprehensive.

Ideally, information from environmental, economic and social aspects should be processed in a consistent manner, allowing integration of the results in a meaningful way. Barriers for implementation and cooperation should be lowered with the help of tools that could be applied for data collection and handling, and improving the interoperability of different softwares and datasets.

The vision statement developed as part of the roadmapping process describes a desired future state related to use of sustainability assessment methods within industry. According to the SAMT vision *"Sustainability assessment provides additional value for industrial decision-making. Related methods are widely integrated in industrial activities, promoting competitiveness, sustainability, co-operation and data exchange within and between sectors and value chains."*

In order to reach this goal, future activities should be targeted to achieve a comprehensive understanding of different sustainability aspects, at the same time allowing easy implementation of the methods. The implementation and interpretation phases should be supported by flexible tools and compatible datasets. Methods and tools should be applicable for addressing different aspects of sustainability, and for conducting either comprehensive or streamlined studies, depending on the purpose. Results of the assessments should be communicated in a way that would help decision-makers and stakeholders in making sustainable choices.

Harmonised principles for conducting the assessments and reporting and communicating the results are required, but due to a variety of needs and actors, it is unlikely that one solution could fit with all needs. While a lot of information on existing methods, tools and data sources is already available, collecting and

comparing information from different sources is a laborious task for which support and new technological solutions would be required.

Important drivers for implementing sustainability assessment originate from strategic choices of individual companies, from stakeholder requests and from the demands posed by the European policy framework. It is expected that demands originating from external stakeholders will increase in the future. This is important since integrating sustainability principles and life cycle thinking as part of daily decision-making requires some effort and long-term commitment at different levels of the organisation. Stakeholder interests are important drivers that can motivate companies to further invest in sustainability management, assessment and reporting.

Conducting an assessment that covers a full life cycle, combines information from many different sources and considers different aspects of sustainability can be a challenging task. Providing simple answers is often difficult, since many issues are interlinked, one decision having an impact on another. And it might not be possible to measure everything that would be relevant in each case. Although sustainability assessement can rarely provide ready-made answers to complex decision-making situations, the findings of the SAMT project highlighted many positive features that act as motivators for further developing and implementing life cycle-based assessement methods to support decision-making.

What is most important, sustainability assessment increases understanding of the evaluated phenomena, helps preventing burden shifting and provides sound, science-based background information for decision-making. As a consequence, methods applied for sustainability assessment can be considered as necessities for dealing with the many environmental, social and economic challenges currently faced.

4.1 Recommendations

In order to reach the vision and to promote the actions highlighted within the roadmap and the implementation plan, specific recommendations were prepared to the process industry, the European Commission and European policy makers and LCA research community. These recommendations have been originally presented as part of SAMT project deliverable D3.3., and only small adjustments and clarifications were included for the purposes of this summary report.

4.1.1 To industry

- Reflect either internally or together with stakeholders, what kind of value the integration of sustainability assessment may create, and what kind of resources it would demand. A thorough integration of sustainability principles is a long process that requires resources, but dividing it in smaller steps and focusing on the most essential issues will make it manageable, also for smaller companies. Learning from experiences of

others is usually helpful. Learning can occur through networking and participation in related seminars and workshops.

- Active communication both internally and externally to increase understanding of relevant sustainability aspects, and on aspects to which each actor may contribute would be important to increase motivation. This will require efforts in engaging with stakeholders to understand their needs and interests.
- Active implementation of sustainability assessment methods, testing the newly available guidelines and frameworks to gain experience regarding their usability and applicability in practice is important. Experiences should be communicated towards method and tool developers, to enable further development.
- Participation in research projects that aim to develop and implement methods and tools for sustainability assessment in order to integrate the user point of view and to test the methods in practice.
- Participation in standardisation activities and increasing knowledge of existing standards and guidelines within one's own value chain is strongly encouraged, in order to promote harmonisation of the applied approaches within and across sectors.
- Communicating in an open and transparent manner, and working together with industry associations is encouraged to increase availability of generalised, high-quality LCI data, and to create harmonised rules for data sharing.

4.1.2 To policy makers

- Life cycle thinking and sustainable development should be kept within the focus of the European policy framework, and as a guiding principle when developing the circular economy.
- Dedicating enough research funding specified for life cycle-based methods and tool development is important. Continuous development of the assessment methods is a necessity to be able to deal with the complex and continuously evolving sustainability challenges. Up-to-date methods are required for ensuring that useful information is created and provided for decision support, both for industrial actors and for policy planning and evaluating purposes. Taking into account the needs of different users as part of the development is crucial, as there is no single solution that would match with the many needs of different users.
- Development of specific tools in the context of European collaborative research projects is required in order to ease the implementation of the

sustainability assessment methods, and to help in assuring the quality of the assessment results.

- Providing enough funding and workforce for development of the European Platform on Life Cycle Assessment (EPLCA) and to the European reference Life Cycle Database (ELCD) or other means for interactive sources of information related to available methods, tools and guidelines and their applicability in different contexts would be required. This could (for example) take the form of a toolbox which would guide users in different stages of the assessment process. Emphasis should be put on availability of up-to-date data, easy access and comprehensiveness of the information, taking into account the needs of the users. In addition, active communication would be required to guide the stakeholders in finding correct information.
- Dedicating enough funding and workforce for solving the issues related to challenges in interoperability of different LCI data formats, and clarifying the role of the ILCD format in relation to other available formats would be important for overcoming some of the technical challenges related to sectorial and cross-sectorial cooperation.

4.1.3 To LCA research community

- User needs should be taken as one of the criteria when developing methods and tools, to increase their adaptability in practice. Needs for streamlined assessment, flexibility, supporting tools and communication are among important topics to consider.
    - In particular, the scientific community should contribute to developing effective (i.e. expressive and understandable), cost-efficient, technically-feasible and scientifically-sound schemes for communicating sustainability at firm, sector and spatial levels.
    - In addition, the research community should contribute to defining stable sustainability benchmarks and assisting decision-makers in setting balanced policy targets within all sustainability spheres.
- Some level of development and testing of new approaches for sustainability assessment should be integrated in all research projects. When conducting sustainability assessments, the assessment should be integrated into other development activities as much as possible, supporting sustainable product and technology or service development and increasing awareness of relevant sustainability activities. A step-wise approach, starting from a simplified assessment and moving towards a more comprehensive assessment, is recommended, also in the context of research and development projects, whenever applicable.

- Consider possibilities to combine LCA-based methods with other existing methods for sustainability assessment in different contexts. This would be important for developing and testing the life cycle sustainability assessment approach.
- Similarly, life cycle-based sustainability assessments could be scaled-up from product level to sector and economy level basing on hybridised methods, addressing global sustainability challenges at a more strategic level.
- Follow-up and participate actively in national, European and global standardisation activities to ensure a solid scientific basis of the standardised methods.
- To contribute to harmonisation efforts by referring to accepted and well-known methods, and applying standardised methods, indicators and vocabulary, whenever available.
- In all cases, report transparently applied methods, functional unit, assumptions and limitations of studies, and related uncertainty (as required by, e.g. ISO 14040-44 standards). Consider the needs and interests of the stakeholders and respondents when communicating the results.

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References

Clark, G., De Leeuw, B. (1999) How to Improve Adoption of LCA. Int J Life Cycle Assess 1999:4(4), 184–187.

EEA (European Environment Agency) (2016a) The European environment — state and outlook 2015 (SOER 2015). Synthesis Report. Executive Summary. European Environment Agency 2016. Available at: http://www.eea.europa.eu/soer-2015/synthesis/report/0c-executivesummary

EEA (European Environment Agency) (2016b) Environmental indicator report 2016 – In support to the monitoring of the 7th Environment Action Programme. Available at: http://www.eea.europa.eu/publications/environmental-indicator-report-2016-2014

EC (European Commission) (2003) Integrated Product Policy – Building on Environmental Life-Cycle Thinking. (COM/2003/0302 final). Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52003DC0302

EC (European Commission) (2008) Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan. (COM/2008/0397 final). Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52008DC0397

EC (European Commision) (2009) Impact Assessment Guidelines. 15 January 2009. Available at: http://ec.europa.eu/smart-regulation/impact/commission_guidelines/docs/iag_2009_en.pdf

EC (European Commission) (2013) Roadmap for the European Platform on Life Cycle Assessment: facilitating data collection and sustainability assessments for policy and business. Simone Fazio, Marco Recchioni, Camillo De Camillis, Fabrice Mathieux, David Pennington, Karen Allacker, Fulvio Ardente, Lorenzo Benini, Malgorzata Goralczyck, Lucia Mancini, Rana Pant, Serenella Sala, Erwin M. Schau. European Commission, Joint Research Centre, Institute for Environment and Sustainability.

European Parliament and the Council of the European Union (2003) General Union Environment Action Programme to 2020 ‘Living well, within the limits of our planet’. DECISION No 1386/2013/EU. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013D1386

Finkbeiner, M., Ackermann, R., Bach, V., Berger, M., Brankatschk, G., Chang, Y.-J., Grinberg, M., Lehmann, A., Martínez-Blanco, J., Minkov, N., Neugebauer, S., Scheumann, R., Schneider, L., Wolf, K. (2014) Challenges in Life Cycle Assessment: An Overview of Current Gaps and Research Needs. In: Klöpffer, W. (ed.), Background and Future Prospects of in Life Cycle Assessment. LCA Compendium – The Complete World of Life Cycle Assessment, DOI 10.1007/978-94-017-8697-3-7.

Freire, F., Thore, S., (2002) Life Cycle Activity Analysis: an integrated environmental and economic mathematical programming decision-support model, in: Comprehensive Economic and Spatial Bio-Energy Modeling. Serie A: Options Méditerranéenes. CIHEAM, pp. 91–101

Guinee, J.B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Ekvall, T., Rydberg, T. (2011) Life Cycle Assessment: Past, Present and Future. Environ Sci Technol. 2011:45(1), 90–96.

Hacking, T., Guthrie, P. (2008) A framework for clarifying the meaning of Triple Bottom-Line, Integrated, and Sustainability Assessment. Environmental Impact Assessment Review, 28(2008): 73–89.

Kralisch, D., Minkov, N., Manent, A., Rother, E., Mohr, L., Schowanek, D., Sfez, S., Lapkin, A., Jones, M. (2016) Roadmap for sustainability assessment in European Process Industries. Report from the MEASURE project. Friedrich-Schiller-University Jena, Jena, Germany, 2016. Available at: www.spire2030.eu/measure

López, A., Mabe, L., Sanchez, B., Tapia, C., Alonso, A. (2015) Best practice solutions: Methods for sustainability assessment within the process industries. Deliverable 2.1 of the SAMT project. Available at: https://www.spire2030.eu/samt

Morrison-Saunders, A., Pope, J. (2012) Conceptualising and managing trade-offs in sustainability assessment. Environ Impact Assess Rev. doi:10.1016/j.eiar.2012.06.003.

Nakamura S & Nansai K. (2016) Input–output and hybrid LCA, in: Finkbeiner, M. (Ed.), Special Types of Life Cycle Assessment, LCA Compendium – The Complete World of Life Cycle Assessment. Springer Netherlands, pp 219–291.

Phaal, R., Farrukh, C.J.D., Probert, D.R. (2004) Technology roadmapping – A planning framework for evolution and revolution. Technological Forecasting and Social Change, 71(2004): 5–26.

Pihkola, H., Pajula, T. (eds.), Tapia, C., Ritthoff, M., Saurat, M. (2016a) Sustainability assessment methods and tools for cross-sectorial assessment. Deliverable 3.1 of the SAMT project. Available at: https://www.spire2030.eu/samt

Pihkola, H., Pajula, T., Tapia, C., Smith, L. (2016b) Future research needs and input for standardization. Deliverable 3.2 of the SAMT project. Available at: https://www.spire2030.eu/samt

Pihkola, H., Pajula, T., Federley, M., Myllyoja, J. (2017) Sustainability assessment in the process industry – Future actions and development needs. Deliverable 3.3 of the SAMT project. Available at: https://www.spire2030.eu/samt

Sala, S., Farioli, F., Zamagni, A. (2013) Progress in sustainability science: lessons learnt from current methodologies for sustainability assessment: Part 1. Int J Life Cycle Assess (2013) 18: 1653. doi:10.1007/s11367-012-0508-6

Saurat, M., Ritthoff, M., Smith, L. (2015a) Overview of existing sustainability assessment methods and tools and of relevant standards. Deliverable 1.1 of the SAMT project. Available at: https://www.spire2030.eu/samt

Saurat, M., Ritthoff, M., Pihkola H., Alonso A., López, A. (2015b) Description of current industry practice and definition of the evaluation criteria. Deliverable 1.2 of the SAMT project. Available at: https://www.spire2030.eu/samt

Tapia, C., Alonso, A., Padró, A., Hugarte, R., Bianchi, M., López, A., Pihkola, H., Saarivuori, E., Ritthoff, M., Saling, P., Schmuck, K., Penru, Y., Dauthuille, P., Roeder, A.M., Jenke, M., Søreide, J., Enström, A., Kuusisto, S. (2016) Case study report: Analysis of best practice solutions in comparison with currently used techniques. Deliverable 2.2 of the SAMT project. Available at: https://www.spire2030.eu/samt

Appendix A: Identified future research needs

Table 5 Areas for future research needs based on SAMT findings (source SAMT D3.2, Pihkola et al. 2016b).

Simplified LCA based methods and tools for regular use within companies
Specific challenge: - Agreement on harmonised principles and approaches for the assessment - Access to site-specific or primary data and possibility to modify pre-defined assumptions - Automatisation of a high number of calculations (including tools for data collection & handling) - Limited simulation capabilities (possibility of building what-if scenarios and alike) - Handling and communicating uncertainty - Interpretation and utilisation of results within a business context, e.g. for strategic decision-making - Limit the complexity and costs of the assessments, in particular among SMEs Examples of recent developments: - Industrial applications and in-house tools: EPD calculator developed by the cement sector, Eco-Efficiency Manager developed by BASF Need: - Internal decision-making, research and development

Comprehensive assessments integrating different aspects of sustainability to support decision-making
Specific challenge: - Harmonisation of principles related to normalisation and weighting - Transparency of the integration step, possibility to trace back and identify impacts of choices made - Further development & integration of social assessments Examples of recent developments: - ISO 14008 Monetary value of environmental impacts - Roundtable for Social metrics and WBCSD guidelines for social LCA Need: -Internal decision-making, internal & external communication
Hybrid methods and tools for cross-sectorial and sectorial assessments[8]
Specific challenge: - Assessing impacts on a sector or economy - Assessing impacts of circular use of resources and raw materials, considering that most hybrid methods and IO datasets neglect end-of-life phases - Extending scope from micro-level evaluations to macro-level assessment (e.g. impacts of new technology at plant level vs. impacts of technology diffusion within or across sectors) Examples of recent developments: - EE-IO[9] - LCAA[10] - LCA/PEM[11] Need: Evaluating impacts of research and innovation actions and circular economy, policy planning & evaluation

[8] Hybrid methods combine the standard or classical form of LCA and IO, with the aim of combining the strengths of each method. It is called a ”hybrid method” because it combines bottom-up LCA inventory analysis based on a stacking method with top-down input–output table inventory analysis (Nakamura & Nansai 2016).

[9] IO is concerned with quantitatively capturing the interdependences among different sectors of the economy via the flow of inputs and outputs at high levels of sectoral resolution. Interdependences emerge because sectors require each other’s outputs as inputs (Nakamura & Nansai 2016).

Methods and tools for addressing circular concepts and regional or local impacts
Specific challenge - Integrating impacts on biodiversity within the standard LCA framework - Assessing impacts of circular use of resources & recycling and understanding the implications of such impacts for local economies and the environment - Considering compatibility of SIA and EIA and other methods (developed for addressing local impacts) with the LCA framework - Addressing local economic and social impacts over the entire value chain of goods and services - Availability of local data & characterisation factors Example of recent development: - Water footprint (ISO14046) with regional characterisation factors , World Impact+ method Specific need: - Policy planning, Internal decision-making, internal & external communication
Assessing and communicating positive aspects within the LCA framework
Specific challenge: - Measuring created benefits (such as societal value or increased well-being) - Agreement on harmonised principles (e.g. definition of the baseline) and verification Examples of recent developments: - Development of the handprint concept that describes positive impacts Specific need: Internal & external communication

[10] Activity Analysis is the economic equivalent to LCA. It is a partial economic analysis modelling that aims at the characterisation of an industry or a sector in economic terms. LCAA combines both approaches, providing a mathematical format suitable for the representation of an entire vertical production chain both in economic and environmental terms (Freire et al. 2002).

[11] Equilibrium models are closely related to IO models. Still, as opposed to LCA and IO, equilibrium models are based on a set of economic assumptions based on a top-down conceptualisation of the economic system. The main assumption is a perfect substitution based on price mechanisms.

Support for method and tool selection in different decision-making contexts
Specific challenge: - Providing open access, balanced and up-to-date information of available methods, tools and databases and their compatibility - Finding the best available methods to support decision-making in different contexts, taking into account requirements for successful implementation (e.g. data availability & resource demands) - Finding appropriate tools to aid implementation of the methods and data handling, and increasing uptake of information within enterprises Examples or recent developments - In-house tools for sustainability assessment - Strategic-LCA Specific need: Internal decision-making, internal & external communication

Appendix B: Proposed future actions

Table 6 Specific actions proposed as part of the SAMT implementation plan (source: SAMT D3.3, Pihkola et al. 2017).

METHODS			
Action	Means	Actors	Timing
Improvement of existing environmental assessment methods	Preparations and related method development for a new initiative “Guidelines for simplified LCA” under ISO TC 207	Standardisation body + dedicated stakeholder, involvement from industry & RTOs, ISO SC5	Short term
	Improvement of current standards in a way that they provide a clear methodological approach to handle "closing the loop" models, i.e. aspects related to circular economy	Standardisation body + dedicated stakeholder, academia, industry	Short term
	Testing the PEF framework and the newly developed biodiversity indicators proposed by PEF and UNEP (see Pihkola et al. 2016b, SAMT D3.2) to gain experience and further develop the approach	Academia, JRC, Industry	Short/Medium term
	Further development and implementation of impact assessment methods related to toxicity (such as ProScale and USEtox), Abiotic depletion potential, Ionisation potentials, micropollutants and others	Academia, JRC, Standardisation body	Medium term
Further development of social assessment methods	Enhancing/increasing use & knowledge of social assessment methods, e.g., by testing the newly developed S-LCA guidelines (see Tapia et al. 2016, SAMT D2.2)	Industry (involving stakeholders, community & market demands), WBCSD, RTOs	Short term

	Standardisation of social impact assessments, in particular Social-LCA	Standardisation body + dedicated stakeholder, involvement from industry & research	Medium term
Standardisation of monetisation aspects	Considering usefulness of input/output systems and monetisation aspects via active involvement in new standardisation initiatives (ISO 14008 & 14007)	Standardisation body + dedicated stakeholder, involvement from industry & RTOs, ISO SC5 & SC1	Short term
Further development of integrated assessment approaches	Harmonisation of integrated assessment methods working in particular on the critical issues of 1) normalisation and weighting 2) possible generation of synthetic scores 3) communication and visualisation, trade-off identification and assessment	RTO's, Industry, Commission (H2020 funding)	Short/Medium term
Guidance for method and tool selection	Extension and continuous development of the ELCD platform	Commission, JRC, stakeholders	Short/Medium term
	Development of a web-based system to support method and tool selection, offering comprehensive and up-to-date information of available methods and tools, with the possibility to search for suitable methods for different decision-making contexts and sustainability challenges according to selected criteria	Commission (H2020), with contributions from industry, academia and stakeholders	Medium term

TOOLS			
Action	Means	Actors	Timing
Development of tools to simplify data handling & management	Development of automatised steps to simplify data collection, handling and uncertainty management. Examples of successful developments from industry include for example PreSelect and Ecovadis	LCA software developers, ICT experts, with contributions from LCA practitioners from industry & academia	Short term
Development of simple tools adaptable to different contexts	Providing access to site-specific or primary data and possibility to modify pre-defined assumptions in simplified tools	LCA software developers, ICT experts, LCA practitioners (industry & academia)	Short term
	Adaptable tools allowing a shift between different levels of assessments: from simplified to comprehensive and vice versa	LCA software developers, ICT experts, LCA practitioners (industry & academia)	Medium term
	Integration of tools for improved visualisation of results, & handling and visualisation of uncertainty	LCA software developers, ICT experts, LCA practitioners (industry & academia)	Medium term
Tools for high throughput calculations of scenarios	LCA Internet Managers/calculation tools for scenario calculations	LCA software developers, ICT experts, LCA practitioners (industry & academia)	Medium term

DATA			
Action	Means	Actors	Timing
Improving interoperability between different datasets and LCA softwares	Improving the interoperability among ELCD/ILCD DN and existing LCA software packages, taking into account related global developments under the UNEP/SETAC Life Cycle Initiative	LCA software developers and data providers, JRC	Short
	A review of the ISO/TS 14048:2002 'LCA data documentation format', considering the possibility to improve interoperability of different datasets and software packages, creating updated and extensive principles for data documentation, and taking into account the developments related to ILCD DN and UNEP/SETAC LCI	Standardisation body, ISO TC207, LCA software developers and data providers, JRC	Short
Improving availability of LCI data	Increasing availability of generalised LCI data from different sectors via cooperation through the industry associations, using agreed principles for transparent data documentation	Industry, Industry associations, database providers	Short/Medium
	Agreed principles for confidential data sharing (e.g. using a black box model proposed by the MEASURE project or similar approach)	Industry associations	Medium
	Considering and developing new approaches to increase availability of generalised data for social assessments	All actors	Medium/long

CO-OPERATION			
Action	Means	Actors	Timing
Dialogue between industry & method and tool developers	Communicating industrial needs & implementation challenges to LCA community	Active dissemination of the results from all the SPIRE4-projects to LCA practitioners working in industry and academia, to software developers and to other stakeholders	Short term
Cross-sectorial forum for exchanging knowledge and good practices	Joint sustainability working group or forum across different process industry sectors and LCA or sustainability experts to share experiences and good practices	SPIRE PPP and partner organisations	Short/Medium term
Increasing market uptake, customer and consumer knowledge	Increasing interest and awareness for making sustainable choices through active communication and education activities, and increasing availability of easy access sustainability information in products	Industry, authorities, academia	Long term

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Title	**Sustainability assessment in the process industries – Current practice and paths for future development** Conclusions and recommendations from the SAMT project
Author(s)	Hanna Pihkola, Tiina Pajula, Maija Federley, Jouko Myllyoja, Carlos Tapia, Michael Ritthoff & Mathieu Saurat
Abstract	Life cycle-based sustainability assessment methods and life cycle thinking are well implemented in many kinds of activities within the different process industry sectors. However, there is room for further improvement and mainstreaming the use of the methods, and especially for integrating the methods in different processes capable of providing decision-support on a daily basis. Important drivers for sustainability assessment originate from the strategic choices of individual companies, and from the demands and recommendations of the underlying policy framework. New development needs seem to arise, as the understanding of different aspects of sustainability increases, and as the demands from stakeholders become more frequent. Although the methods can rarely provide ready-made answers to complex decision-making situations, they increase understanding of the evaluated phenomena, help preventing burden shifting and provide a sound, science-based background for decision-making. As the development of the LCA-based methods is moving from environmental assessments towards multidimensional assessments that would include economic and social aspects and extend from the product level to sector level, requirements related to successful implementation and interpretation of the results increase. Future activities should be targeted to achieve a comprehensive understanding of different sustainability aspects, at the same time allowing easy implementation of the methods. The implementation and interpretation phases should be supported by flexible tools and compatible datasets. Methods and tools should be applicable for addressing different aspects of sustainability, incrementally, and for conducting either comprehensive or streamlined studies, depending on the purpose. Results of the assessments should be communicated in a way that would help decision-makers and stakeholders in making sustainable choices.
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Nimeke	**Kestävän kehityksen arviointi prosessiteollisuudessa – Esimerkkejä ja tulevaisuuden kehityspolkuja** Johtopäätöksiä ja suosituksia SAMT-projektista
Tekijä(t)	Hanna Pihkola, Tiina Pajula, Maija Federley, Jouko Myllyoja, Carlos Tapia, Michael Ritthoff & Mathieu Saurat
Tiivistelmä	Elinkaaripohjaisia kestävän kehityksen arviointimenetelmiä hyödynnetään tällä hetkellä monipuolisesti prosessiteollisuuden eri sektoreilla. Lähitulevaisuudessa menetelmien ja niiden käyttöä tukevien työkalujen kehityksessä tulisi kiinnittää huomioita erityisesti siihen, kuinka erilaisia arviointimenetelmiä olisi mahdollista integroida osaksi yritysten jokapäiväistä päätöksentekoa. Kestävä kehitys on laaja kokonaisuus, ja uusia kiinnostuksen ja huomion kohteita nousee esiin säännöllisin väliajoin. Tämä asettaa haasteita myös arviointimenetelmien ja työkalujen kehitykselle, sillä niiden olisi pystyttävä vastaamaan yhä moninaisempiin kysymyksiin ja ottamaan huomioon mahdolliset vaikutukset ihmisiin, ympäristöön ja talouteen. Monet tarkasteltavista kysymyksistä edellyttävät erikoistuneita menetelmiä ja erikoisosaamista. Tämä asettaa haasteita erityisesti tulosten tulkinnalle ja viestinnälle, jotta tulokset olisivat mahdollisimman hyvin hyödynnettävissä sekä yritysten päätöksenteossa että sidosryhmäviestinnässä ja edesauttaisivat kestävien valintojen tekemistä. Tutkimukseen osallistuneiden yritysten näkökulmasta merkittäviä kannustimia kestävän kehityksen arvioinnille ovat yrityksen omat strategiset valinnat, lainsäädännön asettamat vaatimukset sekä sidosryhmien esittämät kysymykset. Elinkaariarviointi lisää ymmärrystä tarkasteltavasta arvoketjusta ja sen vaikutuksista sekä tuottaa tutkimukseen pohjautuvaa tietoa päätöksenteon tueksi. Lisäksi arvioinnin perusteella voidaan välttää kuormituksen siirtämistä elinkaaren vaiheesta tai vaikutusluokasta toiseen. Koska laaja arviointi voi olla työläs toteuttaa käytännössä, tulevaisuudessa tarvetta on erityisesti ns. kevyille menetelmille, joiden pohjalta olisi mahdollista tunnistaa tärkeimpiä vaikutuksia ja kehityskohteita. Toisaalta samanaikaisesti lisääntyy tarve myös entistä kokonaisvaltaisemmille arvioinneille, joissa erilaisia vaikutuksia pystyttäisiin tarkastelemaan samanaikaisesti. Erityistä tarvetta on menetelmille, työkaluille ja tietopankeille, jotka olisivat yhteensopivia muiden tietojärjestelmien ja ohjelmien kanssa ja jotka mahdollistaisivat joustavan siirtymän tarkastelunäkökulmasta toiseen.
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Sustainability assessment in the process industries – Current practice and paths for future development

Conclusions and recommendations from the SAMT project

This report summarises the main conclusions of the SAMT 'Sustainability assessment methods and tools to support decision-making in the process industries' project. The aim of the SAMT project was to review and make recommendations concerning the methods with the greatest potential for evaluating sustainability in the process industry, focusing especially on energy and resource efficiency.

SAMT collected the experiences of leading industrial actors from the cement, oil, metal, water, waste and chemical industries, and reviewed and applied existing life cycle-based sustainability assessment methods in a cross-sectorial context. As an outcome of the project, a roadmap and an implementation plan for developing consistent sustainability assessment methods and for mainstreaming their use within process industries was created.

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