SAMT
SUSTAINABILITY ASSESSMENT METHODS AND TOOLS TO SUPPORT DECISION-MAKING IN THE PROCESS INDUSTRIES

COORDINATION & SUPPORT ACTION

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Case Study Report: Analysis of best practice solutions in comparison with currently used techniques

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Abstract / Executive summary:

The aim of the SAMT project (2015-2016) is to review and make recommendations about the most potential methods for evaluating sustainability and therein the energy and resource efficiency in the process industry. SAMT will collect, evaluate and communicate the experiences of leading industrial actors from cement, oil, metal, water, waste and chemical industry and review the latest scientific developments within the field of sustainability assessment. SAMT is a coordination and support action that will promote the cross-sectorial uptake of the most promising tools by conducting case studies, organising workshops and producing recommendations for further implementation of the best practices in sustainability assessment.

The overall aim of the case studies conducted within the SAMT project is to identify best practices with respect to tools, methods and indicators for assessing sustainability and resource and energy efficiency. On a practical level, methods and tools currently applied by the industries were tested and compared with existing methods that were considered promising and powerful in order to assess either the overall sustainability, or energy and resource efficiency.

By means of the case studies presented in this report, the applicability and comparability of some of these methods is evaluated, and future research and development needs are identified. In essence, two levels of implementation were followed, each performed on a group of methods with different scopes and ambitions:

- The first group focused on three environmental sustainability methods, namely Carbon Footprint (CF), Exergetic-Life Cycle Assessment (E-LCA) and Life Cycle Activity Analysis (LCAA). These methods were tested – i.e. without full implementation.
- The second group focused on a total of eight sustainability assessment methods and six alternative methodologies covering environmental, economic and social aspects. All methods were fully implemented. The first study was based on two different industrial processes and examined the following methods: Life Cycle Assessment (LCA), Material Input per Service (MIPS), Life Cycle Costing (LCC), Eco-Efficiency Analysis (EEA), Green Productivity (GP) and Social-Life Cycle Assessment (S-LCA). The second study focused on the available impact assessment methods for Water Footprint (WF).

The following table provides an overview of the methods tested in this work:

Table 1: *Implementation levels for the methods tested within the SAMT case studies*

Selected methods	Type	Level	Contributing partner	Main motivation	Main focus
LCA	LCA-based	Full implementation	Tecnalia, Bayer, BASF	Needed as a basis for other methods	Validation
MIPS	LCA-based	Full implementation	WI, Bayer, Tecnalia, SUEZ, VTT	LCA-based. Focus on materials	Validation
LCC	LCA-based	Full implementation	Tecnalia, Bayer	LCA-based. Focus on costs	Validation
S-LCA	LCA-based	Full implementation	Tecnalia, BASF	New methods available	Testing and comparison
EEA	Integrated	Full implementation	Tecnalia, Bayer, BASF	High interest among partners	Comparison
GP	Integrated	Full implementation	Tecnalia, Bayer	High interest among partners	Comparison
WF	LCA-based	Full implementation	VTT, SUEZ	LCA-based. Focus on water. High interest among partners	Validation and comparison
CF	LCA-based	Simulation	Tecnalia, CEMEX	LCA-based. Focus on energy	Testing

E-LCA	LCA-based	Simulation	Tecnalia, Neste	High relevance according to the RACER evaluation	Testing
LCAA	Hybrid	Simulation	Tecnalia, Hydro	Hybrid method	Testing

Basing on this research setting, we discuss the value added of the different methods and we identify a number of barriers that potentially undermine sustainability assessment within the process industry. Building on these findings, we provide a series of recommendations for enhanced sustainability evaluation practice at the industrial level. The report is accompanied by three appendices that provide the complete case study reports.

KEY WORDS:

Process industry, Sustainability, Life Cycle Assessment (LCA), Material Input per Service (MIPS), Carbon Footprint (CF), Water Footprint (WF), Exergetic-Life Cycle Assessment (E-LCA), Life Cycle Costing (LCC), Social Impact Assessment (SIA), Social-Life Cycle Assessment (S-LCA), Eco-Efficiency Analysis (EEA), Green Productivity (GP) index, Life Cycle Activity Analysis (LCAA)

List of abbreviations

AA: Activity Analysis
CED: Cumulative Energy Demand
CF: Carbon Footprint
EEA: Eco-Efficiency Analysis
EIA: Environmental Impact Assessment
EPD: Environmental Product Declaration
E-LCA: Exergetic Life Cycle Assessment, Exergy analysis
GP: Green Productivity
LCA: Life Cycle Assessment
LCAA: Life Cycle Activity Analysis
LCC: Life Cycle Costing
LCI: Life Cycle Inventory
LCIA: Life Cycle Impact Assessment
LCSA: Life Cycle Sustainability Assessment
MI: Material Input
MIT: Material Intensity
MIPS: Material Input Per Service
PEF: Product Environmental Footprint
SIA: Social Impact Assessment
S-LCA: Social Life Cycle Assessment
TCA: Total Cost Assessment
TCO: Total Cost of Ownership
WBCSD: World Business Council for Sustainable Development
WF: Water Footprint
WWTP: Wastewater Treatment Plant

Contents

Specific case study reports are included as appendices to this main report. Each case study is reported in its own report. The appendices include the following three reports:

- Integrated case study – Appendix 1
- Water footprint case study – Appendix 2
- Simulation methods – Appendix 3

1 Introduction

1.1 Background

Sustainability assessment methods are needed for various industrial sectors to support sustainable technology development, decision-making 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 tool or assessment method is challenging, or even impossible. While there are aspects and indicators that are common to all process industries, sector specific methods, tools, or indicators are often required to address the specific features of each industrial sector in a fair and transparent way.

The SPIRE Public –Private Partnership (PPP)[1] brings together several sectors of process industry: cement, ceramics, chemicals, engineering, minerals and ores, non-ferrous metals, and water. 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. Within the Horizon 2020 work programme, the specific and common goals listed for the SPIRE sectors are:

- A reduction in fossil energy intensity of up to 30% from current levels by 2030.
- A reduction of up to 20% in non-renewable, primary raw material intensity compared to current levels by 2030.
- A reduction of greenhouse gas emissions by 20% below 1999 levels by 2020, with further reductions up to 40% by 2030.

For the SPIRE sectors, sustainability assessment methods are crucial for evaluating the current state and the achievement of the goals related to resource and energy efficiency. For evaluating the overall resource and energy efficiency of the SPRIRE sectors as a whole, tools and indicators that are applicable for cross-sectorial assessment are required.

At the moment, several tools, assessment methods and indicators exist, but they differ in their goal and scope and are intended for different kind of use within companies, by consumers or by authorities to support policy planning and evaluation. Additionally, different methods and tools are focused for different levels of assessment: product, company, industry or society. Thus the problem is not so much the existence of proper methods and tools but rather the lack of understanding and knowledge on how they should be applied and in which context. Thorough understanding of the underlying mechanisms and calculation principles incorporated in the tool in question is often required to make a trustworthy assessment. Furthermore, it should be recognised which of the existing methods and tools are suitable for analysing

[1] SPIRE stands for Sustainable Process Industry through Resource and Energy Efficiency. For more information see: www.spire2030.eu

resource and energy efficiency within the process industries and across the different sectors of the industry.

The SAMT project will respond to the need for cross-sectorial sustainability assessment methods by bringing together representatives of several process industry sectors, namely cement, metal, oil, water, waste and chemical industry, and collecting and evaluating the current best practices from each industrial sector, together with the latest research know-how related to sustainability assessment methods and recent activities in standardisation within the field.

SAMT is funded by the Horizon 2020 work program SPIRE.2014-4: Methodologies, tools and indicators for cross-sectorial sustainability assessment of energy and resource efficient solutions in the process industry.

1.2 Some definitions

In this report we use consequently the terms 'method', 'tool', and 'indicator'. The definitions applied here were first defined in the context of the first SAMT deliverable D1.1, and slightly updated for the second SAMT deliverable D1.2. The definitions are as follows:

- **Method:** set of instructions describing how to calculate a set of indicators and how to asses 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.
- **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. the environmental pressure.

Those definitions are by no means "official" but the ones we use in this project to avoid confusion. These terms are indeed used differently by many stakeholders in the scientific community, in policy, in the industry etc. For more information, please see SAMT D1.1 (Saurat et al., 2015b).

1.3 Aim of this report

The overall aim of the case studies conducted within the SAMT project is to identify best practices with respect to tools, methods and indicators for assessing sustainability and resource and energy efficiency. On a practical level, methods and tools currently applied by the industries were tested and compared with existing methods that are considered interesting and potential for assessing either overall sustainability, or energy and resource efficiency. Within the cases, the applicability and comparability of the methods is evaluated, and future research and development needs are identified.

This report presents some findings related to the implementation of a number of sustainable assessment methods and tools in a realistic industrial context. The focus is on the applicability of the methods and tools rather than on accuracy of data and the assessments themselves. Accordingly, the assessment does not pursue the purpose of generating precise numbers, but the results rather have a simplified illustrative character.

Neither this report, nor any of its sections or appendices should be used to generate any claims on the environmental, economic or social sustainability of the industrial processes assessed in the SAMT case studies. These evaluations shall be considered as intermediate information collected for the only purpose of testing a group of methods – and related tools – for sustainability assessment within the process industry.

The report is structured as follows: Section 2 presents the goals of the SAMT case studies and outlines the objectives. Section 3 provides an overview of the criteria that drove the selection of methods. Chapter 4 describes the methodology that was followed for each one of the two implementation levels that were applied. Section 5 provides a succinct description of the case studies, including the processes that were assed as well as the methods that were tested. Section 6 elaborates on the added value of the different methods, the barriers for implementation and the areas for improvement. Section 7 contains our recommendations. Finally, Appendices 1 to 3 present the full case study reports.

2 Objectives of the case studies

The main goal of the SAMT case studies is evaluate and select the best practices with respect to tools, methods and indicators for the assessment of sustainability, resource and energy efficiency, based on the results of the evaluation of methods performed on previous stages of the SAMT implementation.

In order to achieve this goal, a number of methodologies and practices classified as the best/most promising – including methods, tools and indicators – were tested within a real industrial context.

Against this framework, the case studies of the SAMT project were conducted with two specific orientations:

- **Validation of methods**: Validation allowed understanding the added value that specific sustainability assessment methods have for different companies, as representatives of their specific sectors. Method validation also allowed collecting information on the performance (in terms of potential strengths and weaknesses) of the different methods in relation to the main research questions of the SAMT project (namely multi-sectoriality, focus on energy and material efficiency, and life cycle orientation). Compared to previous evaluations performed within the scope of SAMT project, the added value here is the real industrial context in which the methods were tested for a specific practice-oriented purpose. Key issues that were analysed through the case studies included method reliability, data needs, the possibility to assess different sustainability aspects (focusing on resource and energy efficiency), the opportunities for decision making at different levels, the quality of the results, and the utility for the industry, amongst other relevant aspects.
- **Comparison of methods**: Comparison of methods was done along two strands: (i) between the methods themselves and (ii) between the methods and the usual practice within the companies participating in the SAMT project. At a simulation level, the comparison of methods was enabled through a series of checklists focusing on a number of relevant aspects linked to the main goals defined by the SAMT project. These checklists are presented as Appendices to this document.

3 Methodology

3.1 Implementation levels

The SAMT case studies focus both on the implementation process and the results delivered by each method. In order to cover both dimensions for the various types of methods included in the assessment, the case studies were developed incrementally. This allowed finding a balance between the types and number of methods to assess and the depth of the assessments. In essence, two levels of implementation were applied, each of them performed on a group of methods with different scopes and ambitions:

Level 1 (simulation): On this level, three sustainability assessment methods were *tested* by three companies participating in the SAMT project. Method testing was based on realistic information derived from the simulated application of the selected methods within the three companies, but without implementing the methods themselves – i.e. the method was not applied on a real product or process, no calculations were done, no intermediate impacts and endpoints were obtained, no outcomes were communicated –. The methods tested at this level were Carbon Footprint (CF), Exergetic-Life Cycle Assessment (E-LCA) and Life Cycle Activity Analysis (LCAA). These are methods that show particular strengths in any of the dimensions considered in the SAMT project, as reported on Table 1 below.

At this level, the main goal was to test the methods in terms of: (i) their specific inputs and requirements (by focusing on e.g. the data needs and its practical availability within companies, their implementation costs, etc.), and; (ii) the nature, quality and usability of the outputs yielded when applied under specific -and realistic- circumstances (this includes e.g. describing the nature and scope of the information generated as well as its relevance within a business context). These questions mainly relate to e.g. replicability and applicability when moving from one sector to another. In order to address these issues in a comparable manner a 'testing criteria' based on a common checklist are presented in Appendix 3.

Level 2 (**full implementation):** This level is based on a fully-fledged application of a number of specific methods within two *complete* case studies that are called "Integrated" and "Water Footprint" case studies. Both of these two comprehensive case studies mainly focus on the assessment of the methods in terms of the potential implementation challenges, obstacles, development needs, etc. when they are implemented along the life cycle (both upstream and downstream). Since some of the methods are relatively new and promising approaches, a comparative framework was set up. The methods tested were Life Cycle Assessment (LCA), Material Input per Service (MIPS), Life Cycle Costing (LCC), Eco-Efficiency Analysis (EEA), Green Productivity (GP) and Social-Life Cycle Assessment (S-LCA) within the integrated case study, which is presented in Appendix 1, and various MIPS and Water Footprint (WF) methods within the water footprint case study, which is delivered in Appendix 2. In all cases, the main research challenge was to identify strengths, weaknesses, limitations of each method for each specific application.

3.2 Case study selection criteria

The SAMT case studies were chosen according to the general goals of the SAMT project (see Section 2). Additionally, when it came to the specific decisions on the methods to test and the products/processes to analyse, the inputs from previous phases of SAMT project pointed the way ahead. These included, amongst others, the following aspects:

1. Diversification of methods according to the clusters defined within SAMT D1.1 (Saurat et al., 2015b), including (i) LCA-related methods; (ii) Hybrid methods, and; (iii) Integrated methods.
2. The cross-check analysis (pre-selection of methods) performed within D2.1 of the SAMT project (López et al., 2015) basing on a selection of 14 out of the 52 methods considered in the overview of methods presented in D1.1 (Saurat et al., 2015b). This analysis based on the following criteria: (i) multi-sectoriality, or capacity of the methods to be implemented across sectors; (ii) multi-dimensionality, informing on the methods' ability to cover more than one sustainability spheres (environmental, economic and social); (iii) life cycle orientation, related to the capacity of the methods to cover more than one life cycle stages of the products or services, and; (iv) simplicity, assessed through the availability of tools easing the implementation of methods.
3. The SAMT-RACER evaluation, also included within SAMT D2.1 (López et al., 2015). The evaluation was based on an adapted RACER methodology, which is an evaluation framework designed by the European Union to assess the value of scientific tools for decision-making (EC, 2009). The SAMT-RACER evaluation was applied as a semi-quantitative assessment performed over a total of 16 criteria, grouped in 5 components: Relevance, Acceptance, Credibility, Easy (simplicity), and Robustness.
4. The interests expressed by the SAMT partners. The selection of the methods to test within the two case studies was a participatory process open to contributions from all the RTO and industrial partners involved in the SAMT project. Eventually, a poll was organised. All partners had the chance to vote for their preferred methods to be tested within the case studies.

3.3 Partner and stakeholder roles

The SAMT project is a Coordination Support Action designed to enable the participation of a large number of stakeholders from the process industry. These stakeholders contributed to the case studies in a number of ways. The RTOs played a supporting role, providing guidelines for the case studies and doing the follow-up. Besides, the RTOs were responsible for most part of the analyses done. Six of the industrial partners participating in the project, namely the BASF, BAYER, CEMEX, HYDRO, Neste and SUEZ companies, had a direct participation in the case studies by answering the questionnaires, providing data, performing specific analyses, checking the assessments and giving feedback for reporting. All project partners contributed to the integration phase, mainly providing inputs to improve the general conclusions section. Other stakeholders participated in the open workshops and got in touch with the project partners though different channels in different phases of the project implementation, including the case studies.

4 Overview of case studies

Life cycle thinking is the conceptual foundation for the environmental, economic, social, and integrated and hybrid methods tested in the SAMT case studies. This section provides an overview of the case studies conducted on Level 2 (full implementation), which are provided as Annexes 1 and 2 to this report, and Level 1 (simulation) delivered as Annex 3 to this report.

4.1 Succinct description of the processes analysed

4.1.1 Integrated case study

Our first case study dealt with the production, use and end of life of an industrial product. The main goal of this case study was to test and compare a number of sustainability assessment methods focusing on the environmental, economic and social spheres within an industrial context. The case study itself was designed as a comparative analysis of two virtual production sites located in Spain and Germany, assuming that that the production was entirely done either in Spain (scenario 1 – plant A) or Germany (scenario 2 – plant B), with identical production routes ending with the same product and an identical function but with different disposal and transportation systems, as well as asymmetric production costs and social indicators.

The case study was prepared jointly by Tecnalia, Bayer, BASF and Wuppertal Institute. This case study is available in Appendix 1 to this report.

4.1.2 Water footprint case study

Our second comprehensive case study focused on a water footprint assessment for a wastewater treatment plant (WWTP) located in France. The case study itself represents a service water footprint of the WWTP that treats high organic load effluents from agri-food industry. The main goal of the case study was to test the water footprint assessment for the WWTP by applying different available characterisation factors for the impact assessment phase, and to consider potential benefits and challenges related to conducting a comprehensive water footprint assessment according to ISO14046. Parallel to water footprint assessment, another LCA-based assessment method, namely MIPS method, was applied within the case study to consider other resource categories besides water, and to consider potential benefits and added-value from applying these different methods together.

The case study was prepared together by VTT, SUEZ and Wuppertal Institute. The WF case study is available in Appendix 2 to this report.

4.1.3 Simulation case study

The simulation level did not entail assessing specific processes or products. This implementation level was mainly conducted via a series of questionnaires that were filled by the industrial partners participating in the project. Respondents answered a vast array of questions designed to describe each sustainability assessment method across a number of relevant dimensions identified on previous steps of the SAMT project. These dimensions are essence, scope, relevance, requirements and outcomes (see López et al., 2015; Saurat et al., 2015b). In order to benchmark such aspects and compare the relative importance they could have for the companies participating in the project, a preliminary questionnaire was distributed among all the industrial partners participating in the SAMT project. This questionnaire is provided as Appendix 3.1.

A second, more detailed, questionnaire was distributed among the three industrial partners – Neste, HYDRO and CEMEX – that volunteered to simulate the implementation of three methods, respectively E-LCA, LCAA and CF. The questionnaire is available in Appendix 3.3.

The questionnaires were accompanied by a detailed description of the methods. This description mirrored the structure of the questionnaire, so that each category of analysis was supported by a detailed overview of the method based on scientific evidence. The template that was used for the characterisation of the simulation methods is delivered as Appendix 3.3 to this report.

This case study was prepared by Tecnalia, Hydro, CEMEX and Neste, with contributions from other partners. All questionnaires and templates related to the case study are included in Appendix 3.

4.2 Description of the methods tested in the case studies

This section provides an overview of the methods applied within the SAMT case studies.

4.2.1 Integrated case study

An ISO-compliant environmental **Life Cycle Assessment (LCA)** was the core component of the sustainability analysis within this case study. The seminal role of LCA is also reflected in the fact that there are a number methods derived from it, such as CED, CF, WF, etc. These can be considered sub-methods of the broader LCA (Saurat et al., 2015b).

The second environmental method applied in this case study, namely **Material Input per Service (MIPS)**, can also be considered a sub-method of the broader LCA. The MIPS method is an established methodology that delivers quantitative results on material efficiency – Material Footprint – by adding the weight of a product and the ecological rucksack of that product, also expressed in a mass unit. There are examples of MIPS applications in most sectors, including most process industries.

Basing on the same life cycle inventory as the LCA and MIPS implementations, an economic **Life Cycle Costing (LCC)** was also developed. The LCC is a costing method that takes account of all the costs incurring during the entire life cycle of any product or process, the so-called life cycle costs, which include the development, production and dismantling/disposal phases. In alternative to traditional accounting, LCC can provide valuable information on the dimension and structure of costs potentially incurred by new processes or products already during their development phase (Sell et al., 2014).

Based on the results of the LCA and LCC, the environmental and economic dimensions were combined as eco-portfolios. The eco-portfolios were produced following two alternative analytical approaches. The first one was based on the concept of eco-efficiency, defined as the ratio of an output value to its environmental influence. It was computed over a number of environmental dimensions, following the **Eco-Efficiency** Method by BASF (Saling et al., 2002). The second one was based on the concept of Green-productivity, defined as is the ratio of productivity of a system to its environmental impacts. It was calculated following the **Green Productivity (GP)** method proposed by Hur, et al. (2004). GP integrates environmental protection and productivity improvement, using the environmental management tools such as LCA and Total Cost Assessment (TCA).

A simplified **Social-LCA (S-LCA)** was performed on top of the environmental, economic and integrated assessments. S-LCA followed the conceptual framework proposed by the UNEP-SETAC Guidelines for Social Impact Assessment (2009). Two specific S-LCA methods were compared, namely the Social Metrics for Chemical Products in their Applications by the World Business Council for Sustainable Development – WBCSD (Coërs, 2015) and the Handbook for Product Social Impact Assessment by the Roundtable for Product Social Metrics (PRé Sustainability and Roundtable for Product Social Metrics, 2016).

Table 2: *A summary of the methods, tools and impact categories applied within the integrated case study*

Used tool	Type of indicators	Impact category	Characterisation model
Standard LCA (comparison of two productions systems located in Germany and Spain)			
SimaPro	Environmental	Abiotic depletion	CML 2001
		Acidification	
		Eutrophication	
		Global Warming 100a	
		Ozone layer depletion 40a	
		Photochemical oxidation	
MIPS			
OpenLCA	Resource Use	Abiotic raw materials	Saurat & Ritthoff 2013
		Biotic raw materials	
		Earth movement in agriculture and silviculture	
		Water	
		Air	
LCC			
Excel	Economic	Development costs	Sell et al., 2014
		Use costs	
		Disposal costs	
EEA			
BASF EEA tool	Environmental	Resource depletion (mineral & fossil)	EU PEF 2014
		Acidification	EU PEF 2014
		Climate change	EU PEF 2014
		Eutrophication (freshwater & marine)	EU PEF 2014
		Human toxicity	BASF 2002
		Photochemical ozone formation	EU PEF 2014
	Economic	Development costs	Total Cost of Ownership (TCO)
		Use costs	

		Disposal costs	
GP			
Excel	Environmental	Abiotic depletion	CML 2001
		Acidification	
		Eutrophication	
		Global Warming 100a	
		Ozone layer depletion 40a	
		Photochemical oxidation	
	Economic	Development costs	Sell et al., 2014
		Use costs	
		Disposal costs	
S-LCA			
Handbook for Product Social Assessment	Social	Basic rights and needs	Roundtable for Product Social Metrics[2]
		Employment	
		Health and safety	
		Skills and knowledge	

4.2.2 Water footprint case study

The evolution of water footprint methods and terminology has been rapid. The water footprint concept was first introduced in 2002 by Hoekstra and the Water Footprint Network[3] to quantify the total volume of freshwater that is consumed and polluted, divided into three different water use categories (blue water, green water, and grey water). The recent developments in LCA have however focused on measuring the actual impacts of water use instead of the volumetric approach, and methodologies have been developed to capture the impact of human activities on water availability (Kounina et al., 2013).

According to the recent ISO standard for water footprint (ISO14046), **Water Footprint (WF)** is a set of metrics that quantifies the potential environmental impact related to water use. It provides the information to which extent a product, service or company is affecting ecosystems and the society, through the use of water.

According to ISO14046, the water footprint assessment is a quantitative assessment that should be based on a life cycle approach, and it can be conducted as a stand-alone assessment, or as a part of a life cycle assessment. This assessment includes the same four phases of LCA mentioned above.

The WF is reported as a water footprint profile that considers a range of potential environmental impacts associated with water and consists of several impact category indicator results. The profile may be further aggregated into a single parameter. The water footprint profile may consist of different types of water footprints that include water scarcity footprint, water availability footprint and water degradation footprint. All these footprints may consist of several impact categories. Although examples of potential impact categories to be included in different types of water footprints are given, specific methods or characterization factors that should be used for the assessment are not defined within the standard, as available methods are in different stages of development.

[2] Applied on the “mandatory” social topics within the WBCSD method.
[3] http://waterfootprint.org/en/water-footprint/

In addition to water footprint, MIPS method was applied in the case study, using the same inventory data and assumptions with the WF assessment. A summary of the applied methods, tools and impact categories and related characterization models is presented in Table 3.

Table 3: *A summary of the methods, tools and impact categories applied within the water footprint case study*

WATER FOOTPRINT			
Used tool	**Type of indicators**	**Impact category (Midpoint)**	**Characterisation model**
Waterlily	Consumptive water use	Water scarcity	Water scarcity index from Pfister et al. (2009)
	Water degradation	Freshwater eutrophication	ReCiPe (Goedkoop et al. 2009)
		Marine eutrophication	ReCiPe (Goedkoop et al. 2009)
		Freshwater acidification	IMPACT 2002+ (Jolliet et al. 2003)
		Freshwater ecotoxicity	USEtox (Rosenbaum et al. 2008)
		Toxicity to human	USEtox (Rosenbaum et al. 2008)
SULCA	Consumptive water use	Water scarcity	WULCA / AWaRe, 2016
	Water degradation	Aquatic eutrophication	WorldImpact+, 2012
		Aquatic ecotoxicity, long-term	
		Aquatic ecotoxicity, short-term	
		Terrestrial acidification	
		Carcinogens, long-term	
		Carcinogens, short-term	
		Non-carcinogens, long-term	
		Non-carcinogens, short-term	
MIPS			
OpenLCA	Resource use	Abiotic raw materials	Saurat & Ritthoff 2013
		Biotic raw materials	
		Earth movement in agriculture and silviculture	
		Water	
		Air	

4.2.3 Simulation case study

Carbon footprint (CF) represents the net emissions of CO_2 and other greenhouse gases over the full life cycle of a product, process, service or organisation. All direct (on-site, internal) and indirect emissions (off-site, external, embodied, upstream and downstream) are considered. Normally, the CF is expressed as a CO_2 equivalent (usually in kilograms or tonnes per functional unit) and as such is usually equivalent to the LCA Global Warming Potential (GWP) impact category within a comprehensive LCA.

Exergetic-LCA (E-CLA) was the second method tested at the simulated level. According to the first law of thermodynamics, energy conversions do not affect the total amount of energy. It is the *quality* of energy that degrades when energy and material forms are transformed. This quality aspect, formulated by the second law of thermodynamics, is what exergy reflects: It can be defined as a minimum work input necessary to realise the reverse process (Rant 1964 cited in Szargut, 2005). Unlike energy, exergy is consumed by processes as a fraction of the energy content becomes useless (De Meester et al., 2009). It expresses the maximum amount of useful work the resource can provide. While the classical LCA has a major emphasis on emissions, exergy analysis is much more resource and product -efficiency oriented (Dewulf et al., 2008). E-LCA is to be understood as a specific implementation of LCA that combines exergy accounting with traditional LCA to enable the analysis of cumulative consumption of resources.

Life Cycle Activity Analysis (LCAA) combines mathematical programming of Activity Analysis (AA) with the LCA methodology providing a computable approach for economic and environmental optimisation of the supply chain of products, processes or services. LCAA extends the LCA framework by recognising the possible presence of alternative activities along the cradle-to-grave life cycle stages and by including economic costs (Freire and Thore, 2002). LCAA distinguishes four types of goods: primary goods (natural resources, material or labour), intermediate goods (outputs which serve as inputs into subsequent activities), final goods (outputs) and environmental goods (energy consumption, emissions of pollutant and disposal of waste)

Table 4: *Methods tested at a simulation level*

Simulation methods	Type	Main motivation
Carbon Footprint	LCA-based	It is a widely used method. CF is the basis for many energy efficiency assessments.
Exergetic-LCA	Exergy-based method. LCA-based	High relevance according to the RACER evaluation
LCAA	Hybrid method	Promising method

5 Lessons learnt

The interviews conducted during the SAMT project with sustainability experts working in different process industry sectors highlighted several needs and demands related to sustainability assessment methods applicable for wide implementation within the industries (SAMT D1.2 - Saurat et al., 2015b). From the point of view of the SAMT case studies and method testing, three of those needs are of particular importance:

- Firstly, the methods should be able to create additional value for decision making. Thus, there is a need to argue for both internal and external stakeholders, why resources should be invested in these types of assessments, and what is the benefit these methods can create for the company? A quote from one of the interviews illustrates clearly this point and the challenges faced: "*In the end, LCA is an oversized tool compared to what use can be made of the results in practice in the industry: it is like having a Ferrari and driving it at 30 km/h*."
- Secondly, the methods should be applicable for different kinds of value chains and activities.
- Thirdly, the results should be easily communicated both internally and externally, to non-sustainability expert audiences.

This Section aims to reflect upon these points considering the potential benefits and drawbacks related to each of the methods tested and the learnings from the case studies, focusing mainly on practical aspects that should be dealt with when implementing these methods in practice.

5.1 Environmental methods

5.1.1 Value added

LCA, E-LCA, CF, WF and MIPS are environmentally oriented life cycle methods. All of them, with the possible exception of WF, lack of predefined geographical boundaries. They cover all life cycle stages, but parts of the life cycle can also be analysed separately. CF and WF can be conducted as stand-alone assessments, or as a part of a LCA. The LCA can also be enlarged to adopt the MIPS and the exergetic perspectives. In general, the main benefit of all the life cycle based methods is the ability to point out indirect impacts within the value chain, and the ability to identify hotspots in which more attention should focused at

Amongst all of the methods, the CF method is the one with a wider diffusion among the process industry. The CF can be calculated using the LCA standard (ISO 14064-2012) as well as other standards largely in compliance with it, such as the GHG Protocol. Given that it only focuses on the climate change impact category, data needs are limited to the potential sources of GHG emissions and processing is also simpler in comparison to a full LCA. Furthermore, as impacts are quantified as CO_2 equivalents the method is easier to understand and communicate to non-experts. This makes it a method widely applied by industries and explains why many companies have developed their own tools for calculating the CF. However, development of own tools has also been due to the need to adapt the tools with specific needs of the organisations (see SAMT D1.2 - Saurat et al., 2015b). With the growing relevance of climate change in global agendas, CF is a de-facto standard for environmental communication in many sectors. There also seems to be an increasing demand of CF for Environmental Product Declarations (EPDs).

Based on the interviews conducted with the industrial experts (see Saurat et al., 2015a), WF is currently of interest for all the sectors represented in the SAMT project and companies are looking for potential methods and tools for conducting a comprehensive water footprint assessment. As such, water footprint inventory (according to life cycle phases) provides useful information on the distribution of water use between life cycle phases, and points out phases in which more attention could be given. Especially in areas with high water scarcity indexes, pointing out indirect water consumption is important for focusing attention on processes in which there is most reduction potential. A water scarcity footprint, together with specific impact category results for the water degradation footprint might be quite easily added to a comprehensive LCA. Together, these aspects already cover many useful and important aspects related to water. However, for a comprehensive understanding of the impacts (as defined in the standard), the assessment should be extended towards the water availability footprint, which would in most cases mean a lot of additional data collection and analysis. However, the results of the previous steps may be used as guidance when considering the need for this next step of the assessment.

The main value added of E-LCA relates to the intrinsic characteristics of the exergy concept. In contrast to other environmental methods, exergy analysis can provide a unified measure for resource accounting, as it equally accounts for materials, movements, currents or heat and the transformations between them (Laner et al., 2015; Maes et al., 2014). Additionally, the amount of exergy destruction in a process is implicitly a measure of efficiency, and the ratio of exergy outputs to total exergy inputs provides an indication of the theoretical potential of future improvement for a process (Maes et al., 2014). Thus, exergy analysis facilitates comparison of different environmental issues and it allows consistent temporal comparisons of environmental performance (Ayres et al., 1998).

All these environmental methods have a broad scope in terms of potential application, including technical and management process optimisation, supply chain optimisation and life cycle wide optimisation, amongst others. All of them can be used for monitoring, reporting and decision making alike. Despite they were developed for status quo analysis, they can also be used to produce scenarios.

5.1.2 Existing barriers and areas for improvement

Albeit all the environmental methods tested in the SAMT case studies are well established, some areas for improvement and barriers for successful implementation remain.

LCA is the most comprehensive and robust method currently available to evaluate the environmental impact of products over their value chain. Comprehensiveness and robustness were achieved over time by countless methodological improvements and harmonisation initiatives since the early 1990s.

But as LCA developed it also became more complex and difficult to communicate. Complexity in LCA relates to a number of methodological steps implicit in the methodology, such as the following aspects: (i) the system boundaries and cut/off criteria; (ii) the impact categories included; (iii) the impact methods and the characterisation level – midpoints or endpoints –, and; (iv) the normalisation and weighting options.

This growing complexity led to a diversity of approaches that created the need for a standard (the ISO 14040 and 14044) and several international initiatives, such as the joint Life Cycle Initiative of the United Nations Environment Program (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC; 2002), as well as the European Platform on LCA of the European Commission (European Commission, 2008), which contributed with relevant harmonisation works such as the International Reference Life Cycle Data System - ILCD (JRC European Commission, 2010a).

However, despite all these harmonisation efforts LCA still lacks of a common, stable and univocal way of conducting the analysis across all the possible implementations. Even when the ILCD guidelines are strictly followed, in most cases the methodological choices and the assumptions that are usually done derive in studies that are not comparable, even when performed on the same product or process. Therefore, benchmarking the different industries, processes or products becomes challenging – particularly when these have not the same function or serve the same purpose. This also holds for simplified LCA or one-dimensional methods like CF or WF, even when the assessment is based on similar system boundaries and cut-off criteria.

Besides, due to the fact that most assessments rely on indirect data retrieved from professional databases, virtually all LCA-based studies lack of specific information on the geographical setting where the value chain actors operate. This makes difficult to understand where the environmental impacts are taking place – or at least are originated – and hampers the evaluation of the social impact of products, which to a large extent is conditioned by local conditions where production is based. When considering geographic distribution of the environmental impacts, an exception is the water footprint, for which characterization factors for evaluating water scarcity even at watershed level are now available[4]. For both, water footprint and life cycle assessment, ImpactWorld+[5] is a new impact assessment method (still in the development phase), which includes regionalized characterization factors for the following impact categories: respiratory effects, human and ecosystem toxic impacts, ionizing radiations, water use, acidification, eutrophication and land use. For these impact categories, characterization factors are available at the following spatial scales: global, continental, country level and fine resolution (e.g. sub-watershed). These new methods are a step towards inclusion of regionalized impacts within life cycle assessments.

The LCI results are also typically unaccompanied by information about the temporal course of the emission or the resulting concentrations in the environment. The impacts that can be calculated under such boundary conditions represent the sum of impacts from emissions released in the past, in the present and even in the future, undermining the usability of these studies within an Environmental Risk Assessment framework (Finnveden et al., 2009).

Since certain aspects of the WF are still under development, it will take some time before this method reaches the same degree of diffusion and accomplishment of other methods such as e.g. CF. However,

[4] see http://www.wulca-waterlca.org/project.html
[5] http://www.impactworldplus.org/en/index.php

currently available characterization factors for water footprint, together with the LCI databases that include information on water balance and water consumption (Ecoinvent v3. & Quantis Water Database), already enable WF assessments according to new ISO standard. Although the results might still include uncertainty, WF assessment is already a useful method for indicating hotspots in the value chain and evaluating the overall water balance of a product or a service (see also Boulay et al., 2015). For better diffusion of the method within the process industries, further work and more process specific, averaged datasets with water specific LCI data are required.

Although the WF is commonly represented aside with CF as an example of one dimensional assessment method (focusing on water), it is important to note that these approaches include many differences, especially when considering the complexity of the assessment and data needs. While CF consists of one impact category (Global warming potential), the WF assessment by definition of the ISO14046 requires assessing several impact categories that should be presented as a water footprint profile. The comprehensive water footprint considers local (or if not available country specific or regional) aspects and impacts whereas in CF, typically only global impacts to climate change are considered. However, while the local aspects require more work, they potentially also increase the usability and significance of the results, connecting the analysis to a real place where actual improvements could be identified and communicated to a targeted audience.

According to the Joint Research Centre of the European Commission (2011), the exergy approach has some particularities that should be acknowledged before implementation within a LCA framework. To begin with, exergy value does not depend on the scarcity of the resource[6], which makes this method inappropriate for the characterisation certain impact categories such as resource depletion. Furthermore, the midpoint method that is currently available, namely the Cumulative Exergy Extraction from the Natural Environment (CEENE; Dewulf et al., 2007), does not consider the differences between the two main types of exergy losses that are possible, namely those coming from solar energy or from the stock of minerals in the earth (JRC European Commission, 2010b).

From a more practice-oriented perspective, the exergy method has specific requirements that make LCI phase slightly more complicated than standard LCA. In the case of E-LCA, considering that this method implies transforming inputs and outputs of a system into exergy units, a detailed knowledge on the exergy content of every single operation unit is required. Similarly, the MIPS method requires that material inputs are calculated for all elementary flows included in a given process. For some inputs this is done by using the MIT factors. For integration in standard LCA a LCI method for Ecoinvent is available (Saurat and Ritthoff, 2013). Whenever such MIT factors or LCI-methods are not available for certain pre-treated flows, separate life cycle modelling using the same MIPS methodology is necessary.

Compared to the S-LCA conducted as part of the integrated case study (see Appendix 1), the application of LCA and MIPS went smoothly without significant issues. Overall, LCA and MIPS can be considered as most mature and well-applicable methods.

[6] Even if the last tonne of the resource is depleted, the exergy value remains the same.

5.2 Costing methods

5.2.1 Value added

LCC is a well-established method too, as companies have the interest to understand the real structure of costs and accurately quantify them, including those difficult to express in monetary form. There are a number of procedures available to account for life cycle costs. Mostly, they differ on the way costs are organised and classified. Depending on which is the purpose of the assessment, costs can for instance be organised as (i) use, ownership and administration costs, or; (ii) engineering, manufacturing, distribution, service, sales and refurbishment costs (Woodward, 1997). Perhaps, this aspect is the main advantage of LCC in relation to standard accounting practice. More than unveiling hidden costs, LCC can be very useful to understand the structure of costs over the entire value chain of a given product or process, contributing to decision making within a management framework and helping to communicate results to a wider audience. Costing methods are also the basis for the preparation of business cases and investment decisions.

But LCC and accounting in general have another important advantage in relation to environmental and Social Impact Assessment (SIA) methods, namely that they only focus on one 'impact category'. Similarly, costing methods only rely on a single and simple to communicate – monetary – unit of measure. Additionally, life cycle perspective is greatly enabled due to the fact that prices at any point of the value chain already reflect the economic value generated upstream. Simply put, prices are a measure of the accumulated value generated within previous transformations of any good, plus the original value of the raw materials that were needed to build them. This explains why competitiveness is greatly conditioned by the degree to which companies are able to optimise the value chain in which they operate. This single characteristic is mostly alien to the environmental and social dimensions, which unless norms and regulations are put in place, do not condition to the same degree the ability of companies to compete.

5.2.2 Existing barriers and areas for improvement

The empirical evidence collected in this study revealed that the two critical points in cost assessment are the scoping phase – which costs to consider – and the evaluation of financial costs – including decisions on the depreciation, amortisation, discount rates, etc. –.

The scoping phase is relevant in itself within a standalone LCC and also when considered in conjunction with the environmental LCA or the S-LCA. Decisions in terms of what costs to consider are not necessarily aligned with the decisions taken during the establishment of the system boundaries and cut-offs within an environmental –or social – assessment. Sometimes, the inability to align these assessments is caused by the lack of costing data for upstream processes, which may make it hardly possible to analyse certain life cycle stages. But discrepancies can also be brought about the different relevance that specific value chain steps and life cycle stages might have within the economic costing analysis in relation to the environmental one or vice versa.

The major challenge of the costing methods is the access to realistic value chain costs and prices. While internal costs are usually well-known for existing products, costs and prices for up- and downstream processes are often difficult to get hold of. This of course implies a degree of uncertainty when applying methods like LCC. However, it is surely not unique to costing methods but rather to all methods that consider a product's/process' entire life cycle. Moreover, for products in a development stage, future investment and marketing costs have to be estimated. In general, for the appraisal of future costs, making assumptions is inevitable and goes along with a degree of uncertainty. Another obstacle is the fact that costs are typically subject to fluctuations, impacting in particular those results which are projected far into the future.

Nevertheless, costing methods are per se the basis for the preparation of business cases and investment decisions.

5.3 Social methods

5.3.1 Value added

In the last few years several international initiatives have enlarged the knowledge basis of life cycle oriented approaches for SIA of products. These have put social well-being at the very heart of their programs, seeking to enable socially-sustainable production and consumption by approaching the evaluation of social sustainability with a similar outlook as environmental sustainability. Since the publication of the Guidelines for Social Life Cycle of Products (UNEP-SETAC, 2009), S-LCA has emerged and gained momentum as a methodology that is in line with the ISO 14040 and 14044 standards for LCA.

Both the methodologies that were tested in this case study are in line both with the UNEP-SETAC guidelines as well as with the ISO standards for LCA. The availability of these methods is in itself a huge leap forwards in relation to classical indicator-based SIA methods. These new LCA-compliant approaches allow for a detailed characterisation of the social implications of all steps within the value chain of products, including the potential positive benefits of products for consumers and local communities. Additionally, both methods are structured in a stable but at the same time flexible way that allow for a certain degree of freedom in terms of which type of assessment to conduct – whether quantitative or qualitative –, which exact social dimensions to consider, and which level of aggregation of results is sought.

These methods, together with the growing availability of social databases, prove that systematically accounting for social impacts along the value chain of products is increasingly possible, and that the information provided by S-LCA in general can help stakeholders to effectively and efficiently engage to improve social and socio-economic conditions of production and consumption by enabling organisations to achieve greater knowledge on the social implications of their products.

5.3.2 Existing barriers and areas for improvement

In comparison to the environmental and economic methods, S-LCA is still on its infancy. Despite the UNEP-SETAC Guidelines for Social Life Cycle Assessment of Products (2009) represented a methodological turning point, the practicalities of such approach have not been established yet. In this report we have assessed a couple of initiatives that seek to advance in this direction, namely a draft version of the Social Metrics for Chemical Products in their Applications by the World Business Council for Sustainable Development – WBCSD (Coërs, 2015) and the Handbook for Product Social Impact Assessment by the Roundtable for Product Social Metrics (PRé Sustainability and Roundtable for Product Social Metrics, 2016).

Although the WBCSD approach has not been published yet, it is already in a late phase of development. The third version of the Roundtable for Product Social Metrics has been published at the beginning of 2016. Both are data-intensive methods. In this case study we did some preliminary comparisons of both methods and understand how S-LCA is developing in practice. Basing on this exercise, we detected several areas for future improvement:

The main area for improvement relates to the selection of the stakeholders, impact categories and subcategories, the social aspects to consider within each category/sub-category and the performance indicators to be used. All these aspects seem to be a challenging issue within most implementations.

The UNEP-SETAC guidelines recognise two types of impact categories, Type 1 and 2, equivalent to the midpoints and endpoints within an environmental LCA, respectively. But the two approaches that were tested in this study – both of which base on the UNEP-SETAC guidelines – do not make any explicit reference to Type 2 impact categories. This reflects on the fact that the performance indicators listed in these approaches focus on inputs and outputs, rather than the final impacts of the product. The delimitation of the second group of impact categories, which correspond to a model of the social impact pathways to the impact endpoints such as e.g. human capital, cultural heritage and human well-being, clearly seems to be an open issue for future research.

Similarly, neither of these frameworks seems to cover the exact same Type 1 impact categories mentioned on the UNEP-SETAC guidelines, namely health and safety, human rights, working conditions, socio-economic repercussions, cultural heritage and governance. Apparently they disregard the latter two.

However, despite including a different number of social topics, both approaches seem to be quite aligned to each other in terms of the impact categories and sub-categories to focus on. The two methodologies assess the same general topics, where the WBCSD guidance covers additional aspects that are of particular relevance for the chemical sector. This is understandable if one considers that the impact categories/sub-categories – and implicitly also the stakeholder groups – that are mostly affected by production vary across sectors. And these two approaches mainly target the industrial sector.

Something similar occurs with the performance indicators. According to the UNEP-SETAC guidelines these can be of any form, from quantitative, to semi-quantitative and qualitative indicators, depending of the goal of the study and the nature of the issue at stake. The WBCSD approach relies on a semi-qualitative – scale-based – indicator framework, whereas the Roundtable method leaves this decision up to the user, offering a scale-based assessment framework as an alternative to a quantitative analysis based on a thorough list of performance indicators that is also provided. But as far as we are aware, all methods foresee in general the aggregation to aggregated results but no method describes in details how to combine different types of indicators in a single assessment yet. This is a potential drawback, considering that social data are difficult to procure and frequently come from a variety of sources and with a variety of formats.

All this implies that comparability across evaluations is greatly undermined by the diversity of approaches which can be followed in the LCIA phase. If each implementation focuses on those impact categories and subcategories with greater relevance and selects indicators being more pertinent for a given sector or product, then the assessments will become hardly comparable.

The second area in the need of further harmonisation is the methodology used during the characterisation phase. This refers to the step where data are aggregated from performance indicators – inventory results – to a subcategory result and from subcategories results to an impact category result. Considering the variety of indicators that can be used in this framework, normally some kind of scoring system based on performance reference points is set up in order to *decode* the data. This is the approach proposed by the Roundtable for Social Metrics. This step may also include some kind of weighting mechanism.

Therefore, considering that the characterisation phase involves the combination of different social aspects into synthetic scores, the conceptual and practical limitations found are similar to those reported below for the integrated methods. Additionally, the characterisation phase becomes even more complicated for those products that potentially show a positive impact on any of the social topics – such as e.g. pharmaceutical products –, in particular under a quantitative evaluation.

Altogether, there is a perceived need for further testing and harmonisation work before a common set of characterisation mechanisms can be broadly accepted.

5.4 Integrated methods

5.4.1 Value added

Integrated methods have the intrinsic value added of combining more than one sustainability sphere dimensions in one single assessment. These approaches allow practitioners and decision makers to organise complex multi-dimensional information and data in a structured form. Potentially, this allows achieving a good understanding of the environmental and/or economic and/or social negative impacts and benefits in decision-making processes towards more sustainable products throughout their life cycle. Furthermore, by providing a more comprehensive picture of the positive and negative impacts along the product life cycle integrated approaches also help to clarify the trade-offs between the sustainability pillars, life cycle stages and impacts considered in the analysis.

The kind of eco-portfolios that have been produced in this study following the EEA and GP approaches can support companies and value chain actors to identify weaknesses and effectively enable further improvements of a product life cycle. In practice, both methods can be applied for strategic decisions, product development, stakeholders and government engagement and marketing and customer relations, among other purposes.

The EEA is a much consolidated approach that has been widely applied by BASF. Its goal is to quantify the sustainability of products and processes under a sound scientific background using a modular design that keeps arithmetic operations transparent and ensure intelligibility of the results. The method has been updated on a regular basis since early 2000s, and the third generation will be shortly published. This new version includes novel normalisation and weighting techniques, along with the possibility of adopting a modular structure based on the selection of those environmental issues that contribute the most to the overall environmental burden. Ecological and economic impacts are very simple to assign to causes under this approach, which simplifies communication and enables customers and data suppliers to validate the overall system. Finally, the results provide a scope for scenario assessments and discussions.

The eco-portfolio built on the concept of environmental productivity represents an alternative way of looking at the eco-efficiency issue. The focus here is not so much on *efficiency* but on *performance*. In comparison to eco-efficiency, total cost is replaced by productivity, which provides as a broader sense of resource utility management than the concept of eco-efficiency, which focuses on total cost from a customer's point of view and ignores the potential revenues for companies. With the GP Index, companies can compare economic and environment performance of processes at once. Since the objective of GP is enhancing productivity and environmental performance simultaneously, it seems to be a good entry point for the persuading companies to include the environmental perspective on their business agendas without sacrificing the economic goals.

5.4.2 Existing barriers and areas for improvement

Simply put, integrated methods inherit all the drawbacks of the contributing methods. Additionally, integrated methods have to deal with the intrinsic complexity of combining, synthesising and communicating results by making use of multi-dimensional indices that, quite paradoxically, are frequently expressed in a-dimensional units. The main criticism within this framework refers to the normalisation and weighting steps.

The normalisation problem mainly relates to the criteria chosen to select the reference value. Two main approaches are usually followed to decide on these reference values. One bases on the definition of a national or international benchmark for comparison, either an average value or a target set by legislation. This would be a compliance-oriented approach. The second one involves identifying business-oriented reference values, these being specific targets set at the company level, product benchmarks or average values for a given sector. This would be a performance-oriented normalisation approach.

It goes without saying that each method has advantages and disadvantages. Each of them is suitable for different applications and scopes. But, whenever different normalisation approaches or reference values are applied, comparability across assessments is compromised.

The weighting issue is one of the most controversial points within impact assessments and multi-criteria evaluations in general. Whenever a final multi-dimensional score is to be produced basing on aggregate values, the mathematics implicit in its computation inevitably involves assigning weights to the contributing sub-indices, either equal or different – if there is enough empirical basis for assigning dissimilar weights.

There are two known issues with weighting. First, as it combines performance indicators from different natures, it is based on *value choices* and implicitly assumes that a decline in one category can be offset by progress in another category, hiding potential trade-offs. Second, the structural relations established among the different contributing sub-categories via the weighting system are normally not stable across time and geographies, but can help systems on the other hand to be always up-to date and following societal requirements. In particular, when weighting is done on the basis of public opinion polls or expert knowledge, these tend to be mutable over time. This compromises backward comparability.

Although normalisation and weighting affect all methods, the limitations implicit to these techniques can be particularly cumbersome for the methods that combine two – like the EEA and GP methods – or even the three sustainability spheres, such as the LCSA. A combination of different systems can only be done on the disaggregated level but enables on this basis the comparison of different weighting systems quite easily. Communicating results for these methods can result particularly tricky, but enables readers on the other hand a better understanding of complex sets of single results. Consequently a thorough reflection should be done before deciding on the best way to deliver results, whether making use of synthetic scores or delivering results in different categories, in particular in external communication.

5.5 Hybrid methods

5.5.1 Value added

Hybrid methods are a powerful tool for building scenarios and model complex and uncertain consequences linked to technology development. By combining the LCA and an optimisation model, the LCAA method tested in this case study is theoretically capable of representing hierarchical production and recovery chains, their economic costs and their impact on the environment. LCAA can be thus used for e.g. a holistic evaluation of new technologies, environmental strategies or policies. Additionally, varying the numerical assumptions of the equilibrium model – and by varying the goals or the priorities parametrically –, LCAA can be used to generate a set of scenarios to be presented to the decision makers (Freire and Thore, 2002).

5.5.2 Existing barriers and areas for improvement

Hybrid methods in general and the LCAA method in particular share four characteristics that potentially undermine their usability within a business context:

- Firstly, most hybrid methods are based on some kind of linear programming interface that increases their complexity – and therefore their implementation costs.
- Secondly, hybrid methods and LCAA are data driven methods that cannot be easily adapted to situations in which data availability or quality is low. Additionally, these models inherit much of the drawbacks of their contributing methodologies. For instance, the economic analysis performed in LCAA presumes that all the relationships between supply and demand are linear, leading to potentially misleading assumptions on the elasticity of substitution of products. Similarly, all the model calibration issues that are implicit in linear equilibrium models are also applicable to LCAA. These include limitations like (i) the fact that calibration must absorb all the errors in the input data; (ii) that the social accounting matrix is not always in equilibrium, and; (iii) that the number of parameters defined through the calibration cannot be bigger than the number of equations in the model.
- Thirdly, many hybrid methods, such as LCAA, are purely quantitative approaches targeting the environmental and economic dimensions, but lacking of specific social dimensions, which are not easily covered using quantitative indicators. These include, e.g. human rights, transparency, behavioural aspects, etc.
- Fourthly, and most importantly, hybrid methods – including LCAA – are analytical frameworks that were conceived and developed to be used at a decision level – the public sector – that is not the one where most enterprises operate. Only the largest companies could probably feel the stimulus to understand – and model – the potential economic-wide impacts of certain technologies or products at sectoral or territorial levels.

5.6 Cross cutting issues

Besides the implementation challenges that are specific to each type of methods, there are a number of cross-cutting issues that can potentially compromise the applicability of virtually all the methods tested in our case studies. Barriers can be organised as *midpoint* and *endpoint* obstacles. The former include:

- data availability and management issues;
- diversity of tools (software etc.) for implementation, and;
- methodological consistency of the impact assessment phase.

The latter include:

- high implementation costs, and;
- compatibility and comparability issues.

The critical phase of all these assessments, environmental, economic, social, and integrated and hybrid alike is data availability. All the methods applied in our case studies rely on the collection of a large amount of value chain data whose absence greatly compromises the overall quality of results. In this phase collaboration from inside the company and suppliers is critical.

Our experience tells that, depending on the assessment method and tool selected, sometimes the LCI methodology does not allow to precisely trace-back data and know the exact source of information. Even when the LCI stage is completed following a transparent and well documented protocol, for virtually all the methods tested in this study additional work is still needed in order to harmonise the data collection process across various implementations, in particular when it comes to accounting for the financial costs in the LCC and the selection of performance indicators in the S-LCA.

Additionally, considering that supplier data are frequently unavailable, for a successful implementation of most of these methods gaining access to a consistent database is an absolutely necessary step to fully characterise the process chain. There are a number of environmental databases publicly available that can be used to build consistent inventories. These provide a good documental basis for applying a vast range of environmental impact assessment methods, including those tested in our case studies. Still, there seems to be some difficulties to obtain updated datasets including targeted information, such as the mass flows and exergy content needed to produce the inventories for MIPS and E-LCA methods.

The increased demand for water footprinting has created a need for data on water flows that traditionally have not been available in the most common databases. Water balance and water consumption are relevant for most water footprint assessment methods. Another inventory problem has been the need for regionalised data and water functionality aspects such as quality. The updated version of EcoInvent (v3) is an effort to create a comprehensive water database in LCA framework. In the new version, it is possible to establish water balance for the unit process, and thus define water consumption needed in the water footprint assessment. In addition, calculation of water embedded in the products has been added to all EcoInvent products with mass. Quality issues are addressed by emission to water and resource use from water. Another useful data source for WF assessments is the Quantis Water Database.

Costing data can also be retrieved from reliable international data repositories available for most sectors, however, specific data and foremost those beyond a company's gate may be difficult to access. In turn, despite social databases are becoming growingly available (see e.g. Benoit-Norris et al., 2012), these do not still have the same quality –i.e. level of disaggregation and accuracy – as the environmental and costing datasets. Therefore, social data is mostly retrieved from a number of dispersed sources, which represents a time consuming process dealing to sometimes inconsistent inventories.

Similarly, with the probable exception of standard-compliant LCA, the impact characterisation stage continues to be an open issue for most of the methods tested in the SAMT case studies. This mostly relates to the definition of widely accepted characterisation factors for each impact category. Additionally, in the case of the S-LCA it also relates to the normalisation and weighting approaches followed to aggregate results across the different stakeholder groups and social topics.

There simply seems to be a myriad of alternative impact assessment methods available to characterise economic, social and environmental impacts, each being suitable for different goals. Although most characterisation methods are documented and reported transparently, decisions on which method to use is not always straightforward, in particular when different versions of the same methods exist or when more than one seems appropriate for a specific implementation. Decisions taken at this point are crucial because they can also undermine backward comparability of the assessment in those cases when updates are foreseen.

As mentioned, all these aspects create the need for further harmonisation work, in particular for those methods that are less mature from a methodological perspective, particularly S-LCA. For the water footprint assessment, (Water Use in LCA, working under the auspices of UNEP/SETAC Life Cycle Initiative) has recently (Jan 2016), after a two-year consensus building process, made a recommendation of the AWARE method to assess water consumption impact in LCA. These types of harmonization efforts would be welcome for the other impact categories as well, and require participation across different industrial sectors.

The first practical consequence of these constraints is that implementation costs may increase. This may happen mainly for two motivations. The first one stems from the need to accomplish time-demanding tasks, such as data collection and classification during the inventory phase – and it also includes commercial data acquisition costs and licensing –. The second motivation reflects the fact that most of the sustainability assessment methods, including those applied in the SAMT case studies, are complex enough to require trained personnel – either in-house or external – to apply them, in particular during the impact assessment phase.

The second practical consequence may arise when, as was done in these studies, a collaborative framework for sustainability assessment is set up, including contributors from different organisations and professional backgrounds. Such a distributed framework ensures a high degree of quality for the analyses done, for the simple reason that more people supervise each step and each partner has to understand and validate the work done by others in order to build his/her own contribution on a solid basis. However, these settings are also almost inevitably linked to coordination issues that may arise while sharing inventory or impact data across different software platforms and database versions. This challenge develops in two different strands:

Compatibility issues: Our implementation showed that the software tools that were used in the case studies are not entirely compatible with the exchange formats available for sharing LCA datasets – particularly with the ILCD standard, and/or some of the tools available for data exchange and transformation did not seem to work properly. This created some degree of uncertainty on the extent to which the analysis done by each contributor was based on the exact same data, impact methods and assumptions. Ensuring analytical coherence across all the implementations entailed a good amount of manual validation and extra work in comparison to centralised assessments.

Comparability issues - We identified two different types of comparability aspects to consider:

- *Vertical aspects*: This refers to the comparability issues that emerged when different software tools and database/model versions were used during the assessment. These issues were mostly motivated by the use of different versions of the databases (e.g. Ecoinvent v 3 vs Ecoinvent v 2) and impact characterisation models (e.g. CML-2001 vs CML-IA) that use slightly – sometimes drastically – different approaches that imply different environmental burdens for each process. Vertical comparability also refers to the hypothetical backward comparability issues that could emerge when deprecated methods or datasets are to be used in order to compare present results with earlier assessments.

- *Horizontal aspects*: These aspects relate to the adoption of different methodological options when performing the sustainability analysis. For instance, this could be motivated by the way multifunctional processes are modelled in a given database (e.g. attributional vs consequential), or to the specific cut-off criteria that are set in each analysis.

When it comes to the non-technical aspects, perhaps the most common limitations of sustainability assessment methods is the perceived *lack of interest/demand* by external stakeholders, including potential customers and the general public alike. The information collected in our case studies, in particular within the simulation questionnaires (see Appendix 3 to this report), shows that despite some of the companies have invested a significant amount of resources and efforts in putting together sound sustainability assessments and in-house tools, quite often the expectations in terms of customer acceptance for such assessments and tools was eventually very limited. Therefore, a number of examples within the case studies seem to suggest that some of the sustainability methods and tools have been designed with a research perspective but are not very well aligned to the real needs of companies. This increased perception that methods are over-dimensioned in relation to the real goals of businesses in relation to sustainability assessment.

Joint initiatives supported by the administration and/or sectoral organizations have sometimes contributed to fill this gap and reorient the focus to those sustainability aspects that seem more relevant for those companies operating in a given value chain. Our case studies showed that EPDs and, more recently, Product Environmental Footprints (PEFs) are amongst the initiatives with a largest pull in this respect. In some sectors there are also specific tools – e.g. EPD CF calculators – that seem to be satisfying the growing need for more fit-to-purpose analyses aimed sectoral benchmarking. Additionally, these tools are frequently less demanding in terms of resources, including both data and expertise needed to achieve meaningful results.

Another relevant issue that has been identified in the case studies is the need for reinforced coordination and joint action with other stakeholders active in the same value chain. This need stems from the fact that, quite frequently, the sustainability assessments done identify potential hotspots and impacts that are sometimes far upstream in relation to the specific stage where the company operates. This creates the need for coordinated action along the entire value chain.

All considered, perhaps the main conclusion that can be drawn from this work is that any of the methods evaluated within SAMT D2.1 and tested in the case studies can be considered as ”best practice” per se – without taking into consideration other aspects related to how the method is specifically applied in practice. In principle, all the methods applied in this study are capable of creating useful information for different dimensions of sustainability. If the potential limitations of the methods are acknowledged and documented, it is how the method is implemented in practice that creates the value, rather that the theoretical and methodological characteristics of the methods themselves.

6 Recommendations

This section provides some general recommendations based on the empirical evidence collected within our case studies. These recommendations are only a first step towards the production of more consistent and comprehensive recommendations that are envisaged for a later stage of project development (see the following section for additional details).

The objective of this work is to support companies – in particular those in the process industry – in the identification of "best practices" with respect to the implementation of sustainability assessment methods. Therefore, we have organised recommendations focusing on the factors that in our experience condition a successful implementation of the sustainability assessment methods for internal or external applications, in particular within the process industry.

All considered, perhaps the main message to be delivered to process industries is that when deciding and applying a sustainability assessment method they should pursue a balance between the specific needs and the availability of resources and reliable data – at least for the key processes. Besides, industries should also achieve a good understanding of the strengths and limitations of the different methods before applying them.

A well-conceived goal

The most obvious – and perhaps most neglected – issue any practitioner must consider before deciding to implement a particular sustainability assessment method is the need to define a well-conceived goal. This not only relates to defining the expected *main* use for the assessment, such as to support management, R&D, process development, marketing or product certification, but also to reflecting on the main sustainability dimensions and environmental aspects to analyse, as well as on the possible evolution of the sustainability aspects within each business sector, as claimed in the following point.

Work incrementally

If priorities are clear in terms of defining the aspects to be analysed and if these seem to be stable over time, then the logical recommendation is to invest on those targeted methods that address those issues more specifically. There are several fit-to-purpose assessment methods in place to evaluate the sustainability on product and corporate level, respectively. Previous SAMT deliverables provide a good overview of the existing alternatives and potential applicability of the existing methods in different contexts (López et al., 2015; Saurat et al., 2015b).

In those situations where future sustainability priorities are unknown or strategic choices are quite broad, the most logical choice would be to adopt a staged evaluation approach, prioritising those methods that allow a *modular* implementation – e.g. full LCA + WF + MIPS –. Some of the methods tested in this study prove that building an *incremental knowledge* on sustainability aspects is possible.

In most situations though, a comprehensive sustainability assessment may be required, but once the hot-spots and reduction potentials are identified, it is usually reasonable to focus on certain aspects with most potential or most significant impacts.

Minimise risk

Another consideration relates to the resources that can be invested. Most of the methods tested in our case studies are rather intensive in terms of their technical implications. Most of them require mastering rather complicated concepts and causal mechanisms – either physical, like in the exergy method, financial, like in the LCC, or social, like in the S-LCA method. Therefore, all the methods applied in our case studies require trained personnel and a very good understanding on the process analysed. Furthermore, all the methods entail collecting a significant amount of data.

All these factors may potentially undermine the attractiveness of these methods and have a direct impact on implementation costs. Thus matching the technical / data requirements and the resources available for implementation is essential for making good decisions. These aspects can be particularly challenging for smaller companies, especially for SMEs. Whenever a reasonable compromise between the goals and the resources available cannot be found internally, subcontracting specific parts or entire assessments should be an option that companies could consider as the most cost-efficient choice.

Along these lines, a good practice identified in previous tasks of the SAMT project include cooperation within the industry sector and for example organizing more thorough assessments jointly via industry associations. Industry associations could further support companies in selecting the appropriate methods for each application, including the interpretation and communication of results. This could for instance be materialised in the form of harmonised industry recommendations on the sustainability dimensions to consider, as well as the impact categories or characterisation models to be used, among other relevant aspects.

Invest on sustainability

Our case studies help to show what sustainability means for a specific business or sector, and how to address environmental, economic and social sustainability aspects. This is not only very valuable for managing risks; it can also be a key factor for competitiveness.

Consider data availability

Data availability is in itself a major constraining factor. In our case study we used a number of data sources from different origins. Like previously pointed out, there does not seem to be better alternative than using direct data in order to characterise a given process or product over its entire life cycle (see SAMT D1.2 - Saurat et al., 2015b). But the data issue is not just a matter of good choice. The lack of data also conditions the feasibility of many assessments.

Although the environmental dimension can be assessed by making use of robust public databases, the economic and especially the social dimensions cannot be properly characterised under a life cycle approach unless direct data for all value chain actors can be accessed. This is an important aspect that should be considered when opting for a specific sustainability method, or a combination of methods. If value chain data cannot be retrieved from direct and indirect suppliers, comprehensive social and integrated assessments can hardly be built.

Work transparently

One of the factors that contribute the most to a successful and consistent result during the implementation phase is transparency. Transparency should drive all the implementation stages, but in particular the assumptions made for data acquisition during the inventory phase and the decisions made for the selection of the characterisation methods, including the normalisation and weighting steps, should be clearly reported. Transparency is not only important to ensure consistency of results, but – just as importantly – to guarantee traceability and replicability across implementations. This aspect can have a paramount importance if a given assessment is to be replicated, updated or completed by future developments.

Improve communication

Communication of results is one of the most important aspects to be accounted for when it comes to selecting and applying sustainability assessment methods. Therefore, a relevant criterion to decide on which method to apply should be the availability of good communication tools. These tools should make possible to develop tailored messages to all types of audience. This is challenging, if one considers that quite frequently the outcomes of sustainability assessment methods base on technical aspects that difficult to communicate to non-experts. However, several of the methods applied in our case studies show that finding innovative ways of communicating results that are both scientifically sound and understandable for the general public is possible –but usually requires dedicated efforts. A good example is the eco-portfolio based on the persons-day concept that can be built within the EEA method.

Involve value chain actors

Involving stakeholders, in particular value chain actors, has a very positive impact on the overall quality and accuracy of the sustainability assessments. Involving stakeholders can be an advantage when it comes to collecting realistic value chain data. Moreover, stakeholder involvement could also allow establishing a shared understanding on the key sustainability challenges in the value chain. This could be a valuable basis to foster up- and downstream partnerships and to define shared sustainability agendas.

The broader picture

So far we have reflected on some specific aspects that are potentially relevant for the direct users of the sustainability assessment methods in order to decide on which methods to apply and how to apply them. But the experience matured in our case studies has also provided lessons that show broader implications for method developers and the scientific community in general. These can be summarised as follows:

Our practical experience emphasise the importance that previous harmonisation efforts like the ILCD and PEF initiatives had for the refinement of several design aspects for a number of sustainability assessment methods. These proved to be particularly relevant – and also successful – for the standardisation and harmonisation of many LCA aspects. The ISO14046 for water footprint is a recent example of standard that aims for harmonising the assessment of the water footprint.

It is thus desirable that similar initiatives that are now being carried forward for the S-CLA – UNEP-SETAC, WBCSD, and the Roundtable for Product Social Metrics – and the more comprehensive LCSA – UNEP-SETAC

– will yield similar results. Harmonisation initiatives need to be encouraged and supported by the scientific community and the decision makers alike.

At a different level, we feel we are now in a phase where method harmonisation should reach a more practical dimension. For example, we are convinced that there is a need for simpler and faster ways for sharing information across the various sustainability tools that are currently available, in particular across the different LCA platforms. In theory, this has already been achieved by means of the ILCD data exchange formats, but in practice this is still far from being a reality.

There is also a need to place additional efforts in producing simpler but scientifically sound tools for sustainability assessment. The experience with the numerous CF calculators that are currently available tells that these tools can be both accurate and simple to be used. Additional resources should be invested in delivering similar tools for other environmental, economic and social dimensions.

Similarly, it will be worthy to develop and use methods that can integrate all three dimensions for decision-making following the principles of sustainability. But this should be done in a way that decision-makers can use them in an easy way, making possible for non-experts as well to utilise different LCA methods assessing different aspects of sustainability in a meaningful way.

In order to make all this happen there is clearly perceived need to improve data availability and quality for the environmental, economic and especially for the social impact assessments. In particular, there is an increasing need to improve aspects such as the temporal and spatial aspects within environmental databases. Furthermore, although an initiative is already on its way, the social dimension is still lacking a comprehensive life cycle-compliant database. These seem to be two areas where data production efforts should be mostly placed in the years to come.

7 Next steps

The analysis of the case studies, together with the results obtained from the previous tasks of the SAMT project (in WP1 and WP2) continue in WP3, which will focus on cross-sectorial and sectorial applicability of the methods. Additionally, the main goal of WP3 is to draft the final recommendations from the project (based on all the previous steps and learnings), and to produce a roadmap and an implementation strategy for developing and implementing consistent sustainability assessment methods for the process industries. The findings from SAMT will also be reflected with the findings of the two other SPIRE 4 projects MEASURE and STYLE. The roadmap, together with the final recommendations will be discussed at the final open workshop that will be held together with the STYLE project in October. Gathering stakeholder input to the produced final recommendations and roadmap is one of the goals of WP3.

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9 Appendices

Specific case study reports are included as appendices to this main report. Each case study is reported in its own report. The appendices include the following three reports:

- Integrated case study – Appendix 1
- Water footprint case study – Appendix 2
- Simulation methods – Appendix 3