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

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

COORDINATION & SUPPORT ACTION

GRANT AGREEMENT NO. 636727

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SAMT Deliverable 2.2 - Appendix 1

Integrated Case Study Report

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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.

This report is presented as an Appendix to the main SAMT case study report (Deliverable 2.2). It provides a case study addressing the environmental, economic and social impact of the activities related to the production, consumption and disposal of one unit of an industrial product at two hypothetical locations in Spain and Germany. The main goal of our assessment was to test and validate complementary methods for sustainability assessment, rather than accurately characterise the environmental, economic and social impacts of the two production alternatives.

The methods tested in this case study include a full life cycle assessment (LCA), a Material Footprint (MIPS), a Life Cycle Costing (LCC) and a Social-LCA (S-LCA). Additionally, two integrated methods including one Eco-Efficiency Analysis (EEA) and one Eco-Productivity analysis (GP method) were also applied. Thus, the analysis tackles all the three spheres of sustainability: the environmental, economic and social impacts of the product.

The evidence collected in the study shows that there are still a number of areas for improvement in sustainability assessment practice. This is applicable even to those methods that seem most mature, like the environmental Life Cycle Assessment (LCA) method and related methods such as the Material Input per Service (MIPS) method. Those are methods whose implementation is underpinned by consistent and reliable databases. Similarly those are methods with agreed standards and guidelines that are the outcomes of long lasting harmonisation efforts.

Although these aspects guarantee an overall solid basis for implementation, some issues can potentially emerge due to the intrinsic complexity and diversity of options within the different phases of a LCA/MIPS, including deciding on 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.

Similarly, life cycle costing (LCC) methods are well established methods that can provide valuable information on the structure of costs over the entire value chain of a given product or process. However, these methods seem to be challenged by the intrinsic difficulty of collecting good quality value chain data, as well as by the uncertainties linked to the estimation of financial costs – that are based on projected interests, amortisation or discount rates.

On the contrary, social assessment methods such as Social-Life Cycle Assessment (S-LCA) seem to be on an early stage of development yet. Despite such methods represent a very promising contribution to comprehensive Social Impact Assessment along the life cycle of products, these methods rely on rather poor or difficult to collect data. Additionally, S-LCA has to face other well-known methodological shortcomings shared with the integrated methods.

These integrated methods, such as the Eco-Efficiency Assessment (EEA) and the Green Productivity (GP) analysis applied in this case study prove that relevant information can be disclosed when efforts are put in the definition of consistent normalisation and weighting approaches. Still, these methodological aspects present some intrinsic limitations that are difficult to overcome. These include the definition of relevant reference values for benchmarking and the adoption of transparent, stable and easy to communicate approaches for weighting.

Altogether, there is a perceived need for reliable value chain data, in particular for the social dimension, as well as further testing and harmonisation of methods before consensus on all the methodological choices involved in the application of the different methods is reached. Similarly, there seems to be a need for more simplified tools for cost-efficient sustainability assessment.

KEY WORDS:

Process industry, Sustainability assessment, Life Cycle Assessment (LCA), Material Input per Service (MIPS), Life Cycle Costing (LCC), Social Impact Assessment (SIA), Social-Life Cycle Assessment (S-LCA), Eco-Efficiency Analysis (EEA), Green Productivity (GP) index

List of abbreviations

EEA: Eco-Efficiency Analysis
EIA: Environmental Impact Assessment
GP: Green Productivity
LCA: Life Cycle Assessment
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
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

1 Introduction

This report is delivered as an appendix to Deliverable 2.2 of the SAMT project. It provides a description of the methodologies and the main outcomes aroused from the implementation of a number of sustainability assessment methods within this integrated case study. The work was developed in the framework of Work Package 2 of the SAMT project.

Our integrated case study addressed the environmental, economic and social impact of the activities related to the production, consumption and disposal of one unit of a product at two hypothetical locations in Spain and Germany.

The methods tested in this case study include a full life cycle assessment (LCA), a Material Footprint (MIPS), a Life Cycle Costing (LCC) and a Social-LCA (S-LCA). Additionally, two integrated methods including one Eco-Efficiency Analysis (EEA) and one Eco-Productivity analysis (GP method) were also applied. Thus, the analysis tackles all the three spheres of sustainability: the environmental, economic and social impacts of the product.

2 Aim of the case study

The main aim of this case study was to apply and compare a number of sustainability assessment methods in a realistic industrial context. The purpose was to test a number of specific aspects linked to the application of the different methodologies, in particular to validate the extent to which:

- the different sustainability assessment methods can be applied incrementally;
- their application can be distributed across various organisations without undermining reliability of results;
- the integration of environmental and economic methods in eco-portfolios provides value added to standard industrial practice, in particular to the process industry;
- the social assessment methods can be applied under similar conditions and constraints as the environmental and economic methods;
- the integration of different sustainability spheres in a comprehensive communication framework, without missing relevant aspects and without inducing to ambiguous conclusions.

In order to address these aspects, we designed a research experiment that focused on the production of one unit of an industrial product. The experiment consists of two scenarios that differ in the geographical region considered. We compared two virtual, non-existing production sites located in two different countries. We assumed that the production is 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 use phase and end of life were also simulated as taking place in either Spain or Germany.

The main goal of our assessment was to test and validate alternative methods for sustainability assessment, rather than accurately characterise the environmental, economic and social impacts of the two production alternatives. On these same grounds, some of the data reported in our assessments were obtained from indirect sources and/or based on bold assumptions that could not be validated. Thus, the numerical results have a rather simplified illustrative character.

Accordingly, the results – as deduced from the environmental impact (LCA), material footprint (MIPS), cost (LCC), eco-efficiency (EEA), productivity (GP) and social impact (S-LCA) assessments – should be treated with caution. In particular, **this study must not be used to generate any claims on the performance of any product, process or production site, neither existing nor planned. Moreover, this case study must not be used to draw any conclusions on the impact and/or efficiency of the regions and countries considered in this case study. The results are not applicable to derive any investment decisions or actions.** Consequently, a comprehensive interpretation of results is not provided in this report.

3 Methods applied

The conceptual foundation for the environmental, economic and social assessments performed in this work is life cycle thinking. A full ISO-compliant environmental Life Cycle Assessment (LCA) is the core component of our sustainability analysis. LCA is the mostly accurate and comprehensive environmental assessment method available in order to model a product´s or service life from "cradle to grave". According to ISO14040, a standard LCA should be composed of four phases:

1. Goal and scope definition
2. Life Cycle Inventory Analysis
3. Life Cycle Impact Assessment
4. Interpretation of the results

LCA is, by far, the most widely implemented environmental assessment method also amongst the process industry. 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. All these can be considered sub-methods of the broader LCA (Saurat et al., 2015).

The other environmental method applied in this work was the Material Input per Service (MIPS), which can also be considered a sub-method of the broader (in terms of indicators) LCA. MIPS is an established method that delivers quantitative results on material efficiency – Material Footprint. For MIPS calculation raw materials are added together in their respective Material Input (MI) categories. Pre-treated inputs like electricity, cold rolled steel, etc. are multiplied with existing Material Intensity (MIT) factors expressed in a mass unit per kg, per kWh or per kg/km, depending if the carrier is a material, a type of energy or a transport service, respectively. This step increments these flows with their own ecological rucksacks (Saurat and Ritthoff, 2013). In other words, the final MIPS value is the sum of the weight of a product plus the ecological rucksack of that product. There are examples of MIPS applications in most sectors, including process industries. Frequently updated support tools for its computation are publicly available.

Both LCA and MIPS are environmentally oriented life cycle methods without predefined geographical boundaries. They cover all life cycle stages, but parts of the life cycle can be also analysed separately. These methods have a broad scope in terms of potential application, including technical process optimisation, management process optimisation, supply chain optimisation and life cycle wide optimisation, amongst others. Both methods 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.

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. These are defined as the sum of the costs incurred during the entire life cycle of a given process or product, including the (i) development (research and development, delivery, installation, insurance, etc.); (ii) production/operation (including energy, fuel and water use, spares, and maintenance), and; (iii) dismantling/disposal (including decommissioning) phases. 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). LCC involves accounting for two main types of costs. The first one includes the baseline operating costs for the existing or planned system. The second one incorporates the concept of decreasing monetary value over lifetime of the process. 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 of these two approaches was based on the concept of eco-efficiency, defined as the ratio of an output value to its environmental influence. Eco-efficiency was computed over a number of environmental dimensions, following the method developed by BASF (Saling et al., 2002). The second one was based on the concept of productivity, defined as is the ratio of productivity of a system to its environmental impacts. The Green Productivity (GP) was calculated following the method proposed by Hur, et al. (2004).

A simplified Social-LCA (S-LCA) was performed on top of previous environmental and economic analyses. The S-LCA followed the conceptual framework proposed by the UNEP-SETAC Guidelines for Social Impact Assessment (2009). Two specific S-LCA methods were tested against this backdrop, 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 1: *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 v8.4	Environmental	Abiotic depletion	CML 2001
		Acidification	
		Eutrophication	
		Global Warming 100a	
		Ozone layer depletion 40a	
		Photochemical oxidation	
MIPS			
OpenLCA v1.4.2	Resource Use	Abiotic raw materials	Saurat & Ritthoff 2013
		Biotic raw materials	
		Earth movement in agriculture and silviculture	
		Water	
		Air	
LCC			
MS Excel	Economic	Development costs	Sell et al., 2014
		Use costs	
		Disposal costs	

Used tool	Type of indicators	Impact category	Characterisation model
Standard LCA (comparison of two productions systems located in Germany and Spain)			
EEA 6 (EEA includes more indicators)			
BASF in-house 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			
Tecnalia in-house tool	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			
Datasheet by the Handbook for Product Social Assessment	Social	Basic rights and needs	Roundtable for Product Social Metrics[1]
		Employment	
		Health and safety	
		Skills and knowledge	

All the any life cycle methods applied in this case study are complex methods that require trained personnel – either in-house or external – to correctly apply them. The critical phase of all of these assessments, regardless if environmental, economic or social, is data collection. In this phase collaboration from inside the company and suppliers is critical. Considering that supplier data was largely unavailable, a widely used environmental database was used to characterise each step in the process chain. In turn, the economic information mostly came from internal sources and estimates based on public databases. Despite social databases are becoming growingly available (see e.g. Benoit-Norris et al., 2012), these could not be accessed at the time of completion of this study. Therefore, social data were mostly retrieved from direct sources and statistical data retrieved from public offices.

[1] Applied on the “mandatory” social topics within the WBCSD method.

4 Case description

4.1 Goal and scope of the study

4.1.1 Goal

In order to meet the ultimate target of testing and comparing alternative sustainability assessment methods, two scenarios which vary from a geographical perspective were set up.

Against this framework, the specific aims of this study are:

1. to compare the environmental impacts derived from the production, use and disposal of one unit of an industrial product in two hypothetical plants located in Spain and Germany, based on a standard Life Cycle Assessment combined with the MIPS method;
2. to compare the associated economic costs over the entire life cycle of the product in both countries;
3. to compare the eco-efficiency of the two alternative production processes following two different eco-portfolios;
4. to understand and communicate the potential alternative social impact assessment approaches – and indicators – that could be used in order to perform a stand-alone product social impact assessment in the process industry sector.

The Environmental-LCA was performed using SimaPro v8.4 commercial software, developed by Pré Consultants. The MIPS method was calculated using OpenLCA v1.4.2 and an impact assessment method prepared by Wuppertal Institute for the calculation of MIPS (Saurat and Ritthoff, 2013). The S-LCA was conducted basing on the datasheet provided by the Roundtable for Product Social Metrics (2016). The EEA method was applied using a tool created by BASF. The EEA tool is very flexible and can use different types of datasets and impact assessment methods. In this study, the SimaPro results and characterization factors for the environmental assessment were used. The green productivity portfolio was generated with an in-house tool designed by Tecnalia. In all cases, the environmental database used was Ecoinvent 2.2.

4.1.2 Scope

4.1.2.1 Functional unit

The functional unit[2] of our system was defined as one unit of an industrial product.

[2] The functional unit normalises data based on equivalent use (or service provided to consumers) to provide a reference for relating process inputs and outputs to the inventory, and impact assessment for the Life Cycle Impact Assessment (LCIA), across product systems.

4.1.2.2 System boundaries

This study adopts a cradle-to-grave approach[3] for all the life cycle assessment-based methods applied in this study, with the only exception of the Social-LCA that followed a gate-to-gate approach. The use phase of the product was only fully considered by the Social-LCA. The remaining environmental (LCA, MIPS) and economic assessment (LCC) and integrated (EEA, GP) methods only consider the distribution of the product from the plant to the final consumer.

The following life cycle stages were considered:

- Upstream: raw material extraction and processing
- At plant: product manufacturing and packaging
- Downstream: distribution, use and end of life

The life cycles stages considered are the following:

- Raw materials extraction/acquisition and processing: activities related to acquisition of natural resources, including mining non-renewable material, harvesting biomass, and transporting of raw materials to processing facilities. These are completed with processing natural resources by reaction, separation, purification, and alteration steps in preparation for the manufacturing stage; and transporting processed materials to product manufacturing facilities.
- Product manufacturing, including packaging: comprising all activities related to the manufacture and packaging of the final product.
- Distribution: transportation to domestic markets, assuming average distance to market based on the relative size of both countries[4].
- End of life: destination and treatment at the end of product life (all the transports to the treatment plant included). The following end of life scenarios were considered:
    - Spain: 50% of packaging waste is incinerated and 50% of it is recycled
    - Germany: 100% of packaging waste is recycled

Figure 1 below provides an overview of the different life cycle stages considered in the study:

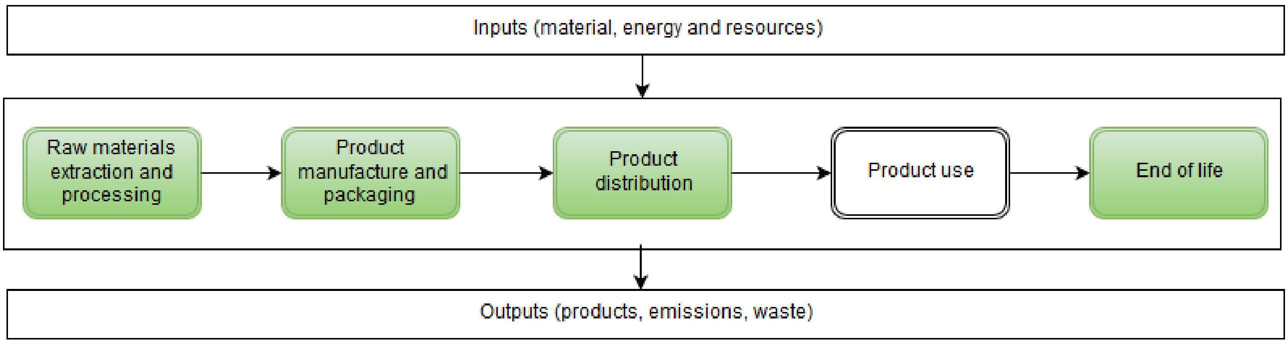


Figure 1: *Overview of the most common cycle stages of a generic product*

[3] Under a cradle-to-grave approach the boundaries of the life cycle assessment are set to analyse the activity from the extraction of raw materials until the end of life phase of the product, including all manufacturing of the product, packaging, transportation and recycling/incineration of the packaging.
[4] It has been assumed 600 km for Spain and 300 km for Germany

4.1.2.3 Allocation criterion

In the manufacturing phase a quantification of raw material and fuel inputs, solid, liquid, and gaseous products, emissions, and effluents is performed. *System expansion* was the allocation criterion[5] chosen to account for by-products. This implies that by-products were accounted for as environmental credits.

4.2 Inventory data

4.2.1 Environmental data

The quantification of life cycle inventory (LCI) is the second phase of a LCA. As shown in the Figure 2 below, each process consists of an inventory of input and output flows.

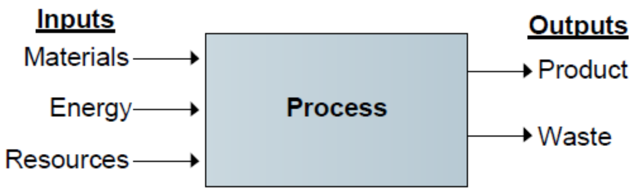


Figure 2: *Process Input and output Flows*

A LCI consists of a set of inventories for different processes throughout the product life cycle – from the extraction of materials, materials processing, manufacturing, transportation, product use and end of life. The result is a LCI that provides information about all inputs and outputs in the form of elementary flows to and from the environment from all the unit processes involved in the study.

The LCI used in this case study included all forms of materials and utilities (including energy) required to manufacture the product, including packaging. Additionally, information on the impacts associated with transportation of raw materials and with the distribution of the product to the business or consumer, respectively, were also estimated for the two scenarios

[5] According to standard LCA practice, whenever a specific process generates more than one product of commercial value the waste treatment option, raw material requirements, energy consumption, and emissions need to be allotted to one or some of those processes or products following one criterion that can be allocation or system expansion.

In order to have a complete LCI, a number of assumptions were made in this phase. The set of variables identified in the LCI – i.e. raw materials, utilities, transport, etc. – were translated into environmental impacts in the Life Cycle Impact Assessment phase, as described in Section 4.3 below.

4.2.2 Economic data

Similarly to the environmental LCI, cost data for utilities and raw materials were mostly derived from commercial databases. Whenever exact cost data could not be obtained, average figures taken from literature were used. Similarly, transport costs were computed basing on the information available from standard data providers aimed at professional transport fleet management. In order to keep analytical consistency, we assumed similar operating conditions in both plants, setting similar yearly operating hours and yearly production quantity.

4.2.3 Social data

The indicators considered in the Social-LCA were selected amongst those proposed by two recent initiatives for the measurement of social sustainability under a LCA perspective, namely the Social Metrics for Chemical Products in their Applications project by the World Business Council for Sustainable Development – WBCSD (Coërs, 2015, final publication mid-2016) and the Handbook for Product Social Impact Assessment by the Roundtable for Product Social Metrics (PRé Sustainability and Roundtable for Product Social Metrics, 2016).

Both of these frameworks classify performance indicators according to three specific stakeholder groups: workers, local communities and consumers. Each stakeholder group is covered by a number of indicators referring to various social topics, including issues such as basic rights and needs, wages, child and forced labour, discrimination health and safety, working hours, work risks, skills and training, general wellbeing, product experience, etc.

Table 2 lists the performance indicators (in reddish colour) used and the data sources for each social impact category (in black colour) and stakeholder group that was included in our Social-LCI. Section 4.3.3 below provides additional information on the selection criteria for these dimensions and indicators.

Table 2: *Indicators used for the Social-LCA (focusing on the mandatory topics by the WBCSD)*

Social impact category	Stakeholder groups		
	Workers	**Local communities**	**Consumers**
Basic rights and needs	**- Fair wages:** *National average wage/plant lowest average wage* **- Freedom of association, collective bargaining and labour relations:** *Percentage of employees covered by collective agreement, especially on compensation and working conditions;* **- No child labour:** *Percentage of workers of the plant who are under the age of 18 and above 15* **- No forced labour, human trafficking and slavery:** *Estimated hours of sub-contracted labour per year*	**- Access to basic needs for human right and dignity (healthcare, clean water and sanitation, healthy food and shelter)** *Estimated number of programmes on Social Initiatives in 2014 at plant (weighted by Share of national tax income invested in healthcare services) - Social community projects*	
Employment		**- Job creation:** *Estimated number of jobs created based on employment ratio: jobs at year 2014/jobs at year 2013; (job creation)*	
Health and safety	**- Worker's occupational health risks:** *Estimated accidents at work per year at plant (more than 3 days lost)* **- Safety management system for workers***: NA*	**- Health and safety of local community's living conditions** *Estimated number of programmes on Social Initiatives in 2014 at plant (weighted by Share of national tax income invested in healthcare services) - Health and social needs*	**- Impact on consumer health and safety:** *Estimated number of complaints identified during the reporting period related to consumer health and safety. Based on Flash Eurobarometer 360 - Attitudes of Europeans towards air quality - Q2 Share of people that believe that air quality has deteriorated over the last 10 years*
Skills and knowledge	**- Skills knowledge and employability:** *Estimated number of hours of training per employee during the reporting period*		
Well being	-	-	-

The indicators used to cover each of these dimensions vary according to the information that was actually available from primary sources and the official statistical offices. When the necessary information could not be accessed for any reason, estimates were proposed basing on the figures available from third-party sources such as press reports, trade-unions, professional associations, etc. Whenever no specific information could be found, bold estimates were proposed basing on sectorial data at the national level or data coming from surveys done at the national level.

4.3 Impact Assessment method(s)

4.3.1 Environmental Impact Assessment method(s)

Environmental impact was quantified using the CML 2001 method. CML 2001 is a LCA methodology developed by the Center of Environmental Science (CML) of Leiden University in the Netherlands. This method elaborates the problem-oriented (midpoint) approach. CML 2001 offers four different normalisation methods: "the Netherlands, 1997", "West Europe, 1995", "World, 1990" and "World, 1995". The following impact categories were taken into consideration:

- **CML 2001/acidification potential, average European (kg SO_2 Eq):** Acidifying substances cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems and materials (buildings). Acidification Potential (AP) for emissions to air is calculated with the adapted RAINS 10 model, describing the fate and deposition of acidifying substances. AP is expressed as kg SO2 equivalents/ kg emission. The time span is eternity and the geographical scale varies between local scale and continental scale. Characterisation factors including fate were used when available. When not available, the factors excluding fate were used (In the CML baseline version only factors including fate were used). The method was extended for Nitric Acid, soil, water and air; Sulphuric acid, water; Sulphur trioxide, air; Hydrogen chloride, water, soil; Hydrogen fluoride, water, soil; Phosphoric acid, water, soil; Hydrogen sulfide, soil, all not including fate. Nitric oxide, air (is nitrogen monoxide) was added including fate.

- **CML 2001/climate change, GWP 100a (kg CO_2 Eq):** Climate change can result in adverse affects upon ecosystem health, human health and material welfare. Climate change is related to emissions of greenhouse gases to air. The characterisation model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected for development of characterisation factors. Factors are expressed as Global Warming Potential for time horizon 100 years (GWP100), in kg carbon dioxide/kg emission. The geographic scope of this indicator is at global scale.

- **CML 2001/eutrophication potential, generic (kg PO_4^{-3} Eq):** Eutrophication (also known as nutrification) includes all impacts due to excessive levels of macro-nutrients in the environment caused by emissions of nutrients to air, water and soil. Nutrification potential (NP) is based on the stoichiometric procedure of Heijungs (1992), and expressed as kg PO4 equivalents per kg emission for freshwater effects. Fate and exposure is not included, time span is eternity, and the geographical scale varies between local and continental scale.

- **CML 2001/photochemical oxidation (summer smog), high NO_x POCP (kg ethylene Eq):** Photo-oxidant formation is the formation of reactive substances (mainly ozone) which are injurious to human health and ecosystems and which also may damage crops. This problem is also indicated with "summer smog". Winter smog is outside the scope of this category. Photochemical Ozone Creation Potential (POCP) for emission of substances to air is calculated with the UNECE Trajectory model (including fate), and expressed in kg ethylene equivalents/kg emission. The time span is 5 days and the geographical scale varies between local and continental scale.

- **CML 2001/stratospheric ozone depletion, ODP 40a (kg CFC-11 Eq):** Because of stratospheric ozone depletion, a larger fraction of UV-B radiation reaches the earth surface. This can have harmful effects upon human health, animal health, terrestrial and aquatic ecosystems, biochemical cycles and on materials. This category is output-related and at global scale. The characterisation model is developed by the World Meteorological Organisation (WMO) and defines ozone depletion potential of different gasses (kg CFC-11 equivalent/ kg emission). The geographic scope of this indicator is at global scale. The time span is infinity.

- **CML 2001/abiotic depletion (kg Sb Eq):** This impact category is concerned with protection of human welfare, human health and ecosystem health. This impact category indicator is related to extraction of minerals and fossil fuels due to inputs in the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals and fossil fuels (kg antimony equivalents/kg extraction) based on concentration reserves and rate of de-accumulation. The geographic scope of this indicator is at global scale.

- **The resource consumption according to the MIPS concept** (Schmidt Bleek at al. 1998, Ritthoff et al. 2003) was calculated. This includes (a) abiotic raw materials; (b) biotic raw materials; (c) erosion (alternatively earth movement in agriculture and silviculture can be calculated); (d) water; € air

4.3.2 Economic Impact Assessment method

Life-cycle costs are the sum of the costs incurred during the development, manufacturing, and the disposal of a product, including those linked to the design and development, construction of infrastructures, manufacturing, transport and dismantling of the entire production line. This approach is conceptually aligned with a life-cycle perspective and closely connected with the areas of costing and investment typically considered within standard management accounting, alike.

The total sum of costs within a typical cost assessment is the sum of costs generated during the development, use and disposal phases of a given production line, as shown in the aggregation formula (1):

$$LCC = LCC_{Dev} + LCC_{Man} + LCC_{Dis} \quad (1)$$

Where LCC: total production costs incurred during the life cycle of products; LCC_{Dev}: costs linked to the development phase of products; LCC_{Man}: costs linked to the manufacturing phase of product, and; LCC_{Dis}: costs linked to the dismantling phase of the production line.

- **Development costs** include costs incurred during the development and implementation of a new technology (or process alternative), such as R&D, investment, acquisition and installation of new equipment, as well as associated material and personnel costs. These are often onetime costs in the life cycle framework.
- **Manufacturing costs** are those related to the operation of the installation and product manufacturing. **Plant-related costs** include energy costs, imputed cost of depreciation and interest, maintenance costs as well as personnel and occupancy costs. **Product manufacturing-related costs** include personnel costs, material and energy costs, transport and disposal costs of the produced goods and by-products.
- **Dismantling costs** are those associated with the recycling and disposal, inspection and maintenance, disassembling and dismantling of the plant or production line.

A detailed list of the costs considered in each cost category is shown in Table 3. These costs are based on the typical LCC assessment for chemical process development, according to Sell et al. (2014).

Table 3: *Cost categories within a typical life cycle cost assessment for chemical process development*

	Development costs	Use costs	Disposal costs
Costs considered in each phase	• R&D • Investment and procurement • Installation and operation • Material • Personnel	Plant-related costs: • Maintenance • Imputed costs of depreciation • Imputed interests • Occupancy costs Product manufacturing-related costs: • Energy • Material • Personnel • Disposal (of by-products)	• Inspection and maintenance • Recycling • Dismantling • Disposal • Scrapping

For the sake of simplicity we excluded dismantling costs from our assessment. We assumed that the dismantling costs of a production line could depend more on strategic decisions taken within a company (e.g. demand-driven and/or profitability decisions resulting on activity transfer or total closure of a production line), rather than on the actual technical differences between the two plants or the specificities of the recycling/disposal/scrapping regulations in both countries. Moreover, it is important to note that also selling, general and administrative costs were excluded from the assessment.

Therefore, we focused our analysis on the "use phase" of the plant, considering only plant-related costs and product manufacturing-related costs. Table 4 and Table 5 below list the indicators respectively considered in these two life cycle phases (adapted from Sell et al., 2014).

Table 4: *Plant-related costs*

Type of costs	Definition
Maintenance costs	$C_{\mathrm{Maint}} = \mathrm{AV} \cdot \mathrm{CRM}$
Energy costs	$C_{\mathrm{E}} = Q_{\mathrm{E}} \cdot P_{\mathrm{E}}$
Imputed depreciation	$C_{\mathrm{ID}} = PRV/UL$
Imputed future value	$C_{\mathrm{IV}} = AV \cdot (1+\mathrm{i})^{UL}$
Imputed interests	$C_{\mathrm{II}} = \frac{C_{\mathrm{IV}} - AV}{UL}$

Table 5: *Product manufacturing-related costs*

Type of costs	Definition
Material costs	$C_{\mathrm{Mat}} = (\sum Q_{Mat} \cdot P_{Mat}) + MOR\ (\sum Q_{Mat} \cdot P_{Mat})$
Energy costs	$C_{\mathrm{E}} = Q_{\mathrm{E}} \cdot P_{\mathrm{E}}$
Personnel costs	$C_P = Q_P \cdot S_P$
Disposal costs	$C_{Dis} = Q_W \cdot P_{Dis}$

where:

AV [€]: acquisition value
C_{Dis} [€ a^{-1}]: disposal costs
C_{E} [€ a^{-1}]: energy costs
C_{ID} [€ a^{-1}]: imputed depreciation
C_{IV} [€]: imputed future value
C_{II} [€ a^{-1}]: imputed interests
C_{Maint} [€ a^{-1}]: maintenance costs
C_{Mat} [€ a^{-1}]: material costs
C_{P} [€ a^{-1}]: personnel costs
CRM [% a^{-1}]: cost rate for maintenance
i [% a^{-1}]: inflation rate
MOR [%]: material overhead rate
P_{Dis} [€ kg^{-1}]: disposal price
P_{E} [€ kWh^{-1}]: energy price
P_{Mat} [€ kg^{-1}]: material price
PRV [€]: plant replacement value
Q_{E} [kWh a^{-1}]: energy demand
Q_{Mat} [kg a^{-1}]: material requirements quantity
Q_{P} [h a^{-1}]: personnel requirements
Q_{W} [kg kg^{-1}]: amount of waste
S_{P} [€ h^{-1}]: salary rate
UL[a]: technical useful life

4.3.3 Social Impact Assessment method

The UNEP-SETAC Guidelines for Social Life Cycle Assessment of Products was one of the first initiatives that tried to develop an accepted methodology for S-LCA (UNEP-SETAC, 2009). This document defines Social-LCA as a methodology designed for the assessment of the "internalities and externalities of the production of goods and services for people and profit/prosperity". It "complements the Environmental-LCA and the

LCC in contributing to the full assessment of goods and services within the context of sustainable development” (UNEP-SETAC, 2009, page 16).

Since the Guidelines were published in 2009, a number of sectoral and specific initiatives made more specific contributions and tools enabling its methodological steps, and/or aimed at specific sectors. As mentioned, this case study builds on two of these initiatives, namely the WBCSD project on Social Metrics for Chemical Products, which will shortly deliver a first guidance report (Coërs, 2015), and the Roundtable for Product Social Metrics Handbook for Product Social Assessment (PRé Sustainability and Roundtable for Product Social Metrics, 2014, 2016). Both of these initiatives claim to be aligned with the UNEP-SETAC Guidelines for Social Life Cycle Assessment of Products.

Due to the lack of global standards on methods for social impact assessment at product level, both approaches focus on consolidating the principles for product social sustainability assessment, harmonising approaches globally, as well as on developing practical tools (e.g. guidance manual, methodologies, supporting tools, etc.) for cross-cutting implementation issues.

In practical terms, both approaches aim at the characterisation of social performance of products by defining key common social metrics, indicators and criteria for qualitative (i.e. scale-based) assessment that reflect positive and negative impacts of products on three common stakeholder groups: workers, consumers and local communities. The WBCSD framework defines a total of 25 social topics – 11 of them mandatory – grouped in 5 categories, namely: (i) health and safety; (ii) basic rights and needs; (iii) well-being; (iv) skills and knowledge, and; (v) employment. The Roundtable identified 19 social topics of interest for the different stakeholder groups.

The preliminary list of the topics included in the WBCSD framework – which has not been yet officially released – is provided as a supplementary material to this report (see Section 8.1). The third version of the Handbook for Product Social Impact Assessment that was published at the beginning of 2016 (PRé Sustainability and Roundtable for Product Social Metrics, 2016) includes a very detailed list of indicators that are also provided as a supplementary material to this report (see Section 8.2).

Table 6: *Comparison of the social impact categories of the Roundtable for Product Social Metrics and the Social Metrics for Chemical Products initiative by the WBCSD*

Stakeholder groups	Social topics	
	WBCSD	Roundtable
Workers	**Workers' occupational health risks** Management of workers' individual health **Safety management system for workers** **Fair wages** Appropriate working hours **Freedom of association, collective bargaining and labour relations** **No child labour** **No forced labour, human trafficking and slavery** No discrimination Social / employer security and benefits Job satisfaction **Skills, knowledge and employability** Management of reorganisation	Health and safety Wages Social benefits Working hours Child labour Forced labour Equal opportunities and discrimination Freedom of association and collective bargaining Employment and employment relationships Training and education Work-life balance Job satisfaction and engagement
Consumers	**Healthy and safe products** Direct impact to basic needs Consumer's product experience Promotion of skills & knowledge	Health and safety Experienced well-being
Local communities	**Healthy and safe living condition** **Access to basic needs for human right dignity** Indigenous' rights Access to basic needs for sustainable development Nuisance reduction Developing relationship with local communities Promotion of skills and knowledge **Job creation**	Health and safety Access to tangible resources Local capacity building Community engagement Local employment

Source: Coërs (2015)

*** Mandatory social topics in bold letters**

Table 6 provides a comparison of both approaches. The main difference between them is that the WBCSD selected 11 of these social topics as *mandatory* (highlighted in bold letters). These mandatory topics cover the main social impact categories and stakeholders groups, as defined in the WBCSD framework (Coërs, 2015). For operational reasons, our Social-LCI focused exclusively on these mandatory social topics, with the only exception of WBCSD's "Safety management system for workers" social topic, which has no equivalent in the Roundtable framework. This makes a total of ten social topics covered, including six topics relevant for the 'workers' stakeholder group – six indicators –, one social topic relevant for consumers stakeholders group – one indicator –, and three social topics relevant for the local communities stakeholders group.

Besides providing guidance on the social topics, both the Roundtable and the WBCSD initiatives propose a number of performance indicators that reflect positive and negative impacts of the product on each social topic. Additionally, both initiatives propose a stage-based methodology to perform either a quantitative (indicator-based, Roundtable only[6]) or qualitative (scale-based, both WBCSD and the Roundtable) characterisation of the 'social footprint' under a LCA approach. The stages of the Roundtable method are illustrated below.

Similarly, the Roundtable for Product Social Metrics defined some guiding principles focusing on the practical feasibility for organisations to conduct product social impact assessment, coupling methodological consistency with potential constraints liked to the availability of human and financial resources for the assessment. The guiding principles were mainstreamed into a support MS Excel sheet that was provided as supplementary material to the Handbook for Product Social Impact Assessment (Roundtable for Product Social Metrics, 2016). We decided to use this tool as it is flexible enough to allow for the kind of simplified assessment performed in this work.

The tool provided by the Roundtable for Product Social Metrics computes an aggregated index of social performance basing on the performance values of each for each contributing indicator included in the assessment. These performance values are established basing on a distance to target approach, under three different reference scenarios, namely:

1. Higher is better (absolute values):
2. Lower is better
3. Higher is better (relative values)

See the Handbook for Product Social Impact Assessment by the Roundtable for Product Social Metrics for additional details on how referencing is implemented by this method (PRé Sustainability and Roundtable for Product Social Metrics, 2016, page 14).

Due to low data availability for supply chain actors we were forced to reduce the system boundaries of this specific social assessment to the manufacturing and consumption life cycle stages – i.e. we performed a gate to consumption analysis –.

[6] This is a preliminary statement. Considering that the WBCSD work is not available yet, it was not possible for this team to check the availability of a quantitative approach. The reference by Coërs (2015) that has been the basis for this work only mentions a scale-based method for scaling and scoring.

4.4 Integrated method(s)

4.4.1 Eco-Efficiency Assessment method(s)

Eco-efficiency is defined as a general goal of creating value while decreasing environmental impact (Huppes and Ishikawa, 2005). Eco-efficiency ratio is commonly understood as the relation between a maximising output (value added) to its environment influence (Hur et al., 2004).

$$Eco - efficiency = \frac{Product\ or\ service\ value\ (cost)}{Environmental\ influence} \qquad (2)$$

Eco-Efficiency Analysis of BASF looks at environmental impact in proportion to a product's cost-effectiveness. It helps companies, customers, and customers' customers to decide which products are the best choice, both ecologically and economically. The Eco-Efficiency Analysis can also be used to identify ways to make improvements in terms of environmental impact and cost.

BASF established this holistic method in 1996 and was one of the first companies in the chemical industry to do so. The Eco-Efficiency Analysis was updated in 2015 and two alternative systems were created. One system, the EEA6 covers the most important indicators which are relevant for industrial processes, another system, the EEA10 covers indicators which include a wider set of indicators, e.g. which are important for renewable materials. The methods can use different impact assessement methods, e.g. EU PEF methods or CML. The EEA method was most recently validated by NSF International in 2016 in will be published soon (Saling 2016, submitted). The Eco-Efficiency Analysis follows ISO 14040:2006 and 14044:2006 for environmental life cycle assessments. The assessment of life cycle costs and aggregation to an overall Eco-Efficiency is based on ISO 14045:2012.

The Eco-Efficiency Analysis compares the life cycles of products or manufacturing processes from "cradle to grave", i.e. all the way from raw materials sourcing, to product manufacture and use, to disposal. For example, it includes the environmental impact of products used by BASF as well as of starting materials manufactured by others. The analysis also takes the consumption behaviour of end-users into account, as well as various recycling and disposal options.

The environmental impact is assessed based on a range of the categories:

- Raw materials consumption
- Water consumption
- Land use
- Human toxicity potential
- Eutrophication
- Acidification
- Ozone depletion
- Photochemical ozone creation
- Climate change

Combining these individual data gives the total environmental impact of a product or process. Economic data are also compiled. All the various costs incurred in manufacturing or using a product are included in the calculation. The economic analysis and the overall environmental impact are used to make Eco-Efficiency comparisons.

Economic and ecological data are plotted on the Eco-Efficiency Portfolio. The costs are shown on the horizontal axis and the environmental impact is shown on the vertical axis. The graph reveals the Eco-Efficiency of a product or process compared to other products or processes. The positions are expressed in so-called person time, which transfers the single results after normalization and weighting in time terms. They are based on impacts people in the European society causes over a 1-year period. Results from case studies are expressed in time shares of the different impact categories. The method allows as well to create future scenarios and enables to use Eco-Efficiency Analysis in making strategic decisions and it also helps to detect and exploit potential ecological and economic improvements.

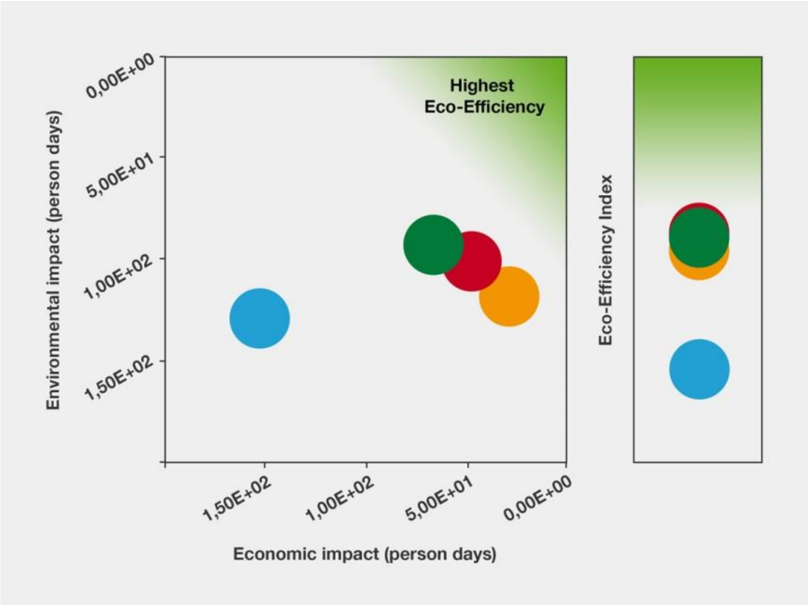


Figure 3: *Example of an Eco-Efficiency Portfolio produced with the Eco-Efficiency Analysis method by BASF (different coloured dots represent different alternatives for a defined functional unit)*

4.4.2 Green Productivity Index

Green productivity (GP) is defined as the ratio of productivity of a system to its environmental impacts. GP management applies productivity measurement tools and environmental management tools to analyse productivity and environmental performance separately.

The GP index developed by Hur, et al. (2004) based on eco-efficiency ratio (2), is a measure of the GP performance of a product system throughout its entire life cycle. These authors extended the numerator of the eco-efficiency ratio to be 'productivity', then decomposed as 'Selling Price (SP)/Life Cycle Cost (LCC)'. The denominator included the overall Environmental Influence (EI). This is expressed in the direct GP index calculation (3).

$$GP\ index = \frac{\frac{SP}{LCC}}{EI} \quad (3)$$

The "overall" GP index can be further decomposed into a "direct" GP index (4) and an "indirect" GP index (5) that are intended to analyse the GP performance of direct production processes and indirect upstream processes, respectively.

$$Direct\ GP\ index = \frac{\frac{SP - SP_{upstream}}{LCC - LCC_{upstream}}}{EI - EI_{upstream}} \quad (4)$$

$$Indirect\ GP\ index = \frac{SP_{upstream} - LCC_{upstream}}{EI_{upstream}} \quad (5)$$

The EI and $EI_{upstram}$ indices were derived from the LCA. For the calculation of the Indirect GP index it was assumed that raw material extraction and correlated activities in the supply chain have a 30% increase in Selling Price (SP) respecting to the real cost supported to perform these activities.

The GP index and its sub-indices allow selecting one alternative out of a list of contenders in order to improve the GP performance of an existing system. A GP portfolio can be drawn up on top of this index to check the strengths and weaknesses of alternatives that are evaluated. The GP portfolio presented on Figure 24 was produced by normalising the environmental and productivity dimensions using a geometric normalisation technique – i.e. unit vectors –. Therefore, the portfolio represents a dimensionless construct.

We have applied GP complementarily to the EEA method in order to compare the environmental productivity of the alternative production scenarios tested in this case study, with the aim of comparing the scope of each method. Section 5 presents the outputs of the assessment.

5 Main results

This Section presents the main results of the different impact assessment methods that were applied to this case study. For the reasons mentioned on Section 2 above, whereas some general descriptions of results are delivered, an interpretation of results regarding their numerical outputs could not be provided.

5.1 Environmental impact assessment

5.1.1 Environmental-LCA

Results of the environmental LCA are presented on Figure 4 to Figure 8 below. All impacts were calculated with the CML-2001 impact characterisation method. Values were normalised using the Netherlands 1997 method.

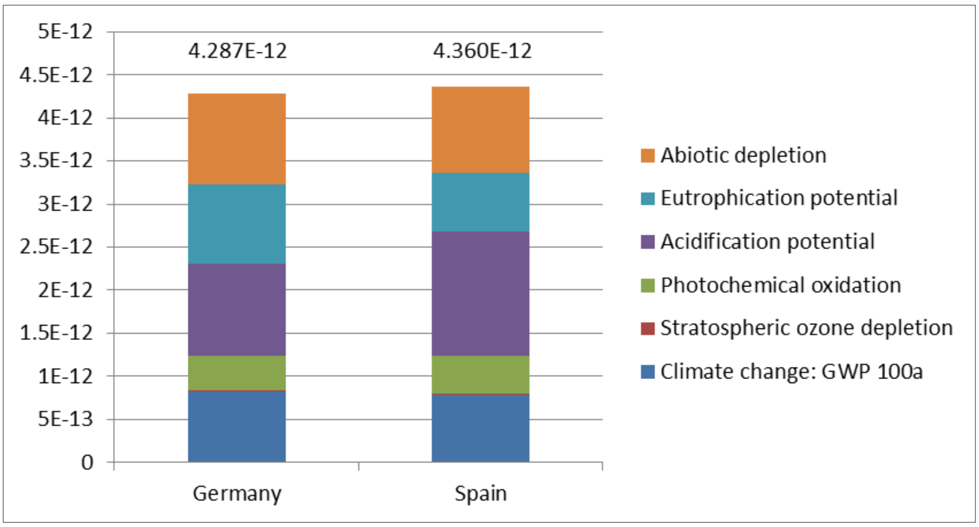


Figure 4: *Contribution of the different impacts categories to the global environmental impact (normalised values)*

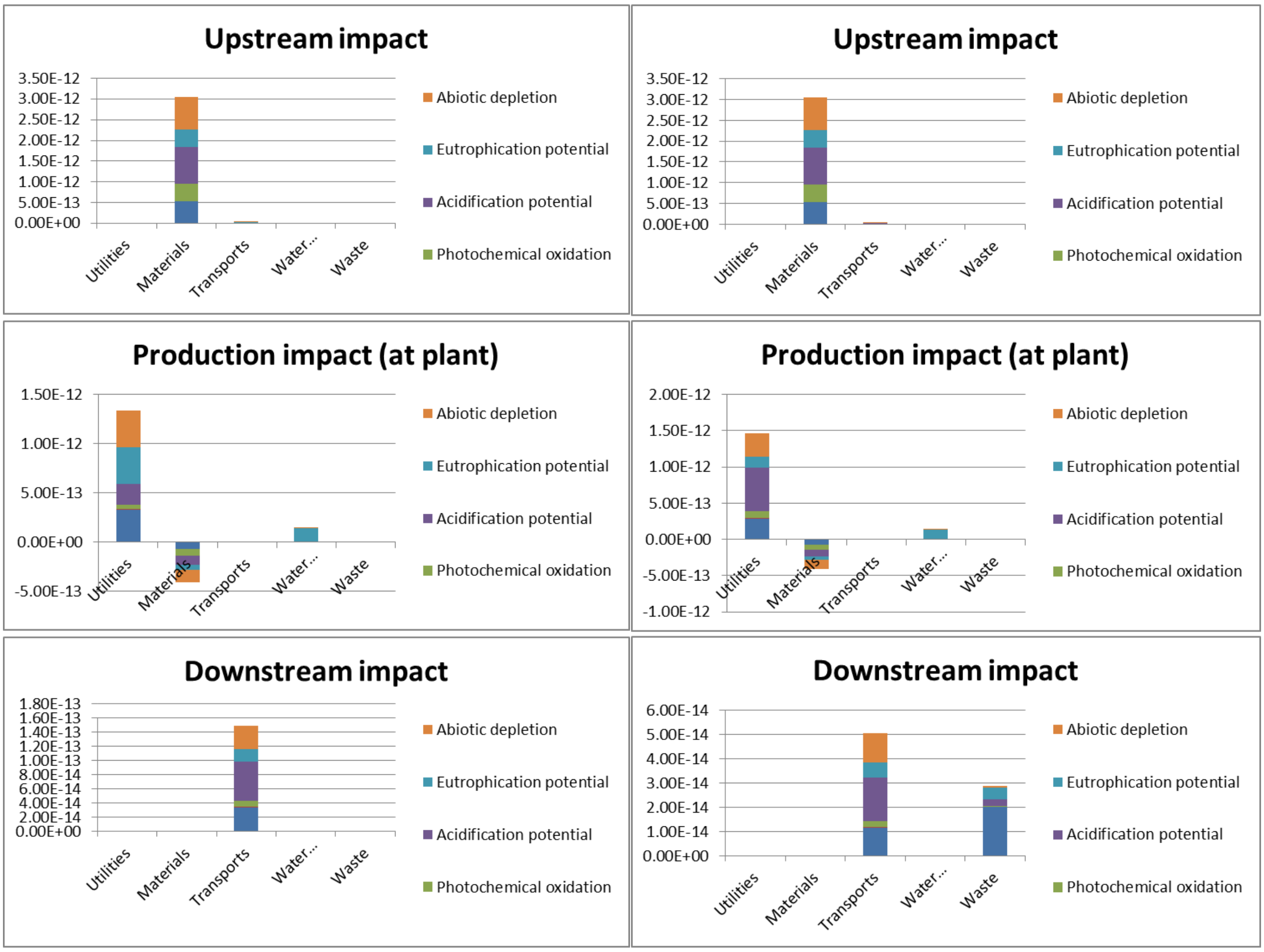


Figure 5: *Comparison of the German (left) and Spanish (right) processes: Normalised environmental impact per impact categories and life cycle stage*

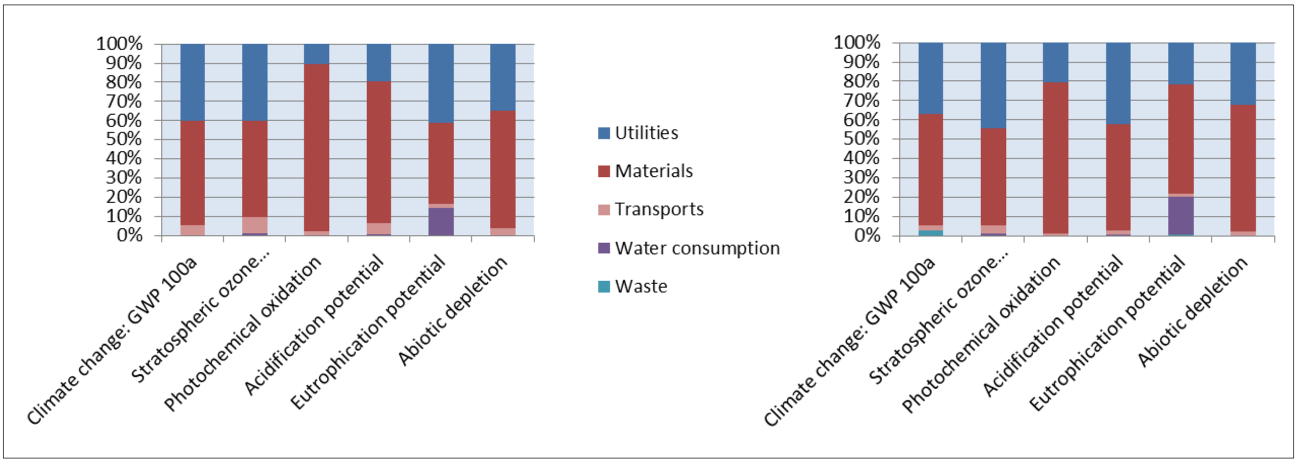


Figure 6: *Contribution of the different environmental compartments to the environmental impact categories in the German (left) and Spanish (right) processes*

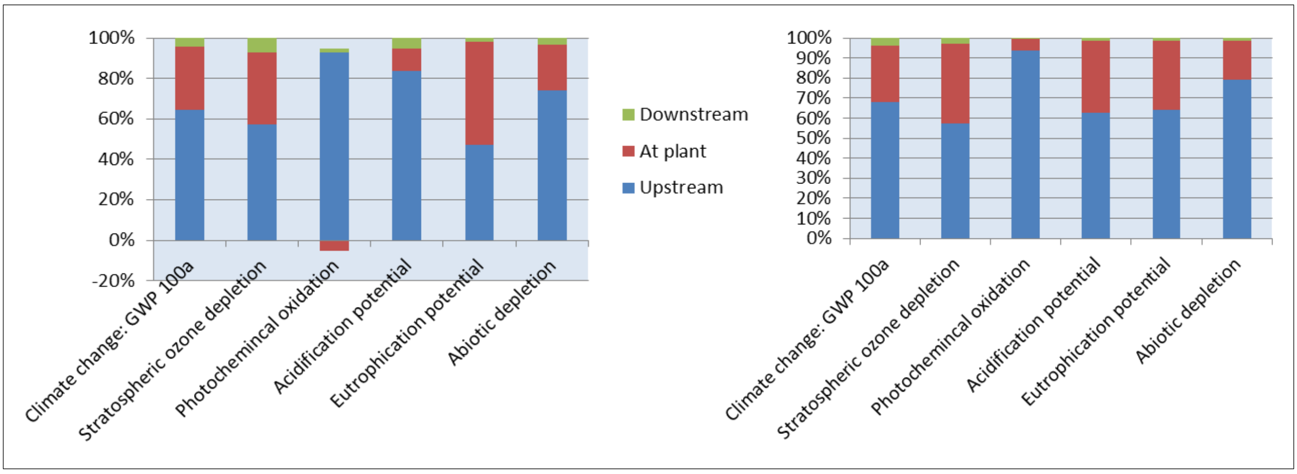


Figure 7: *Contribution of life cycle stages to the environmental impacts categories in the German (left) and Spanish (right) plants*

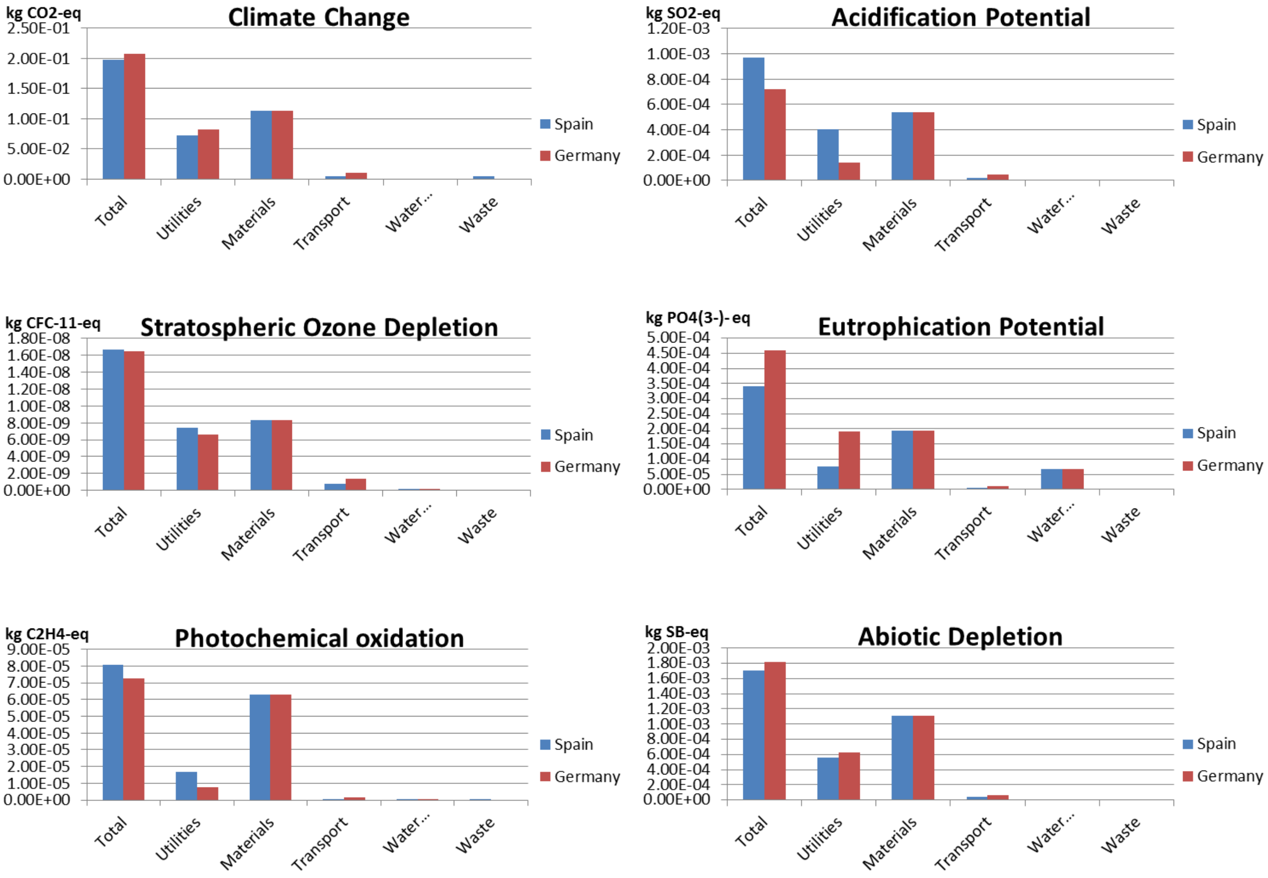


Figure 8: *Comparison of the contribution of the environmental compartments to the different impact categories for the German (red) and Spanish (blue) plants*

The LCA shows an environmental impact highly dominated by raw material extraction (upstream) and utility consumption (at plant). Transport impacts clearly dominate the use and end of life phases, but these are much smaller across all impact categories.

The main differences between the two scenarios are driven by the specificities of the two end of life models. In the production and use phases the different the electricity mixes and average transport distances seem to cause the disparities between both countries. All impact categories considered, the Spanish process seem to have a slightly higher environmental impact that the German one.

Due to the reasons mentioned in Section 2, these results must not be used to draw any conclusions on the impact and/or efficiency of two countries considered in this case study.

5.1.2 MIPS method

For the comparison of the two scenarios, the material intensity of a production in Germany and in Spain was calculated by applying the MIPS method. All processes considered in the LCI were regionalised, including fuel and electricity input. All raw materials for the chemicals and connected upstream products are calculated for European average conditions and not specific for Germany and Spain. The biotic materials used in the production of the product and packaging were calculated for the specific conditions of Spain and Germany.

The main results are presented in Table 7 and from Figure 9 to Figure 14.

Table 7: *Material Intensity of the production of the product in Spain and Germany*

	Product (Germany) [kg/unit]	Product (Spain) [kg/unit]
Abiotic raw material	0.7198	0.5131
Biotic raw material	0.0414	0.0410
Erosion	0.0081	0.0096
TMR (∑ abiotic, biotic and erosion)	0.7693	0.5636
Water	13.64	13.68
Air	0.1236	0.1392

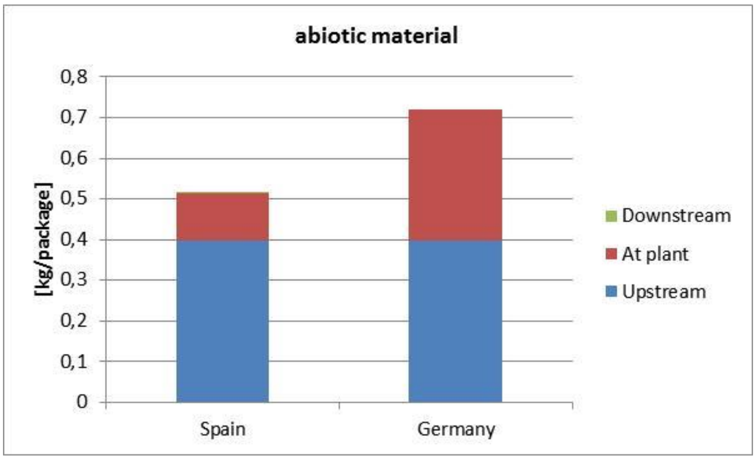


Figure 9: *Abiotic raw material consumption for the production of the functional unit*

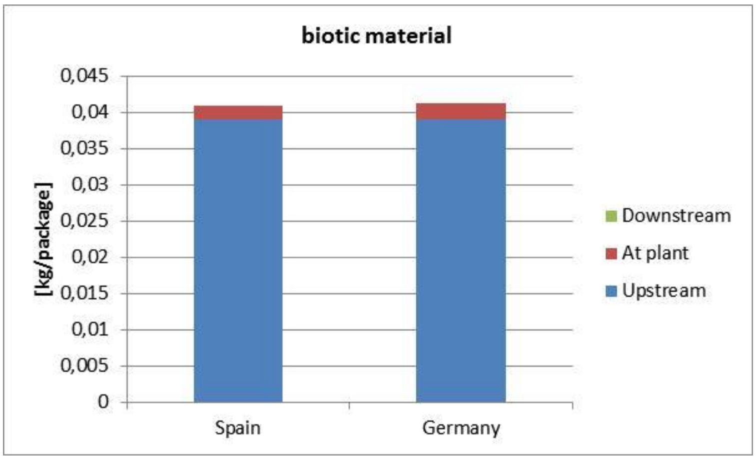


Figure 10: *Biotic raw material consumption for the production of the product*

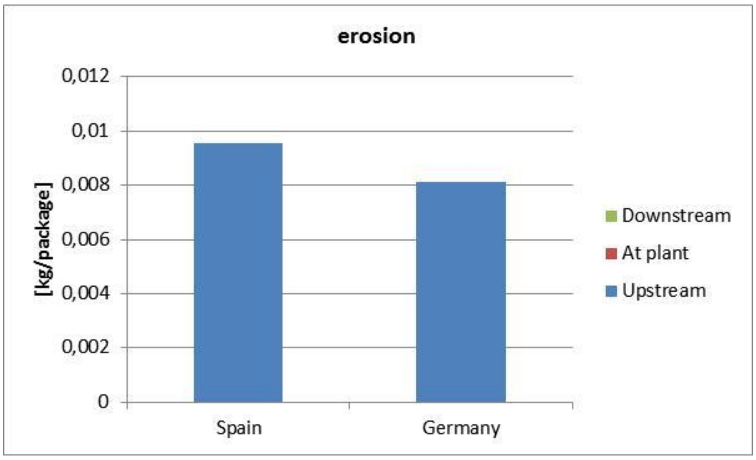


Figure 11: *Erosion for the production of the product*

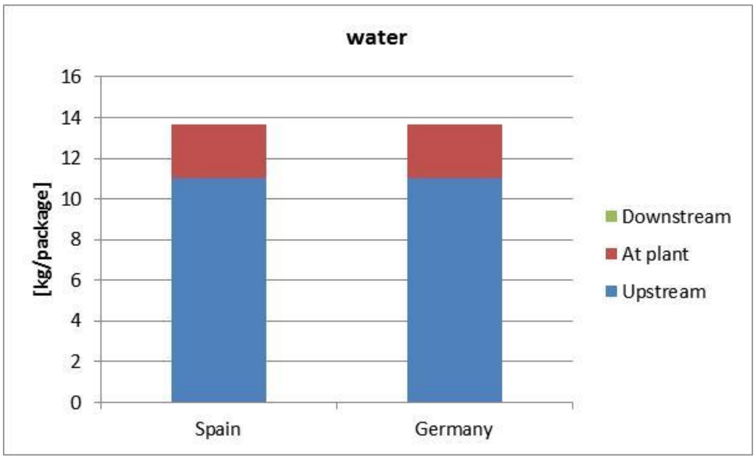


Figure 12: *Water consumption for the production of the product*

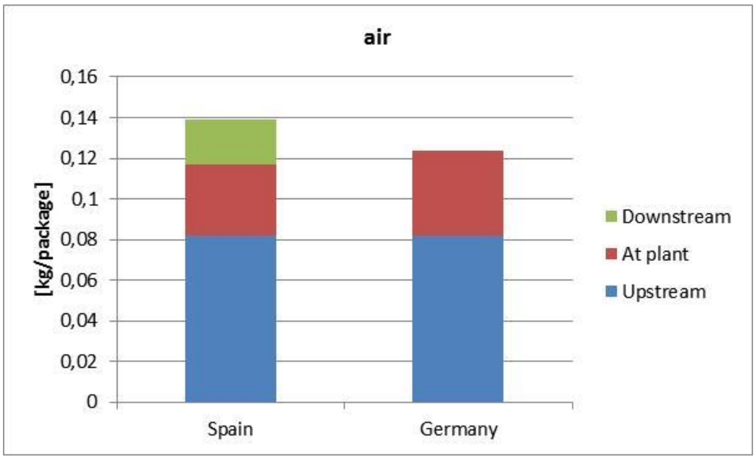


Figure 13: *Air consumption for the production of the product*

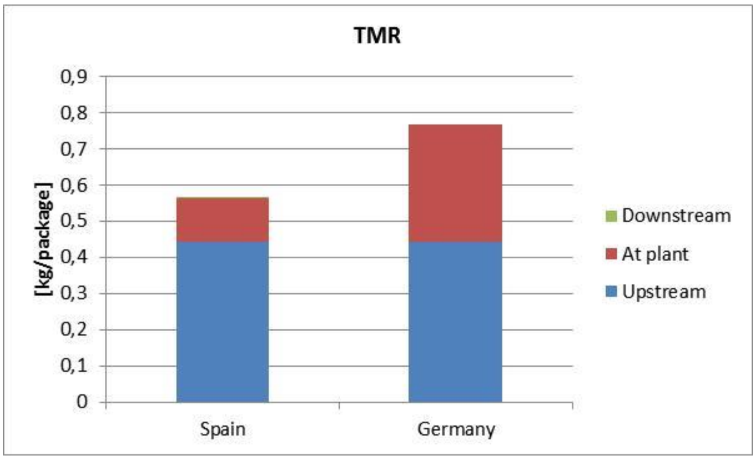


Figure 14: *Total Material Requirement (TMR) for the production of the product*

The abiotic and biotic material consumption is dominated by the upstream processes of the product. The utility consumption at plant and the downstream processes are of minor relevance.

Relevant differences between the production in Germany and Spain occurred for the abiotic raw material consumption and the erosion. The abiotic raw material consumption is dominated by the raw material for the product and especially by the used fuels and energies and fuels used for the specific electricity mix. The difference is mainly caused by the very material intensive German electricity mix. On the other hand, the used agricultural products can be produced in Germany with a higher specific yield and less erosion and use of agricultural land. The air consumption is for the German production slightly higher compared with the Spanish production. This is again a result of the electricity mix and the used fuels for it.

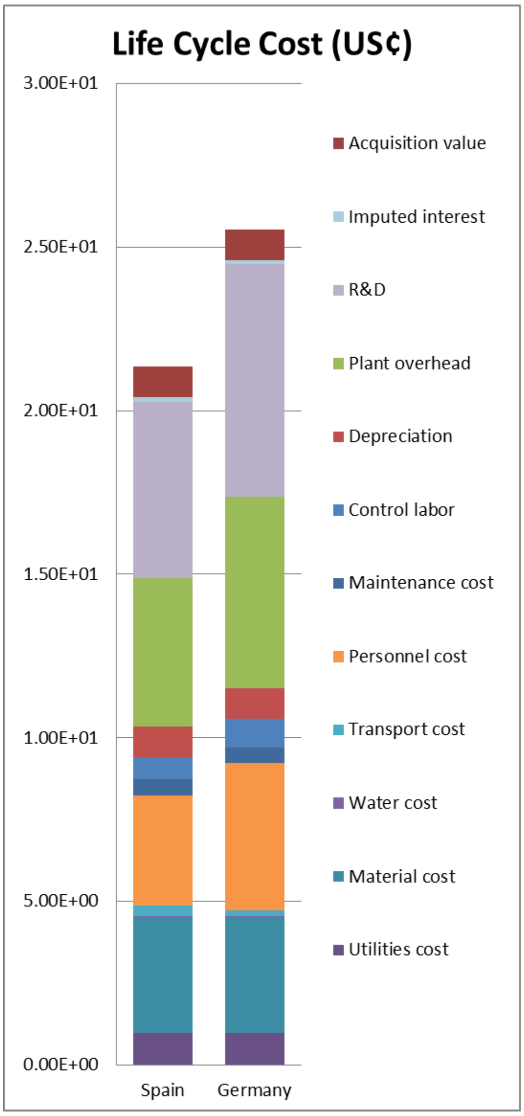
For the widely used indicator TMR (A Adriaanse et al., 1997), the production in Spain is in favour as well.

The results show that differences in electricity mix and fuels can have a significant influence on the abiotic material consumption.

Due to the reasons mentioned in Section 2, these results must not be used to draw any conclusions on the impact and/or efficiency of two countries considered in this case study.

5.2 Life Cycle Costing

Life Cycle Costing results are presented on Figure 15 to Figure 17.



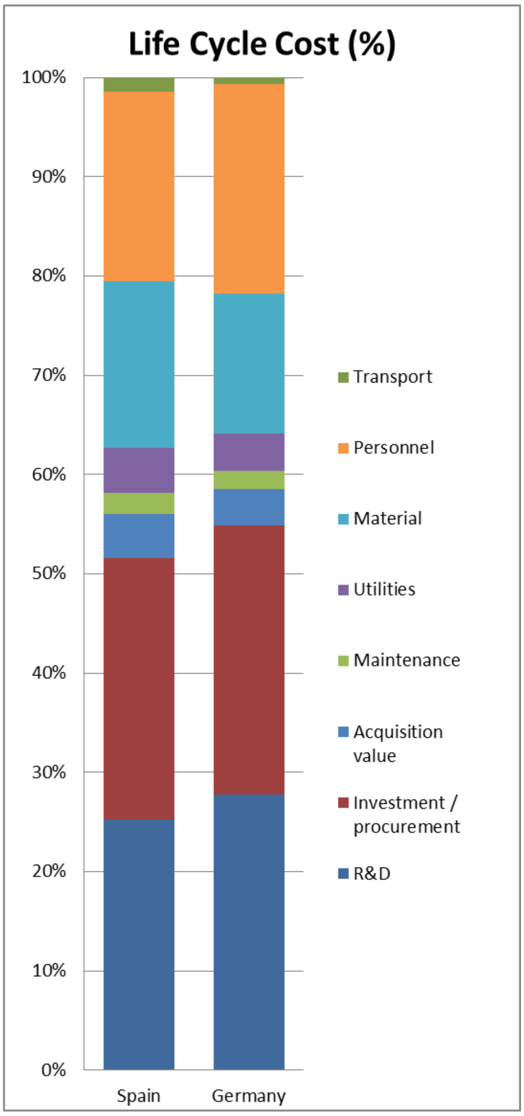


Figure 15: *Total product costs in the two plants under comparison, expressed as absolute costs per detailed cost categories (left) and relative costs per broader cost categories (right)*

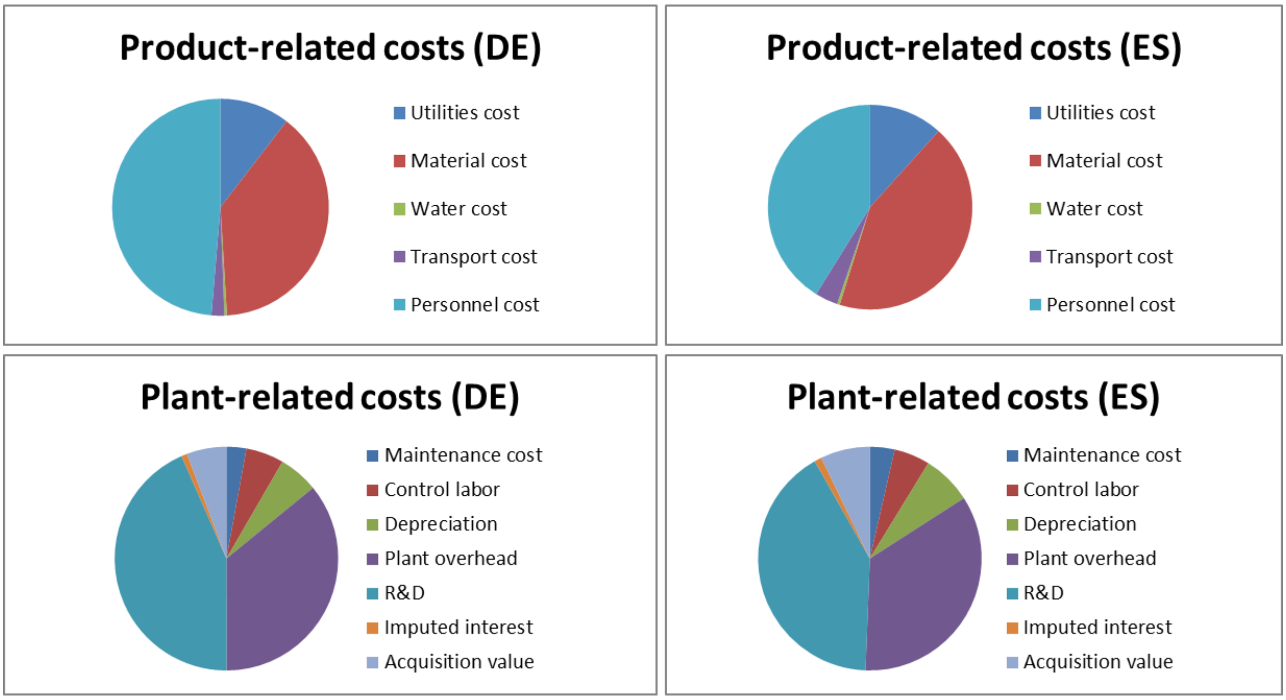


Figure 16: *Cost structure relative to the German (left graphs) and Spanish (right graphs) processes*

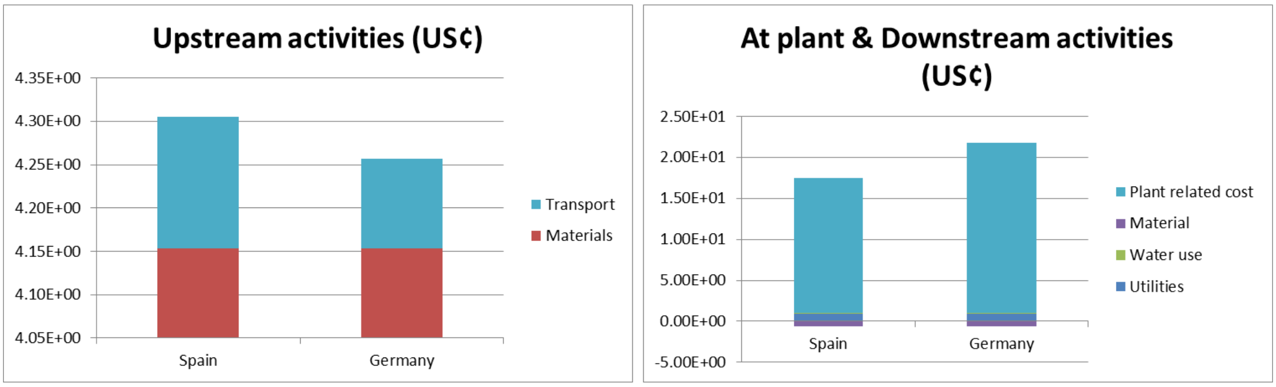


Figure 17: *Contribution Analysis per life cycle stage (downstream activities include the use and end of life costs)*

The cost analysis shows that the structure of costs is heavily dominated by at plant costs, mostly driven by R&D, personnel costs and plant overheads. Upstream costs are almost equally distributed between transport and materials. The main different between the cost structure of the two countries seems to lay on personnel costs, including direct costs and overheads, which seem to be smaller in the Spanish plant.

Due to the reasons mentioned in Section 2, these results must not be used to draw any conclusions on the impact and/or efficiency of two regions considered in this case study.

5.3 Social-LCA

As discussed in Section 4.3.3 above, the analysis was conducted using the quantitative assessment datasheet tool provided by the Roundtable for Product Social Metrics (PRé Sustainability and Roundtable for Product Social Metrics, 2016). This tool proved to be a promising step forwards but it still a rather immature instrument for S-LCA. We found a number of potential drawbacks linked to either design issues linked the Roundtable methodology and/or a wrong implementation of the spreadsheet tool. These include:

- The tool includes some references to local file systems, which does not help to navigate through all the steps.
- Some sheets have incongruences in the units of measure for a number of performance indicators (e.g. step 6.2 for forced and child labour).
- The allocation step (step 6.3 - indicators - PLC) seems to produce inconsistent results for relative performance indicators. For example, if the same amount of output is obtained with less processing time, the global performance indicator (PLC values) becomes smaller for similar performance levels – i.e., this allocation system seems to penalise the more productive systems, those where more quantity of output is produced with less amount of input.
- The tool does not seem to build on stable benchmarks. On step 7 – referencing the highest possible Indicator score (i.e. 1.00) is always given to the best performing alternative considered within a comparative framework, regardless if this alternative is performing above or under a predefined target.
- It is not easy to exclude specific social dimensions from the analysis. Whenever particular social topics are not covered by performance indicators, zero divisions cause repetitive failures in the scoring system. This mainly affects step 7 – referencing, but also step 8 – scoring.
- The whole scoring system and the final representation of results seem counterintuitive, as larger values of the final score denote smaller social footprints.

In practice, a number of *corrections* had to be implemented in order to conduct the assessment with this tool. These addressed the following aspects:

- The child labour social topic was wrongly formulated in step 7 – referencing. Contrary to other social topics, in this case lower values of the indicator led to smaller scores. This was corrected and all the formulas included in this step were verified to reflect the exact referencing scenarios envisaged by the Handbook (PRé Sustainability and Roundtable for Product Social Metrics, 2016 pages 14 and 15).
- The datasheet was adapted to the specific dimensions covered in this assessment: All the formulas included in the scoring step (step 8) were corrected to account for missing values, thus avoiding the errors caused by zero divisions.

The analysis included the manufacturing and use phases of the product – i.e. gate to consumption –. Upstream value chain stages and end of life steps were not considered due to data constraints. The assessment relied on indirect data derived from publicly available sources as proxy indicators.

Table 8 below presents the final scores for the ten social topics considered in the S-LCA analysis. The global score is 0.67 for the Spanish product and 1.00 for the German one. Higher scores denote better-off situations both for the global score as well as for each of the dimensions individually[7].

Table 8: *Social impact of the production of the product in Spain and Germany*

Stakeholder group	Social topics	Germany	Spain
Workers	Health and safety - W	0.94	1.00
	Wages	0.99	1.00
	Child labour	1.00	1.00
	Forced labour	1.00	0.13
	Freedom of association and collective bargaining	1.00	0.90
	Training and education	1.00	0.50
Consumers	Health and safety - C	1.00	0.44
Local communities	Health and safety - LC	1.00	0.89
	Access to tangible resources	1.00	0.89
	Employment	1.00	0.67

Figure 18 below provides a visual representation of results. The Spanish production model is represented by a blue line and the German one by a yellow line. The further the indicator is located in the outer edge, the lower (better) is the social impact, as indicated by the traffic light colours.

[7]This does not necessarily imply higher values of the contributing performance indicators. For example, for the health and safety dimension a 0.94 score for the German process in relation to a 1.00 score for the Spanish one implies a higher incident rate over the life cycle of the German product in relation to the Spanish one. The indicator used to illustrate this specific dimension is the estimated number of accidents at work per year at plant (more than 3 days lost). Table 2 above lists all the quantitative indicators that were used in our S-LCA.

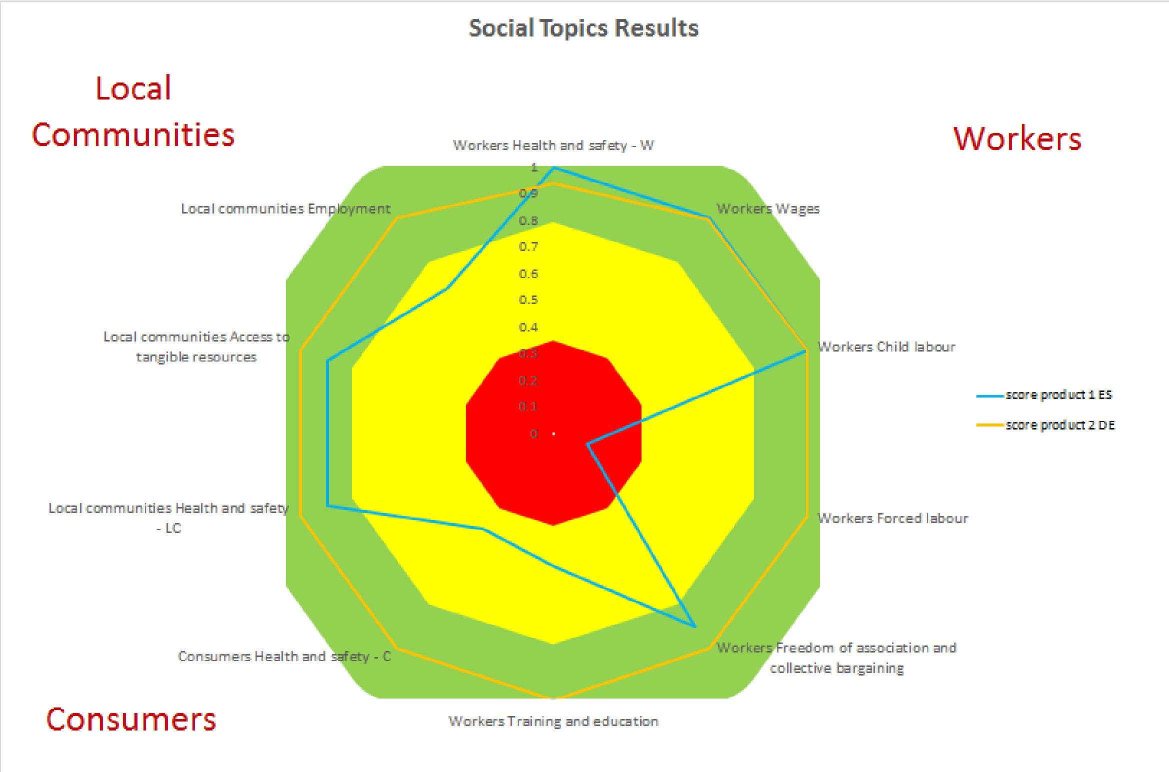


Figure 18: *Summary graph of the S-LCA results for the social dimensions under analysis*

Figure 18 show a structurally better social result of the German alternative in relation to the Spanish one. In all the dimensions with the exception of workers wages and workers health and safety, the German alternative outperforms the Spanish one. The most significant difference between the two alternatives is the one related to the Workers Forced Labour social dimension. This is motivated by the use of a proxy indicator, namely the estimated hours of sub-contracted labour per year, which is almost eight times higher in the Spanish scenario in relation to the German alternative. This should not be interpreted as a higher incidence of *forced labour* in the Spanish system.

Considering the difficulties faced during the execution of this S-LCA, results should be taken as illustrative only. As previously mentioned the severe scarcity of primary data imposed a narrower scope for the analysis in relation to the environmental, economic and integrated ones, whereas the issues stemming from the use of the tool provided by the Roundtable for Product Social Metrics compromised consistency and interpretation. In particular, these results must not be used to draw any conclusions on the social conditions of two countries considered in this case study.

5.4 Integrated methods

Results from the integrated methods are delivered as tow eco-portfolios presented in the following two Sub-Sections.

5.4.1 EEA method

Based on the LCA results and the LCC results, the EEA portfolio was generated. The calculated figures were implemented, normalized and weighted by the BASF system. In the final step, all figures were transferred to person times, which show which time share of a person of the overall environmental burden per year is needed, to cover the environmental burden of the alternatives of the case study. Different normalization figures from different systems caused longer discussions and needed further effort. That might be difficult for unexperienced practitioners and should be avoided by publication of normalization factors in line with the used assessment systems. To avoid inconsistencies, the LCA results were directly linked with normalization factors extracted from the LCA assessments of Tecnalia.

Table 9: *Overview of different normalization factor sets*

	Global Warming 100a **kg CO2 eq**	**Ozone layer depletion 40a** **kg CFC-11 eq**	**Photochemical oxidation** **kg C2H4 eq**	**Acidification** **kg SO2 eq**	**Eutrophi-cation** **kg PO4 --- eq**	**Abiotic Depletion** **kg Sb eq**
Normalisation factors for "the Netherlands, 1997" from SimaPro (inverse value)	2.53E+11	9.17E+05	1.82E+08	6.71E+08	5.03E+08	1.71E+09
Normalisation factors from "the Netherlands, 1997" from "*Normalization figures for life-cycle assessment, The Netherlands (1997/1998), Western Europe (1995), and the world (1990 and 1995)*"	2.50E+11	9.20E+05	1.80E+08	5.30E+08	1.40E+08	1.70E+09

Results for the EEA are presented on Figure 19 and Figure 20.

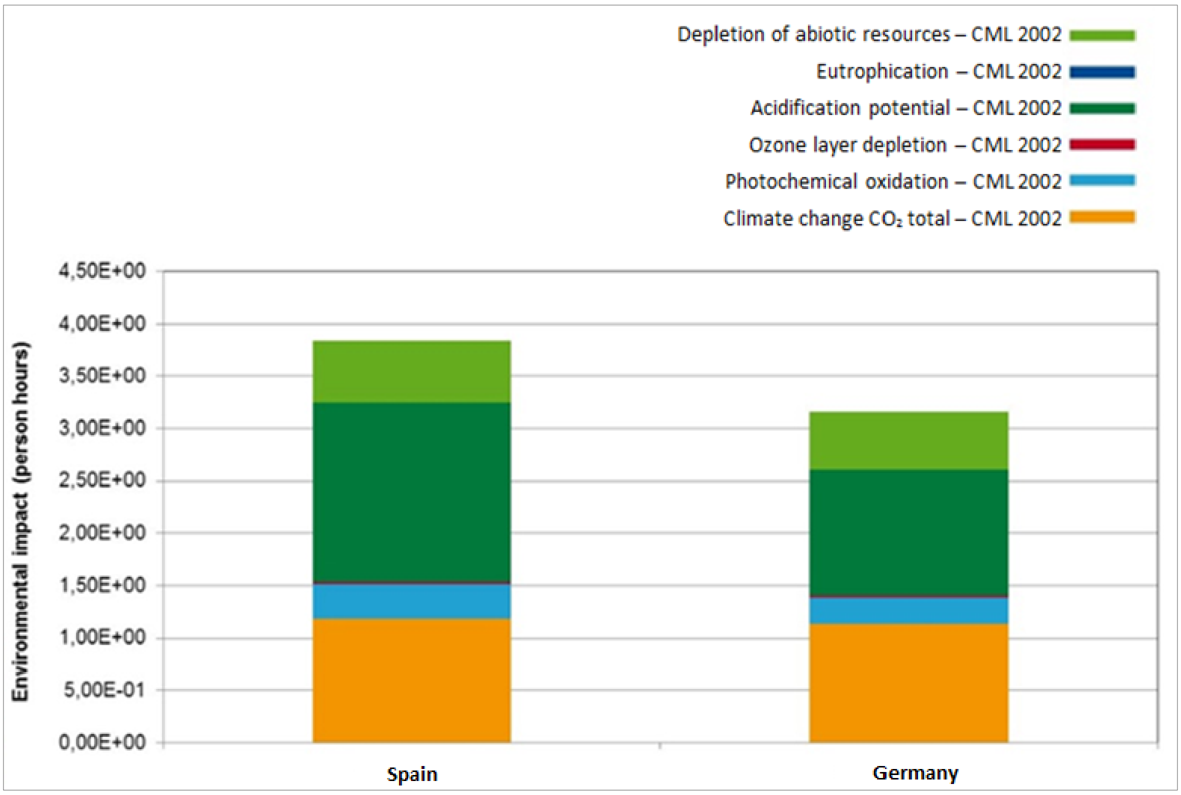


Figure 19: *Eco-efficiency analysis (EEA method): Contribution Analysis (relevance check)*

It is important for the interpretation of the study to see where the most relevant impacts to the overall result come from. Therefore, in the BASF EEA a contribution analysis was developed which clearly shows, which impact from which impact categories is linked with a certain contribution in the portfolio. Therefore it is important that the indicator results and the normalization factors fit to each other. Figure 19 shows the contributions after normalization and weighting. The most relevant contributions in this case study are linked to the Global-warming potential and Acidification Potential for both alternatives in the system. They are followed by Abiotic Depletion Potential and Photochemical Ozone Creation Potential. The higher overall environmental impacts are generated in the process in Spain, mainly caused by the higher AP contribution.

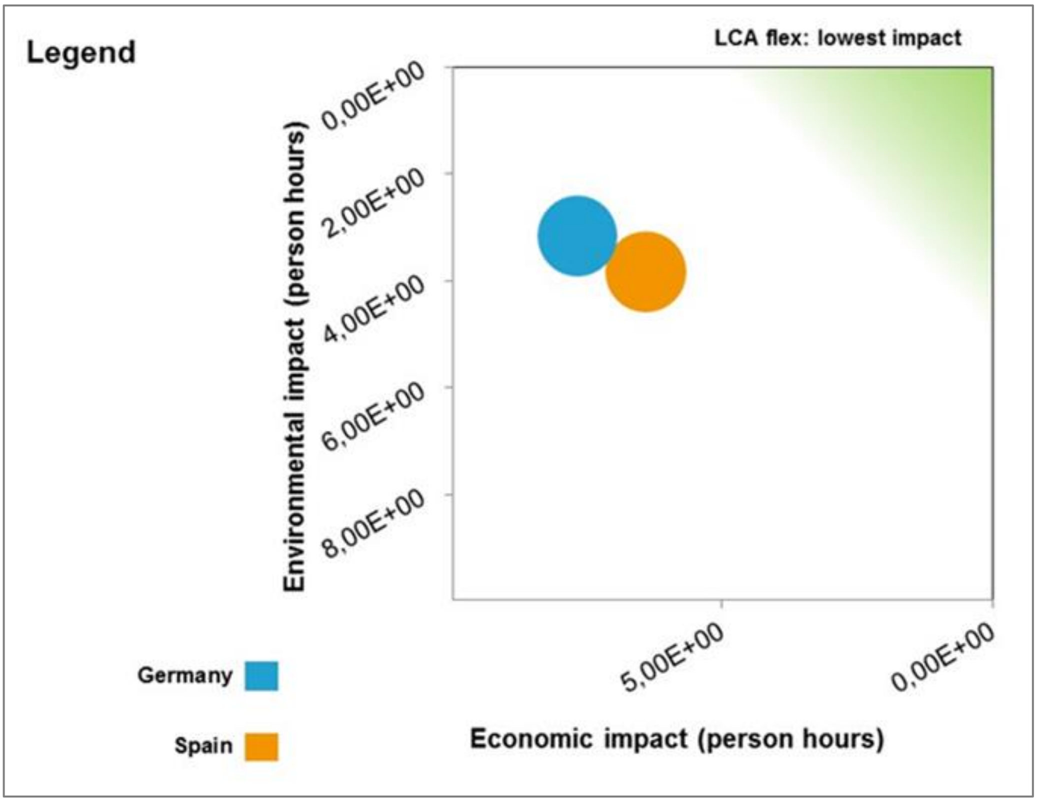


Figure 20: *Eco-efficiency analysis (EEA method): Summary of results (upper right corner or higher position in the graph showing the more eco-efficient solutions/processes)*

Together with the LCC figures which are also expressed in person time, the portfolio is generated (Figure 20). The portfolio shows the two dimensions in one figure, expressed in the same comparable unit. In this case the person time is expressed in person hours. The unit is scalable and can be adjusted, depending on the specific case study. The Spanish process is economically better compared to the German process. To combine economy and ecology, the portfolio is generated. In the upper right corner, the more eco-efficient alternatives are located. In this case study, the German process has a better environmental performance and the Spanish process the better economic performance. Both processes have comparable positions concerning the upper right corner and can be detected as having the same eco-efficiency (Figure 20). The differences of both alternatives concerning their Eco-Efficiency positions are too small to have a significant difference of both alternatives.

Due to the reasons mentioned in Section 2, these results must not be used to draw any conclusions on the impact and/or efficiencyof two countries considered in this case study.

5.4.2 GP method

Results for the productivity analysis based on the GP method are presented on Figure 21 to Figure 24. In comparison to the EEA method, the productivity approach also includes in the analysis the expected market value of the products –via the selling prices.

The analysis shows relatively higher productivity values in the German process in comparison to the Spanish one, given the significantly higher selling price of the product in the German market. This is entirely related to at plant and downstream phases, as reflected by the Direct GP index. The Indirect GP index, which account for upstream costs renders similar results for both alternatives.

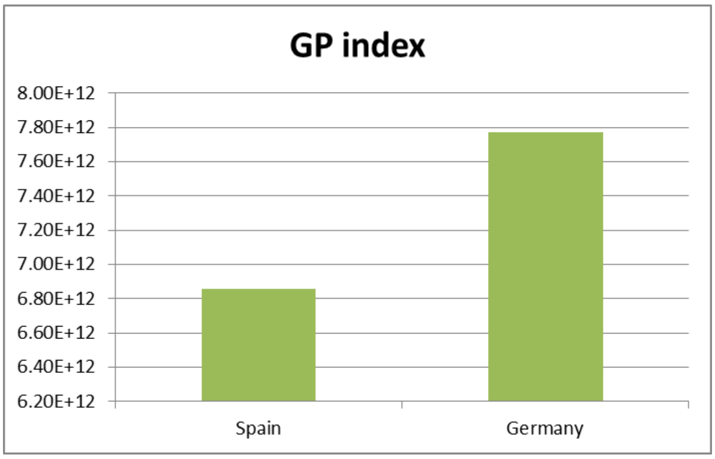


Figure 21: *Eco-productivity analysis (GP method): GP index*

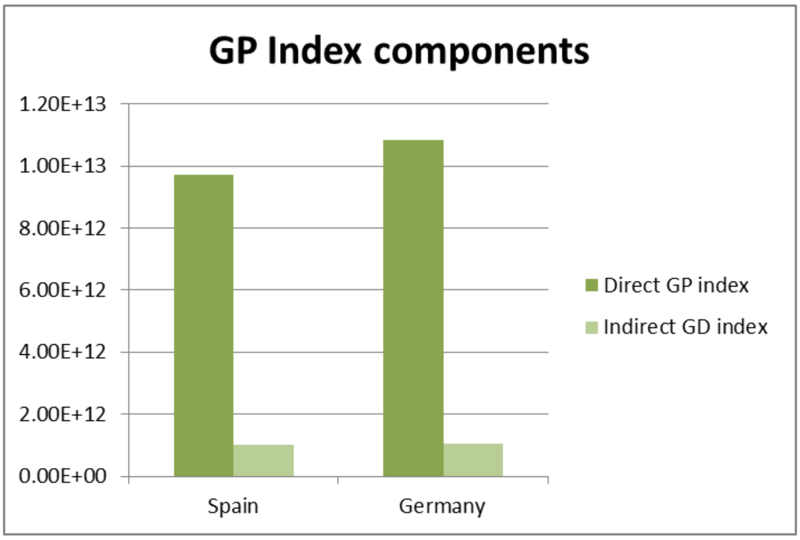


Figure 22: *Eco-productivity analysis (GP method): GP index components*

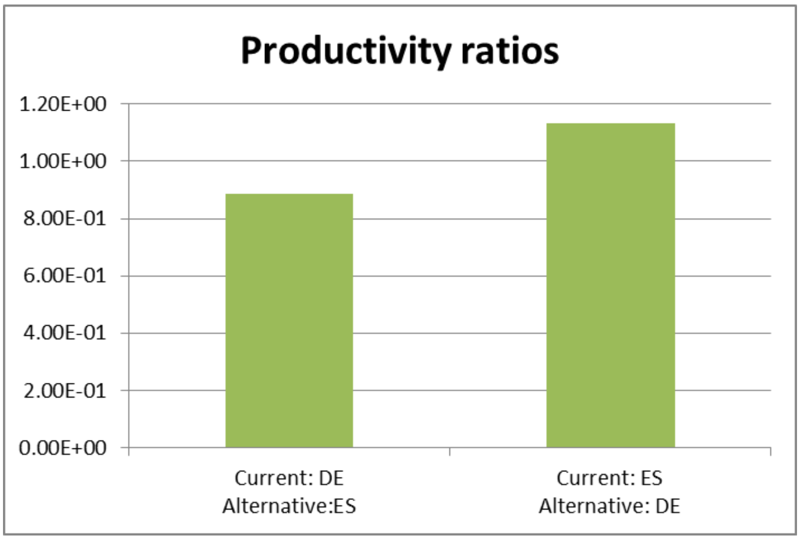


Figure 23: *Eco-productivity analysis (GP method): productivity ratios*

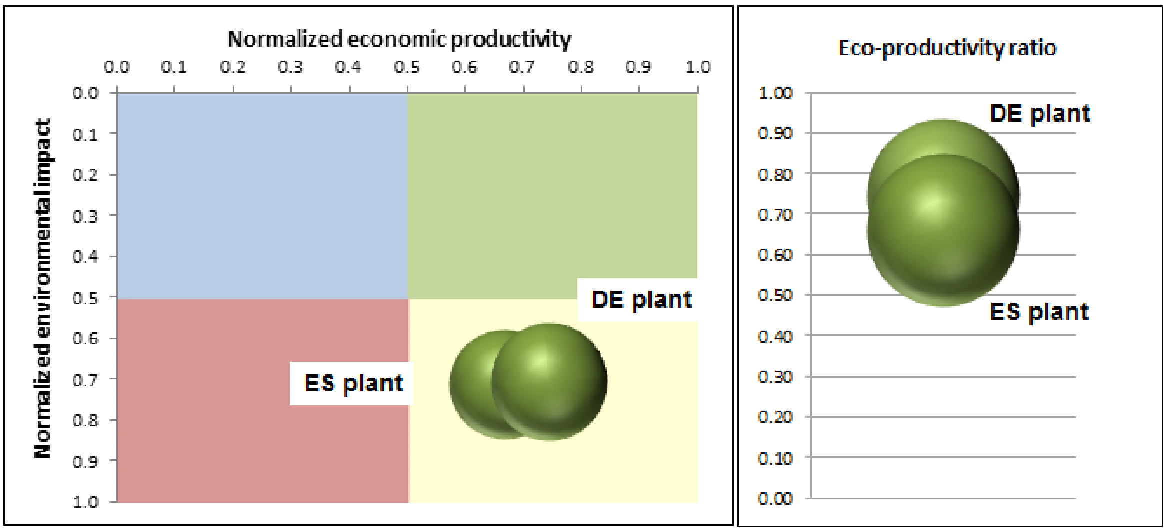


Figure 24: *Eco-productivity analysis (GP method): Summary of results (lower right corner or higher position in the graph showing the more eco-productive solutions/processes)*

Figure 24 shows the eco-productivity portfolio generated by combining the GP values with the environmental burden derived from the LCA results presented in Section 5.1.1. All values were normalised using unit vectors, a normalisation technique that produces a dimensionless measure that allows the two economic and environmental spheres to be compared in a unified scale. Considering environmental burdens, life cycle costs and market values per functional unit, the German process shows a slightly better productivity than the Spanish alternative. Still, differences between the two alternatives are negligible.

Due to the reasons mentioned in Section 2, these results must not be used to draw any conclusions on the impact and/or efficiency of two countries considered in this case study.

6 Conclusions and lessons learnt

This section provides an overview of the main conclusions that can be drawn from the practical implementation of the methods tested in this case study. The paragraph are organised by type of methods, each one providing some insights into the value added and the main limitations of the different methods within a sustainability assessment framework.

6.1 Environmental methods

LCA and MIPS are environmentally oriented life cycle methods. They cover all life cycle stages, but parts of the life cycle can also be analysed separately. The LCA can be enlarged to adopt the MIPS perspective.

In general, the main value added of these methods stems from their ability to identify potential hotspots and point out indirect impacts within the value chain. Furthermore, these 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. They 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.

However, some areas for improvement and barriers for successful implementation of these methods remain.

LCA and MIPS are rather complex to implement and difficult to communicate methods. In both cases, complexity relates to the availability of a number of methodological choices, 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.

As a result the LCA, and in some aspects also the MIPS method, still lack of a common, stable and univocal way of conducting the analysis across all the possible implementations. Even when the ILCD guidelines are strictly followed, like in this case study, the methodological choices and the assumptions made undermined the comparability of some outcomes. However, compared to the S-LCA as conducted in this case study, 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.

6.2 Costing methods

LCC is a well-established method. There are a number of procedures available to account for life cycle costs. Mostly, they differ on the way costs are organised and classified. 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 production system, contributing to decision making within a management framework and helping to communicate results to a wider audience. The experience matured in this case study shows that, provided that costing data can be accurately collected, arranging and displaying results in different ways is pretty straightforward. Costing methods are also the basis for the preparation of business cases and investment decisions.

Perhaps 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.

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.

6.3 Social methods

Both methodologies that were tested in this case study are in accordance with both with the UNEP-SETAC guidelines (UNEP-SETAC, 2009). 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. 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 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.

However, in comparison to the environmental and economic methods, S-LCA is still on its infancy. 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.

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.

6.4 Integrated methods

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 were 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 – i.e the person days concept – 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. However, the use of different data sets from different methods and assessed with different impact assessments, need some focus due to the use of normalization schemes with the same calculation and assessment basis. The transfer from different data systems is often not easy because flows are not harmonized. That might be done in the PEF process and will enable practitioners to use harmonized assessment and normalization systems.

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.

When it comes to barriers, the 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. 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 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. In particular, when weighting is done on the basis of public opinion polls or expert knowledge, these tend to be mutable over time, but can help systems on the other hand to be always up-to date and following societal requirements. This compromises backward comparability.

Although normalisation and weighting affect all methods, these limitations can be particularly cumbersome for the methods that combine two – like the EEA and GP methods – or even the three sustainability spheres. 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. In this respect, several of the communication tools tested in this case study show how designing good communication materials that are both scientifically sound and understandable for the general public is possible.

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8 Supplementary information

8.1 Social sustainability topics included in the WBCSD framework

This section presents the list of indicators included in the third version of the WBCSD framework that should be published shortly (Coërs, 2015).

Table 10: *Social topics included in the WBCSD Social Metrics for Chemical Products*

Social impact categories	Stakeholder groups		
	Workers	Local communities	Consumers
Health and safety	**- Worker's occupational health risks** - Management of workers' individual health **- Safety management system for workers**	**- Health and safety of local community's living conditions**	**- Impact on consumer health and safety**
Basic rights and needs	**- Fair wages** - Appropriate working hours **- Freedom of association, collective bargaining and labour relations** **- No child labour** **- No forced labour, human trafficking and slavery** - No discrimination - Social/employer security on benefits	**- Access to basic needs for human right and dignity (healthcare, clean water and sanitation, healthy food and shelter)** - Respect for indigenous' rights	- Direct impact on basic needs (healthcare, clean water, healthy food, shelter, education)
Well being	- Job satisfaction	- Access to basic needs for sustainable development (infrastructure, ITC, modern energy) - Nuisance reduction - Developing relationship with local communities	- Consumers' product experience
Skills and knowledge	**- Skills knowledge and employability**	- Promotion of skills and knowledge	- Promotion of skills and knowledge
Employment	- Management of reorganisation	**- Job creation**	

*** Mandatory social topics in bold**

8.2 The Roundtable for Product Social Metrics framework

This section presents the list of indicators included in the third version of the Handbook for Product Social Impact Assessment (PRé Sustainability and Roundtable for Product Social Metrics, 2016). The indicators are classified by stakeholder group. Those categories highlighted in reddish colour are those coincident with the Mandatory group of the WBCSD framework (see Section 8.1).

8.2.1 W. Performance Indicators selected for the Stakeholder group 'workers'

W.1. Equal opportunities and discrimination

- **W.1.1.** Equal rights and opportunities: The company/facility does not engage in or support discrimination in hiring, remuneration, access to training or promotion, termination or retirement based on race, colour, language, caste, national origin, indigenous status, religion, disability, gender, marital status, sexual orientation, union membership, political affiliation, age, pregnancy or any other condition that could give rise to discrimination except when specifically required by applicable laws or regulations (e.g. as required in South Africa mandating positive discrimination towards disadvantaged groups).
- **W.1.2.** Percentage of women in total workforce and percentage of women in leadership position.
- **W.1.3.** Percentage of workers with a disability.

W.2. Child labour

- **W.2.1.** No child labour: absence of children in the facility or organisation under the legal age of 15 years old (or 14 years old in developing countries).
- **W.2.2.** Percentage of young workers, i.e. percentage of workers who are under the age of 18 and above 15 (or under the age of 18 and above 14 in developing countries).
- **W.2.3.** If young workers are employed, the company/facility ensures the following:
  - **W.2.3.1.** Young workers that are attending school are not employed during school hours (except if permitted under apprenticeships or other programmes in which they are lawfully participating)
  - **W.2.3.2.** Safe working environment: the company/facility does not expose young workers to situations or activities that are deemed to be hazardous or unsafe to their physical and mental health and development. The minimum age for hazardous work is 18 years.
  - **W.2.3.3.** Day-time work: young workers do not work at night.
  - **W.2.3.4.** The number of hours in which such employment or work may be undertaken per day is compliant with local laws.

W.3. Health and safety

W.3.1. Percentage of injuries or fatal accidents in the company/facility by occupation (e.g. per one million hours worked).

W.3.2. The company/facility complies with applicable health & safety laws or regulations and provides a safe & healthy working environment which includes, with due regard to the health & safety hazards posed by the activities being undertaken, taking reasonably practicable steps to prevent accidents and ill health.

W.3.3. The company/facility ensures that all personnel receive adequate health & safety training or awareness in line with the requirements of their job function and required by local law, including the use of any essential personal protective equipment (PPE). Such training or awareness is also provided for new or temporary contracted and reassigned personnel, and is refreshed periodically.

W.3.4. The company/facility provides adequately stable and safe buildings.

- **W.3.4.1.** access to adequate toilets and potable water, adequate exits for use in the event of a fire or emergency;
- **W.3.4.2.** first aid and medical treatment in the event of a workplace injury, as well as essential safety equipment (e.g. personal protective equipment) free of charge;
- **W.3.4.3.** adequate lighting & ventilation;
- **W.3.4.4.** sanitary facilities for food storage where applicable;
- **W.3.4.5.** provision of physical guards, interlocks and barriers which are properly maintained where machinery presents an injury hazard to workers;
- **W.3.4.6.** where living quarters are provided, assurance that they are clean, safe and sufficient.

W.3.5. The company/facility identifies, evaluates and controls:

- **W.3.5.1.** workers' exposure to the hazards of physically demanding tasks, including manual work, material handling and heavy repetitive lifting, prolonged standing and highly repetitive or strenuous assembly tasks;
- **W.3.5.2.** workers' exposure to hazardous substances which should not exceed the Occupational Exposure Limits (OEL);
- **W.3.5.3.** when risks cannot be adequately controlled by such means, that workers' health is protected by appropriate personal protective equipment programmes.

W.4. Freedom of association and collective bargaining

W.4.1. Workers' representatives are invited to contribute to planning of significant changes in the company which will affect the working conditions.

W.4.2. Right to organise: The company/facility does not obstruct the right of all personnel to form, organise and/or join trade unions of their choice and to bargain collectively, where these activities are not restricted under applicable law. Joining trade unions will not result in any negative consequences to personnel or retaliation from the company/facility.

W.4.3. The company/facility, in those locations where the right to freedom of association and collective bargaining are restricted under law, allows workers to freely elect their own representatives without contravening applicable laws and regulations.

W.5. Forced labour

W.5.1. Workers voluntarily agree upon employment terms. Employment contracts stipulate wage, working time, holidays and terms of resignation. Employment contracts are comprehensible to the worker and are kept on file.

W.5.2. The company/facility does not require, and neither retains nor keeps part of personnel's wages, benefits, property or original documents (e.g. passport, work permit, etc.), either upon hiring or during employment.

W.5.3. The company/facility does not engage in, and neither does it use nor support, the use of forced, bonded or involuntary prison labour.

W.5.4. Workers are free to leave their employer after giving reasonable notice and have the right to leave the workplace after their shift.

W.6. Wages

W.6.1. Compensation paid to workers complies with applicable laws.

W.6.2. The lowest paid wage compared to the living wage, the sector wage or the minimum wage (e.g. the lowest paid worker earns 20% more than local minimum wage).

W.6.3. Deductions from wages where not permitted by applicable law (e.g. as result of disciplinary measures) are not permitted without written permission of the worker concerned.

W.6.4. Payment to workers is documented accordingly.

W.7. Working hours

W.7.1. Normal working hours per day: The company/facility complies with applicable laws or regulations on working hours. 2. The normal working week (excluding overtime) for non-management workers does not exceed 48 hours on a regular basis (except in operations with rotation periods, e.g. one week on, one week off).

W.7.2. Workers are normally provided with at least one day off in every seven-day period (except in operations with rotation periods) and receive all public and annual holidays required by local law.

W.7.3. Overtime work for non-management workers is voluntary and is reimbursed at a premium rate and the total hours worked in a week shall not exceed 60 hours on a regular basis (except in operations with rotation periods).

W.8. Social benefits

W.8.1. Number of social benefits provided to the workers (e.g. health insurance, pension fund, child care, education, and accommodation).

W.8.2. Percentage of benefits which are only provided to full-time workers that are not provided to temporary or part-time workers.

W.8.3. Number of complaints and registrations of violation of obligations to workers under labour or social security laws and employment regulations.

W.9. Training and education

- **W.9.1.** Average hours of training to improve skills and capabilities per worker by gender by worker category compared with the average number of hours worked.
- **W.9.2.** Number of workers trained to ensure employability in the long term (e.g. managing career endings).

W.10. Job satisfaction and engagement

- **W.10.1.** Percentage of workers who have participated in worker surveys on worker satisfaction.
- **W.10.2.** Percentage of workers who claim in the surveys to be satisfied with their job according to a specified list of factors.

W.11. Employment and employment relationships

- **W.11.1.** All work is performed by women and men who are legally recognised as workers or who are legally recognised as being self-employed, e.g. no illegal work.
- **W.11.2.** The organisation meets all the responsibilities that the labour law places on employers and provides decent working conditions for their workers.
- **W.11.3.** Work is contracted or subcontracted only to organisations that are legally recognised, or are otherwise able and willing to assume the responsibilities of an employer and to provide decent working conditions.
- **W.11.4.** Home workers are not treated differently from other workers.

W.12. Work-life balance

- **W.12.1.** Average number of hours that the workers spend at work annually compared to the average number of working hours stipulated in the workers' contracts.
- **W.12.2.** Presence of an active dialogue with workers on how the organisation can contribute to a healthy work-life balance, e.g. by means of a worker satisfaction survey on work-life balance.
- **W.12.3.** Number of stress-related injuries in the company/facility. Table 17: Performance Indicators selected for the stakeholder group 'consumers'

8.2.2 C. Performance Indicators selected for the Stakeholder group 'Consumers'

C.1. Health and safety

- **C.1.1.** Percentage of products in compliance with regulations and voluntary codes concerning health and safety impacts of products and type of outcomes.
- **C.1.2.** Number of consumer complaints regarding impacts on health and safety
- **C.1.3.** Presence of management measures to assess consumer health and safety.
- **C.1.4.** Industry certification that assures healthy and safe use of the product (if applicable).
- **C.1.5.** Scientifically proven evidence of positive health status change associated with the use of the product under defined conditions, measured with defined markers of health.
- **C.1.6.** Scientifically proven evidence of increased safety/reduced risks of accidents associated with the use of the product under defined conditions.

C.2. Experienced well-being

C.2.1. Transparent, fact-based product information is available to help consumers and shoppers make informed product choices and to use to product correctly.

C.2.2. Perceived comfort related to the use of the product under defined conditions, proven by market research.

8.2.3 L. Performance Indicators selected for the Stakeholder group 'local communities'

L.1. Health and safety

L.1.1. Damage and risks of damage caused by the organisation on the living conditions of the community are identified.

L.1.2. A monitoring system is in place to track health and safety issues, and is evaluated and updated regularly.

L.1.3. Programme is in place targeting the improvement of health and safety in the community.

L.2. Access to tangible resources

L.2.1. Damage and risks of damage to the material resource of the community by the organisation are identified.

L.2.2. Competition and risk of competition by the company/facility with local public services are identified.

L.2.3. Improvement in the infrastructure by the organisation is identified, and it is a permanent benefit to be shared with the local community.

L.2.4. Number of involuntary land changes in the local community by the company/facility.

L.2.5. Amount of extraction of material resources by the company/facility.

L.3. Community engagement

L.3.1. Number of different community stakeholder groups that engage with the organisation.

L.3.2. Company/facility support (e.g. financial, time and expertise) for community activities.

L.3.3. Number of community development programmes implemented.

L.3.4. Number of training or meetings to engage with, inform or educate the community.

L.4. Local employment

L.4.1. Percentage of workforce hired locally.

L.4.2. Percentage of workers who already resided in the area of the major company locations before employment in management position (%).

L.4.3. Strength of policies on local hiring preferences.

L.4.4. Percentage of product components that are supplied by locally-based companies, i.e. % of local supplies.

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

COORDINATION & SUPPORT ACTION

GRANT AGREEMENT NO. 636727

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SAMT Deliverable 2.2 – Appendix 2

Water footprint case study

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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, organizing workshops and producing recommendations for further implementation of the best practices in sustainability assessment.

This report is presented as an Appendix to the main SAMT case study report (Deliverable 2.2). The aim of the water footprint (WF) case study was to test different indicators and impact assessment methods for calculating a comprehensive water footprint based on life cycle assessment, and complying with the requirements of the ISO14046 (2014) standard for water footprint. The case study represents a service water footprint of the wastewater treatment plant (WWTP).

Additionally, the aim of the case study was to learn about the methods, tools and databases currently available for water footprint assessment. Parallel to water footprint assessment, MIPS method was applied to consider other resource categories besides water, and to consider potential benefits and added-value from applying these different methods together.

Within the case study, WF was calculated for two scenarios that describe situation at the WWTP before and after modifications done on the treatment line. The aim of the modifications was to improve the economic and environmental performance of the treatment, and to better manage with the increased amounts of industrial effluents to be treated. The results of the case study are reported as a water footprint profile that includes water scarcity footprint and water degradation footprint. Specific impacts related to local river basin (except from the quality of treated and released water) are not considered within the assessment due to lack of specific local data. Thus a fully comprehensive water availability footprint was not included in the assessment.

The findings of the case study and the scenario analysis using different tools, impact categories and impact assessment methods showed that modifications of the WWT process line lead to decreasing environmental impacts in all evaluated impact categories except from eutrophication. However, in both scenarios COD emissions stay below the discharge standard. Although the evaluated impact categories applied within different softwares were not identical or directly comparable as such, they showed very similar results. Understanding of the differences between the characterization models is however required for correct interpretation of the results.

The results of the water footprint inventory and the single value water footprint highlight that compared to impacts from water degradation, water consumption is in a minor role in this case. While the case study has been focused on assessing water related impacts and resource use, the results reveal a clear connection between use of water and other resources. Improved energy efficiency and reduced chemical consumption lead to reduced water consumption and decreasing environmental impacts in most of the assessed impact categories related to water, but also in other assessed resource categories.

The strength of the life cycle based methods, such as water footprint, is the ability to point out also the indirect impacts within the value chain. In this case, water footprint assessment and related scenario analysis were capable to highlight changes in water related environmental impact categories due to process modifications, and also to indicate potential changes in indirect impacts along the value chain. 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. Use of MIPS extends the point of view from water to other resource categories, from which the findings are somewhat similar to the actual water assessment.

At the moment, the WF approach as defined in the ISO14046 can be considered as "best practice" for water footprint assessment. The findings of this case study indicate that overall, the requirements of the standard are comprehensive but as a consequence quite demanding. The comprehensiveness of the assessment increases the amount of information produced by the assessment and thus also the usability of the results, but also the amount of work required for the assessment. Clear benefit of the standard is the harmonization of terminology related to WF.

The amount of work required depend of the complexity of the case study and the value chain in question. 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. The results of the previous steps could be used as guidance when considering the need for next steps of the assessment (water availability).

A practical challenge is the incompatibility of the data files related to different impact assessment methods and databases. While the results of this case study showed that rather similar results could be achieved using different impact assessment methods and characterization factors, better transferability of the data files would be needed to make cooperation along the value chain and between different actors easier. Additionally, knowledge of the available characterization factors, or harmonized recommendations of the most potential ones for different kinds of cases would be needed.

In the context of the ISO standard, the WULCA recommendation for a consensus based water scarcity indicator is a good beginning towards a more harmonised approach. Consideration of the quality component of water availability would however be necessary in the future in order to capture the water use impacts in a more complete way.

Despite the fact that the water impacts modelled in water footprint assessments are local, the LCIA methodologies currently mainly offer generic characterisation factors that represent average conditions for a country or even a continent, and not accounting for the seasonal variations either. The ImpactWorld+, used in this study, is in its final testing phase, and is still a beta-version of the final product. In this impact assessment method, water use impacts are for the first time included in a comprehensive LCIA method, making this method (once finalized) a potentially interesting choice for WF assessments.

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. At the moment, Ecoinvent (v3) and the Quantis Water Database provide useful information for WF assessments. However, it is acknowledged that lack of relevant process data is still one of the main factors delimiting the scope and system boundaries of the assessments, also in this case study.

KEY WORDS:

WATER, WATER FOOTRINT; LIFE CYCLE ASSESSMENT, SUSTAINABILITY ASSESSMENT, RESOURCE USE

Contents

1 Introduction

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. This is done on a practical level by testing and comparing methods and tools currently applied by the industries, 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.

2 Aim of the case study

Water is an important natural resource, and water footprint (WF) assessment is a technique that has been developed for better understanding of water related impacts (ISO14046:2014). The aim of the water footprint case study is to test different indicators and impact assessment methods for calculating a comprehensive water footprint based on life cycle assessment, and complying with the requirements of the ISO14046 (2014) standard for water footprint. The standard should provide an assessment that could be applied in an internationally consistent manner. The outcome of the assessment can be used for improved water management. (ISO 14046:2014)

In addition to water footprint calculation, the aim of the case study is to learn about the methods, tools and databases currently available for water footprint assessment. The aim of the case study is to highlight current good practices and development needs especially when considering the applicability of water footprint to support decision-making. Parallel to water footprint assessment, another method based on life cycle assessment (LCA), namely MIPS (Material Input Per Service unit) 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.

In the case study, available and newly developed methods for calculating a water footprint profile are applied for assessing the water footprint of a service provided by an existing industrial wastewater treatment plant. The applicability of the methods is tested, and the transferability and consistency of the assessment under certain assumptions is evaluated. The case study contributes to the overall goals of the SAMT project by providing practical information and recommendations related to methods available for assessing impacts on water and availability of water resources (including both WF and MIPS), and considering the potential of the water footprint to support decision-making related to water management and sustainability.

3 Methods to be applied

3.1 Water footprint assessment

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 (http://waterfootprint.org/en/water-footprint/) 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).

The life-cycle approach has been reflected in the development of the global standard, ISO14046 Water footprint – Principles, requirements and guidelines. According to the standard, the water footprint assessment should be comprehensive, which means that all environmentally relevant attributes or aspects of natural environment, human health and resources related to water are considered within the assessment. The volumetric approach to water footprint thus represents only one of the aspects of water footprint assessment, according to ISO14046 approach. In case a comprehensive assessment has not been conducted, the term water footprint should be used with an informative qualifier (such as water scarcity footprint). Water footprint is a quantitative assessment that should be based on life cycle approach, and it can be conducted as a stand-alone assessment, or as a part of a life cycle assessment.

Water footprint assessment includes four phases that are identical with the phases of LCA according to ISO14040 (2006): 1) Goal and scope definition 2) Inventory analysis 3) Impact assessment 4) Interpretation.

Water footprint 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. Water scarcity footprint considers only impacts on water quantity, and it should be calculated utilizing characterization factors that account for local differences in water scarcity. Water scarcity footprint may also be a part of a more comprehensive water availability footprint, in which the level of temporal and geographical coverage and resolution for evaluating water availability shall be described. Water degradation footprint should include an assessment of the contribution of the product to potential environmental impacts related to water quality. (For a detailed description, see ISO14046:2014)

Although examples of potential impact categories to be included in different types of water footprints are given, specific methods or characterization factors[1] that should be used for the assessment are not defined within the standard.

Brief overview of the method to be applied:

- ***Essence:*** Water footprint is a quantitative assessment that should be based on life cycle approach. A recent ISO standard for WF assessment is available (ISO14046:2014), but so far only a few examples of water footprints for industrial products have been published (see e.g. Boulay et al. (2015) WF study for a laundry detergent). 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

[1] Characterization means converting the results from the inventory into a common unit thus permitting to aggregate them in the same impact category

standard. LCI databases are offering more and more information on water use, but there is still lack of specific regional data for comprehensive WF assessment. The complexity of the assessment depends on the comprehensiveness and level of detail included in the assessment. A water scarcity footprint is fairly simple compared to water availability footprint in which complexity ranges from medium to high. Scenarios are possible and often required for decision-making purposes.

- ***Scope:*** Water footprint can be used to assess both resource use and environmental impacts related to water. Results may be communicated considering potential impacts to human health and environment. WF can be calculated as part of a full life cycle assessment (in which case a more comprehensive picture of overall environmental impacts could be drawn), or as a stand-alone assessment. While water related impacts may have social and economic implications, economic and social impacts are typically outside water footprint assessment. Other methods (quantitative or qualitative) could be used with water footprint to increase the scope of the assessment towards economic and social aspects. WF can be applied to products, organizations or services in different parts of the value chain. Ideally, WF covers the whole life cycle but different parts of life cycle can be studied individually. WF can be applied to any sector.
- ***Relevance:*** Based on the interviews conducted with the industrial experts working in the SAMT project, water footprint 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 (Saurat et al. 2015).
- ***Requirements:*** WF can be calculated using standard LCA softwares but water specific LCI-data is required and might not be available in required detail in all databases. One of the challenges related to water footprint is the need of large amount of local level data. At the moment, there seems to be a lack of local or regional data for comprehensive water footprint assessment. Additionally, available methods or tools might not be readily applicable in all areas or industrial sectors.
- ***Outcomes:*** Depends of the goal and scope of the study. A comprehensive water footprint may include a water scarcity footprint, a water degradation footprint and water availability footprint. It can be communicated as a WF profile or as a single indicator. A non-comprehensive assessment should be presented with an informative qualifier. WF includes specific vocabulary that might not be easily communicated to non-experts.

3.2 MIPS

To extend the view from water towards resource use in general, MIPS (Material Input Per Service unit) method was applied to the case study, using the same inventory data as in the water footprint case. A brief description of the MIPS method is presented below:

- **Essence:** MIPS (= Material Footprint) can be considered as one of the sub-methods of the broader (in terms of indicators) LCA. It is an established method and delivers quantitative results. Like all life cycle methods, the complexity is medium to high, and trained personnel are required to implement MIPS. Support tools are publicly available and have been updated. MIPS is developed for status quo analysis, but can be used to produce scenarios.
- **Scope:** MIPS is an environmentally oriented life cycle method with focus on material efficiency. There are no predefined geographical boundaries in a MIPS model. MIPS can be used for

technical process optimization, management process optimization, supply chain optimization and life cycle wide optimization. MIPS covers all life cycle stages, but parts of the life cycle can be also analysed separately. There are examples of MIPS applications in most sectors, including process industries.

- **Relevance:** MIPS can be used for monitoring, reporting and decision making.
- **Requirements:** MIPS needs data from inside the company and suppliers (for each step in the process chain), alternatively environmental life cycle databases can be used. MIPS needs trained personnel whether in-house or through consultants, the critical phase of any life cycle study is data collection: collaboration from inside the company and suppliers is critical.
- **Outcomes:** In comparative MIPS studies, the outcome is a performance comparison of the considered products. Further assessments of hot spot analysis in the supply chain or whole life cycles are also possible.

Within the case study, resource consumption according to the MIPS concept (Schmidt Bleek at al. 1998, Ritthoff et al. 2003) was calculated. The five assessed resource categories encompass the following inputs in detail:

I. Abiotic raw materials, including

- mineral raw materials (used extraction of raw materials, such as ores, sand, gravel, slate, granite)
- fossil energy carriers (amongst others coal, petroleum oil, petroleum gas) unused extraction (overburden, gangue etc.)
- soil excavation (e.g. excavation of earth or sediment)

II. Biotic raw material, including

- plant biomass from cultivation
- biomass from uncultivated areas (plants, animals etc.)2

III. Earth movement in agriculture and silviculture, including

- mechanical earth movement or
- erosion

IV. Water, including

- surface water
- ground water
- deep ground water (subterranean)

V. Air, including

- combustion
- chemical transformation
- physical transformation (aggregate state).

[2] Domesticated animals are already part of the technosphere, and are therefore referred back to biomass taken directly from nature, e.g. plant or animal fodder.

4 Case description

4.1 Goal and scope of the study

The aim of the study is to make a water footprint and a MIPS assessment for a wastewater treatment plant (WWTP) that treats high organic load effluents from agri-food industry. The studied WWTP is located in France.

Wastewater treatment capacity of the plant is 250 m^3 per day. The treatment line is composed of several pre-treatments (neutralization, coagulation, flocculation) followed by a dissolved air flotation. Then wastewater is treated by biological treatment and tertiary flotation. The WWTP line assessed within the case study is presented in Figure 1.

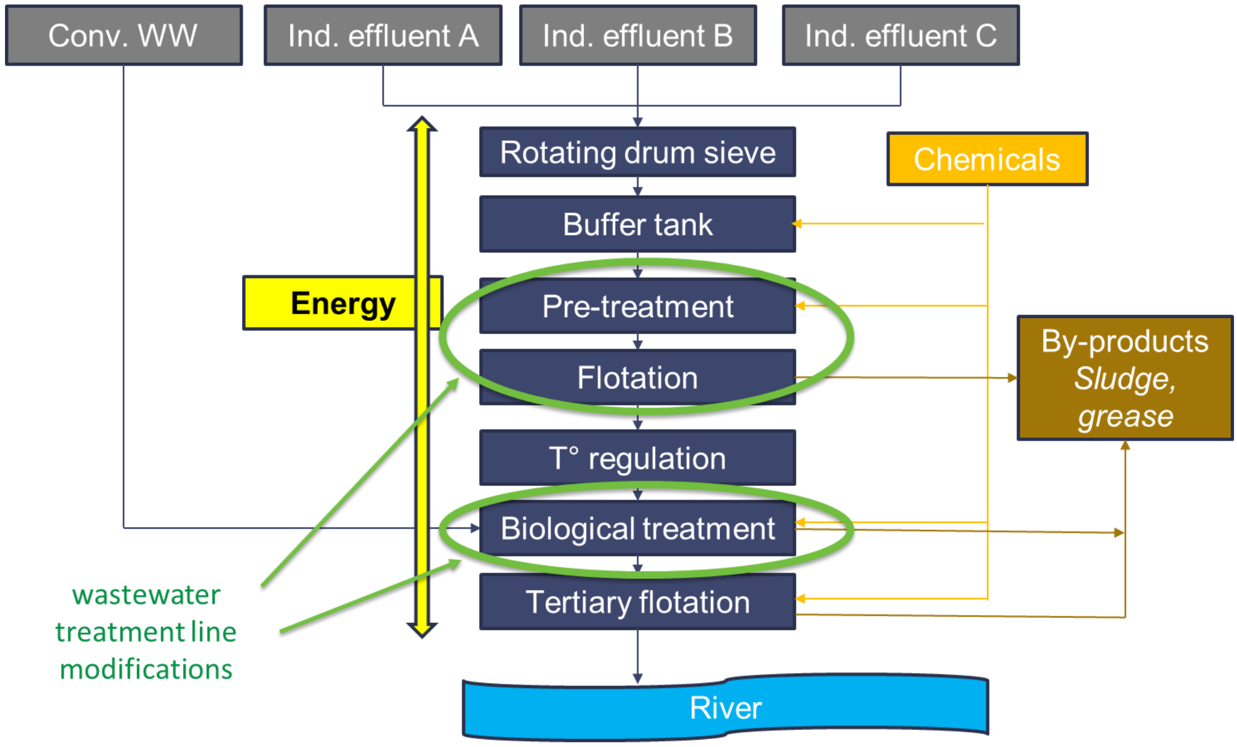

Figure 1 Waste water treatment line

The case study represents *a service water footprint of the wastewater treatment plant*. The WF inventory was conducted using a life cycle perspective considering direct and indirect activities associated with the WWTP, but not the original water intake by the industrial actors producing the industrial effluent treated at the plant.

The main goal of the case study is to test the water footprint assessment for the WWTP treatment plant by applying different available characterization factors for the impact assessment phase, and to consider potential challenges in conducting a comprehensive water footprint assessment according to ISO14046.

Within the case study, WF is calculated for two scenarios that describe situation at the WWTP before and after modifications done on the treatment line. The aim of the modifications was to improve the economic and environmental performance of the treatment, and to better manage with the increased amounts of industrial effluents to be treated. Thus one of the aims of the case study was to evaluate, how would the process changes be reflected in the water footprint, and if the WF assessment would bring additional value (or point of view) compared to other assessments and measurements conducted.

Other assessments applied earlier (independently of this case study) include calculation of the key performance indicators such as economic indicator OPEX (operational expenses), which was improved due to improved process energy efficiency.

The results of the case study are reported as a water footprint profile that includes water scarcity footprint and water degradation footprint. Specific impacts related to local river basin (except from the quality of treated and released water) such as potential impacts to stream flow or water withdrawal are not considered within the assessment due to lack of specific local data. Thus a fully comprehensive water availability footprint is not included in the assessment.

Functional unit used in the study is 1 kg eliminated COD (chemical oxygen demand). In general, functional unit should describe the quantified performance of a system aimed to be used as a reference in an LCA study. In this case, selected functional unit describes the service provided by the WWTP and so the associated performance of the plant.

4.2 System boundaries

Water source considered in the study is the agri-food plant from which the wastewater originates. Thus the water footprint is only calculated starting from the wastewater treatment facility, and not considering the original water intake of the agri-food plant. Additionally, a smaller amount of water originates from social water use at the plant.

After treatment, treated wastewater is released to the nearby river. By-products from the treatment are sludge and grease. Typically, by-products are transported to other sites in which sludge is composted and used as a soil enrichment product. Grease is typically used for biogas production in an anaerobic digestion. However, in this assessment, end-use of grease was excluded and sludge was landfilled due to lack of relevant data.

Transports of chemicals and by-products by a truck are included in the assessment. Applied energy production profile is the French grid electricity for all processes. Manufacturing of chemicals used at WWTP are included in the assessment (based on database data).

4.3 Scenarios

“Before and after modifications of the treatment line”

In the case study, two scenarios were assessed. The scenarios present the performance of the WWTP plant before (year 2014) and after (year 2015) process modifications done at the plant. Modifications were done at the pre-treatment, flotation and biological treatment processes (see Figure 1 above). The modifications were done due to the need to adapt the wastewater treatment line according to the evolution of industrial effluents (increase in organic load and volume, respect of regulation discharge). Additionally, there was a potential for improvement of the WWTP energy efficiency, measured using OPEX (operational expenses). Modifications done at the plant led to reductions in electricity use and chemical use (reagents).

The main differences between the scenarios 2014 (before) and 2015 (after) are presented in Table 1. Related modifications in the life cycle of the WWTP service are presented in Figure 2.

Table 1 Characteristics of the scenarios for 2014 and 2015

	2014 (Before)	**2015 (After)**
Functional unit	1 kg COD removed	1 kg COD removed
Energy consumption/FU	Reference case	-61%
Waste water quantity/FU		-11%
Total amount of reagents/FU		-48%
Incoming waste water quality		+70% organic load +40% grease
		(change compared to reference)

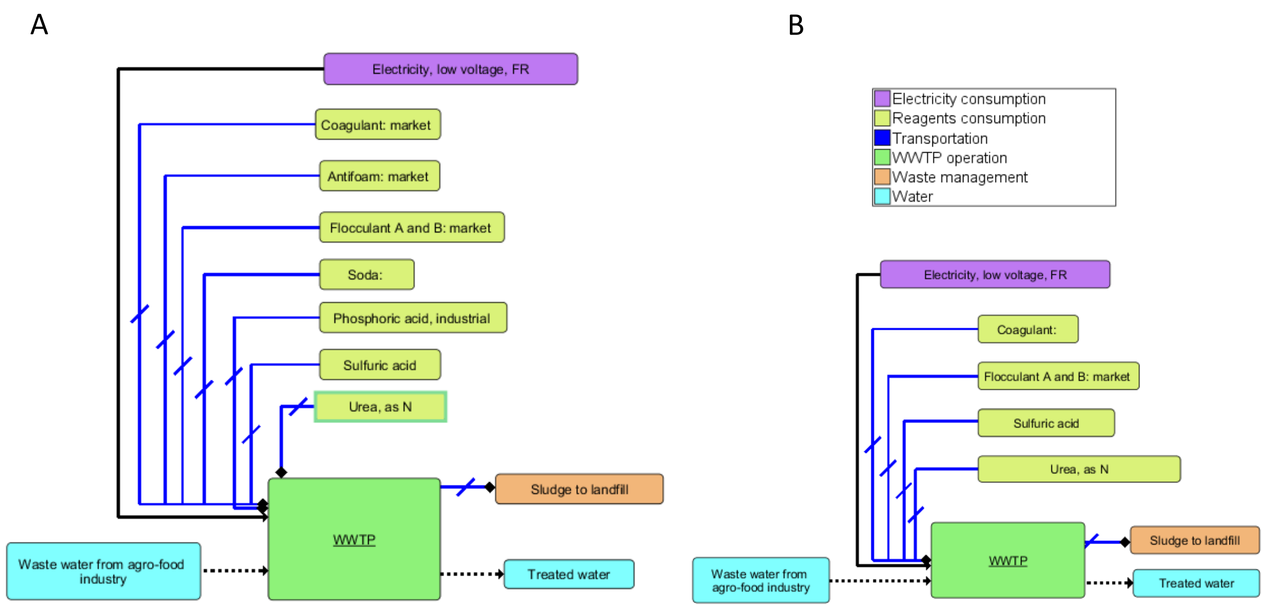

Figure 2. Before (A) and after (B) scenarios for the studied WWTP process, extracted from SULCA software.

"French and Spanish"

For the purpose of understanding the impact of geographical location on the water scarcity footprint, a second scenario, "French and Spanish" was assessed. In the Spanish case, it was assumed that the WWTP process is located in Spain, and that both the electricity and reagents used in the process are produced in Spain. The French case was then compared with the Spanish case. Applied country specific AWaRe scarcity factors are presented in table 2.

Table 2 Country specific AWaRe scarcity factors applied

France	Spain
2.315	31.49

4.4 Inventory data

A water footprint inventory includes compilation and quantification of inputs and outputs related to water to each process belonging to the studied system.

According to ISO14046, certain amount of data representing elementary flows[3] should be collected and presented within water footprint inventory. This includes for example information on water balances according to resource types of water used (where relevant). Within the WF standard, an elementary flow means water entering the system being studied that has been drawn from the environment, or water leaving the system being studied that is released into the environment. However, treated water (such as drinking water or industrial water) or waste water that is not directly released to the environment, but for example sent to the wastewater treatment plant, are not elementary flows but intermediate flows from a process within the technosphere.

In the new version of EcoInvent (v3), it is possible to establish water balance for the unit process, and thus define water consumption needed in the water footprint assessment. Physical water flows recorded in EcoInvent v3 include water output to air (evaporation), which was considered as consumed water. Quantis Water Database is another source for water inventory data that is available (Quantis 2012). It builds on existing water data from Ecoinvent 2.2, and provides a comprehensive water balance for over 4000 unit processes, including water inputs and outputs regionalised at country level, classified by source (e.g. surface water, shallow groundwater, etc.) and use (e.g. agricultural, cooling etc.).

Primary data: The water footprint assessment requires inventory data for the energy, material and effluent flows of the different scenarios. Available primary data for the WWTP scenarios (provided by the WWTP operator) included chemical and energy usage, by-products production, transports, and wastewater flux and quality before and after treatment. Primary data can be considered as good quality data describing the performance of the plant in question, based on on-site measured data.

Secondary data: No specific primary data were available for the background processes, i.e. process chemicals, transport, energy production and end-of-life treatment for sludge. Here, secondary data was sourced from Ecoinvent v2.2 (for Waterlily and MIPS) and Ecoinvent v3 (for SULCA) (Frischknecht et al., 2010, Steubing et al., 2016). No relevant data was available for the end-use of grease. Chemical data is generic data that might not reflect the manufacturing of the specific chemicals applied by the plant. Similarly, the electricity production profiles have been obtained from Ecoinvent and might not well represent the local grid emissions. Thus the results related to chemicals and electricity may be considered as indicative in nature.

All processes and the related data sources are listed in Table 3.

[3] In LCA terminology, an elementary flow means any material or energy input coming from the environment without prior human transformation

Table 3. Data sources and specifications.

Process	Data specification	Data source
WWTP process data, including energy and chemical consumption.	primary data	Measured monthly data was averaged to yearly data, taking into account potential seasonal changes.
Chemical manufacturing	secondary data	Ecoinvent v3 / v2.2
Energy production	secondary data	French and Spanish grid electricity (Ecoinvent v3 / v2.2)
End of life treatment of sludge	secondary data	Ecoinvent v3 / v2.2
Transport	secondary data	Conducted by a truck. Distances according to estimations based on primary data, emissions based on secondary data (Ecoinvent v3/v2.2)

4.5 Applied tools and methods

Within the case, two different tools were applied for the water footprint assessment using the same inventory results and data, but applying different impact assessment methods. SUEZ applied its own, in-house developed WATERLILY® tool, and VTT applied its own SULCA LCA software. Applied tools and methods are shortly described in the following paragraphs. Additionally, a MIPS assessment was conducted by using Open LCA software and an impact assessment method prepared by Wuppertal Institute for the calculation of MIPS (Saurat and Ritthoff 2013). The same inventory data was applied also for the MIPS assessment. A summary of all the methods and characterization models applied within the case study is presented at the end of the chapter, in table 6.

4.5.1 WATERLILY

The WATERLILY® tool was developed by SUEZ to calculate water footprint of the whole urban water cycle management including the drinking water and wastewater treatment plants as well as the drinking water distribution networks and sewer, based on the LCA approach. This assessment permits to integrate the environmental aspect along with technical and economic aspects in the definition of urban water cycle management strategy or the monitoring of the environmental performance along years.

The comprehensive water footprint profile is composed of several category indicators that may be evaluated at both midpoint and endpoint levels and further aggregated in a weighed single-score water footprint. Those indicators come from two recognised scientific calculation methods used in LCA methodology: ReciPe and UseTox. ReciPe is a very comprehensive method which characterizes all kind of data, and suggests 18 environmental impacts (midpoints), including 4 impacts focusing on water[4]. UseTox, with 3 environmental impacts (midpoints), is more centred about the chemicals effects on the human toxicity and the ecotoxicity. Category indicators (midpoints) and areas of protection (endpoints) and their associated characterization models are summarized in Table 4.

[4] In the midpoint level, emissions of substances and extractions of natural resources are converted into impact category results, such as eutrophication. In the endpoint level, the assessment of these impacts is focused on enpoint indicators 'damage to human health', 'damage to resource availability' and 'damage to ecosystems'.

Table 4 Indicators and associated characterization models used in the Waterlily tool

Type of indicator	Impact category (midpoint)	Characterisation model	Area of protection (endpoint)	Characterisation model
Consumptive water use	Water scarcity	Water scarcity index from Pfister et al. (2009)	Ecosystems	Water deprivation effect to ecosystems from Pfister et al. (2009)
			Human Health	Water deprivation effect to human health from Pfister et al. (2009)
			Resources	Water deprivation effect to resources from Pfister et al. (2009)
Water degradation	Freshwater eutrophication	ReCiPe (Goedkoop et al. 2009)	Ecosystems	ReCiPe (Goedkoop et al. 2009)
	Marine eutrophication	ReCiPe (Goedkoop et al. 2009)		ReCiPe (Goedkoop et al. 2009)
	Freshwater acidification	IMPACT 2002+ (Jolliet et al. 2003)		IMPACT 2002+ (Jolliet et al. 2003)
	Freshwater ecotoxicity	USEtox (Rosenbaum et al. 2008)		USEtox (Rosenbaum et al. 2008)
	Toxicity to Human	USEtox (Rosenbaum et al. 2008)	Human Health	USEtox (Rosenbaum et al. 2008)

Based on the indicators assessed, a weighed water footprint is calculated according to an adaptation of the Ridoutt and Pfister (2013) method by Penru et al. (2014), which permits the aggregation of the impacts of both consumptive and degradative water use into a single stand-alone indicator.

Concerning the application of the ReCiPe impact assessment method, the individual endpoint results are normalised with European factors and weighted using the Hierarchist cultural perspective (Ridoutt & Pfister 2013). This approach considers an equal weighting given to the current impacts on the area of protection "human health" and the current impacts on the area "ecosystems". It is important to note that the application of alternative weighting procedures could impact on the absolute results and potentially change the relative importance of water consumed and water degraded in their contribution to the water footprint.

The final result is expressed in litre of water equivalent (l H_2O-eq) as this is more meaningful for public communication. Conversion factors used to go from impact categories to weighed results are presented in Table 5. (Penru & al 2014).

Table 5 Conversion factors used to go from impact categories to weighed results in a single score water footprint

	Degradative water use	Consumptive water use
Aquatic eutrophication	53	-
Aquatic acidification	$2{,}5\times10^{-2}$	-
Freshwater ecotoxicity	$1{,}0\times10^{-2}$	-
Human toxicity	$9{,}2\times10^{7}$ (cancer) $2{,}2\times10^{7}$ (non-cancer)	-
Water scarcity	-	1,7

4.5.2 SULCA LCA software

SULCA is a transparent LCA-software suitable for calculating LCAs and water footprints of products, processes, technologies or any other systems. The commercially available software has been developed and is maintained by sustainability and ICT-specialists at VTT (www.simulationstore.com/sulca). The software allows performing water footprint inventory and impact assessment calculations either as a stand-alone assessment or as a part of more comprehensive LCA. Within SULCA, comprehensive water footprint profile can be composed of several category indicators that may be evaluated at both midpoint and endpoint levels using the available methods on consumptive and degradative water use. SULCA is compatible with several impact assessment methods that can be applied in parallel. The program does not include a database but can be applied together with the main LCI databases (such as Ecoinvent, Gabi and the Quantis water database).

The characterization models applied within the SULCA tool in this study included WULCA Aware for water scarcity and ImpactWorld+ for water degradation. The main principles of these methods are briefly presented below.

4.5.2.1 WULCA Aware

To date, no consensus-based approach has existed for applying the water footprint framework formalised in the ISO 14046 standard. Because of this, results have not been always comparable when different scarcity or stress indicators have been used for characterising the impacts (Boulay et al., 2016, submitted). WULCA working group (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.

AWARE method is to be used as a water use midpoint indicator for calculating water scarcity impact. The method is based on the quantification of the relative Available WAter REmaining per area once the demand of humans and aquatic ecosystems has been met. It assesses the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived (Boulay et al., 2016, submitted). The Aware indicator is limited to a range from 0.1 to 100, with a value of 1 corresponding to the world average, and a value of 10, for example, representing a region where there is 10 times less available water remaining per area than the world average.

4.5.2.2 ImpactWorld+

Most of the impacts modelled in LCIA are regional or local. Despite that, LCIA methodologies currently offer generic characterization factors (CFs) that represent average conditions for a specific area (country or continent) that do not account for the spatial variability of impacts. In response to the need of regionalised impact assessment, ImpactWorld+ was developed and is a joint major update to Impact2002+, EDIP, and LUCAS. (Bulle et al. 2014)

ImpactWorld+ was selected as one of the test methods in this study, because water use impacts are for the first time included in a comprehensive LCIA method with continent-specific factors and consistent spatialized alternatives. Water use impact category has developed characterization models for local and regional impact categories, each of them based on an appropriate spatial scale. Regionalized characterisation factors exist 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) (Bulle et al. 2014). In this case study, water use category was the only impact category where local characterisation factors were tested.

In ImpactWorld+, midpoint indicators have been further divided into midpoint subcategories: for example, the "human toxicity" category is composed of non-carcinogen, carcinogen, respiratory inorganics and ionizing radiation on human health, while eco-toxicity is further subdivided into freshwater eco-toxicity, marine eco-toxicity, terrestrial eco-toxicity, and ionizing radiation impacts on ecosystems.

During the project, in correspondence with the method developers (April 2016), it was found out that water use category in the ImpactWorld+ was being updated to the WULCA/AWaRe method. Hence the AWaRe method was used in water consumption impact category, while other impact categories related to water degradation and human toxicity were applied as presented in the current version of ImpactWorld+ method. The ImpactWorld+ midpoint and endpoint files can be downloaded from a website (www.impactworldplus.org), but it must be noted that these files are BETA version and in the final test phase.

4.5.3 A summary of the applied tools, impact assessment methods and categories

Table 6. Summary of methods, tools, indicators and applied midpoint methods.

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	ImpactWorld+, 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	

5 Results from the case study

5.1 Water inventory

Water inventory results of the product system before and after modifications are shown in Figure 3 and Figure 4, and in Table 7. The inventory was separated according to the amount of water withdrawal, discharge and consumption by the life cycle phases. Total amount of withdrawn water per functional unit is 3.6 m^3 before modification and 1.5 m^3 after modification. Water withdrawals are dominated by the electricity production for the use of the WWTP operations (95% before modification, and 91 % after), just as are the water discharges. Amount of consumed water (withdrawal minus discharge) per functional unit is 0.0037m^3/FU before modification and 0.0017 m^3/FU after modification.

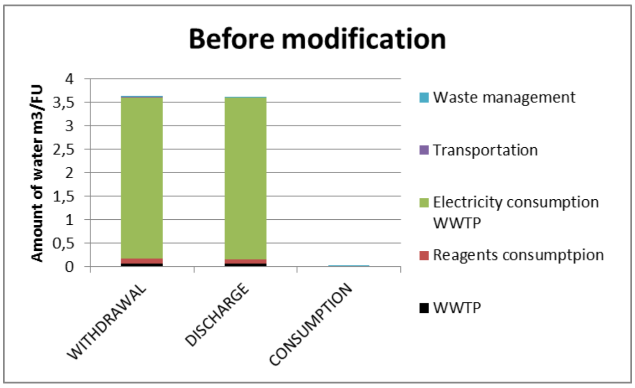

Figure 3 Water inventory results for before modification scenario

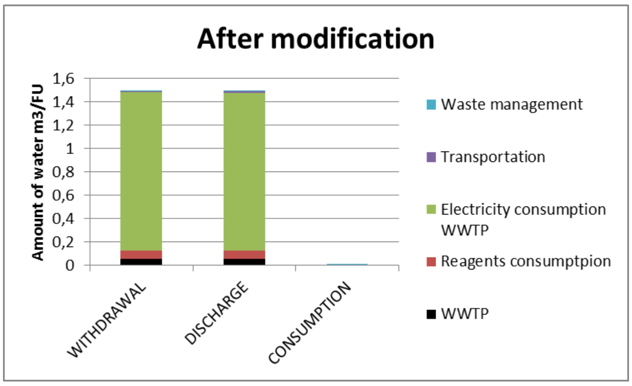

Figure 4. Water inventory results for after modification scenario

Within the studied system, water consumption is dominated by the electricity production (76% of the overall water consumption in the before modification scenario, and 65% in the after modification scenario, respectively). Reagents production is causing 23% of the overall water consumption (before modification), and 33% (after modification), respectively. The share of transport of the total water consumption is around 1-2%, and the share of waste management is less than 1%. As regards the WWTP operations, it is assumed that withdrawals equal the discharges, i.e. evaporation from ponds and water integrated to sludge are not taken into account.

Table 7. Water inventory results presented as relative shares per life cycle stage.

	BEFORE MODIFICATION			**AFTER MODIFICATION**		
	Withdrawal	**Discharge**	**Consumption**	**Withdrawal**	**Discharge**	**Consumption**
WWTP	1,6 %	1,6 %	0 %	3,5 %	3,5 %	0 %
Reagents consumption	2,9 %	2,9 %	23,1 %	4,8 %	4,8 %	32,8 %
Electricity consumption at WWTP	95 %	95 %	75,9 %	90,6 %	90,6 %	65,1 %
Transportation	0,3 %	0,3 %	0,9 %	0,7 %	0,7 %	1,8 %
Waste management	0,2 %	0,2 %	0,2 %	0,4 %	0,4 %	0,3 %

As discussed in section 4.4, the water footprint inventory should include the elementary flows of water and classification of water resources by type (precipitation, surface water, sea water, etc.). In the studied case, the water entering the system at the WWTP comes from the technosphere (agri-food plant), and the original water source is not known. For this reason in the water inventory, the input waters are not classified by source.

5.2 Water footprint profile of "before and after" scenarios

The water footprint profile (and a set of additional environmental indicators) of the service before and after modification, provided by the existing WWTP, was assessed with Waterlily tool and with commercial LCA software tool (SULCA). The tools differ in the methods chosen to be applied in the impact assessment, as presented in Table 6. Of the presented impact indicator results, water scarcity, eutrophication, aquatic acidification and aquatic eco-toxicity (long-term and short-term) are purely water related impacts and form the water footprint profile of the WWTP service. Results for additional environmental indicators such as terrestrial acidification and toxicity to humans (carcinogens and non-carcinogens) are provided for informative purposes.

The midpoint impact indicator results are presented below for Waterlily (Table 8) and for SULCA (Table 9). The results have been normalised by the "after" scenario values to provide possibility to compare the wastewater treatment scenarios, and to make the interpretation of the results easier.

Table 8. Normalized impact indicator results (Waterlily)

WATERLILY RESULTS					
Midpoint	**Water scarcity**	**Toxicity to human**	**Ecotoxicity**	**Eutrophication**	**Aquatic acidification**
Before modification	2,5	21	46	0,6	2,4
After modification	1	1	1	1	1

Table 9. Normalized impact indicator results (LCA-software SULCA).

SULCA RESULTS									
Mid point	**Water scarcity, AWARE**	**Eutrophication**	**Aquatic ecotoxicity, long-term**	**Aquatic ecotoxicity, short-term**	**Terrestrial acidification**	**Carcinogen, long-term**	**Carcinogen, short-term**	**Non-carcinogen, long-term**	**Non-carcinogen, short-term**
Before	3,6	0,4	4,1	13	3,7	2,7	3,1	2,7	19
After	1	1	1	1	1	1	1	1	1

The comparison of the normalised Waterlily and SULCA values (Figure 5) shows that the results are parallel with each other. The differences are caused by the different characterisation factor values used in the impact assessment methods, giving dissimilar emphasis on various elementary flows. Additionally, the assessed impact categories are not exactly the same.

During the course of this study it remained somewhat unclear how the different impact categories of the old and the new versions of Impact 2002+ and ImpactWorld+ compare with each other. As an example, Impact 2002+ contains "aquatic acidification", whereas this impact category is missing from the new version. Within SULCA tool, terrestrial acidification from ImpactWorld+ was applied instead, for illustrating potential impacts related to acidification. In addition, within Impact World+, midpoint indicators have been further divided into midpoint subcategories: for example, the "human toxicity" category is composed of non-carcinogen, carcinogen, respiratory inorganics and ionizing radiation on human health, while eco-toxicity is further subdivided into freshwater eco-toxicity, marine eco-toxicity, terrestrial eco-toxicity, and ionizing radiation impacts on ecosystems.

When considering water scarcity, in this case, the AWARE method reflects greater proportional benefit in the water scarcity indicator results compared with the results obtained with Waterlily, calculated using characterization models according to Pfister et al. (2009). This is due to the different approach in characterising the water consumption. The Pfister characterisation factor is based on the ratio of water withdrawal-to-availability (WTA), where the total water input into a product system is considered to contribute to local water scarcity. The AWARE characterisation factor on the other hand is based on the available water that is remaining per unit of surface relative to the world average, after the needs of the ecosystem water demand and human consumption have been met.

In the case study, the modifications in the treatment line lead to decreased need of reagents and electricity. Both tools show significant reduction of impact after the WWTP process modification in all impact categories but eutrophication (kg Phosphorous eq/FU). Highest reduction is seen in the eco-toxicity (short-term aquatic ecotoxicity in SULCA) and toxicity to humans (short-term non-carcinogens in SULCA) related impact categories and a medium reduction in the water scarcity. These impacts are mainly caused by reagents and electricity production. The reason for the increased eutrophication impact is that the load of phosphorus emitted in the treated wastewater increase with the hydraulic load despite it remains below the discharge standard. Similarly COD emissions increase after modification, but emissions stay well below the limits of the environmental permit. It must also be pointed out that the impact of improved nitrogen removal after modification is not reflected in the eutrophication results, because phosphorus is considered as a limiting nutrient in the watershed.

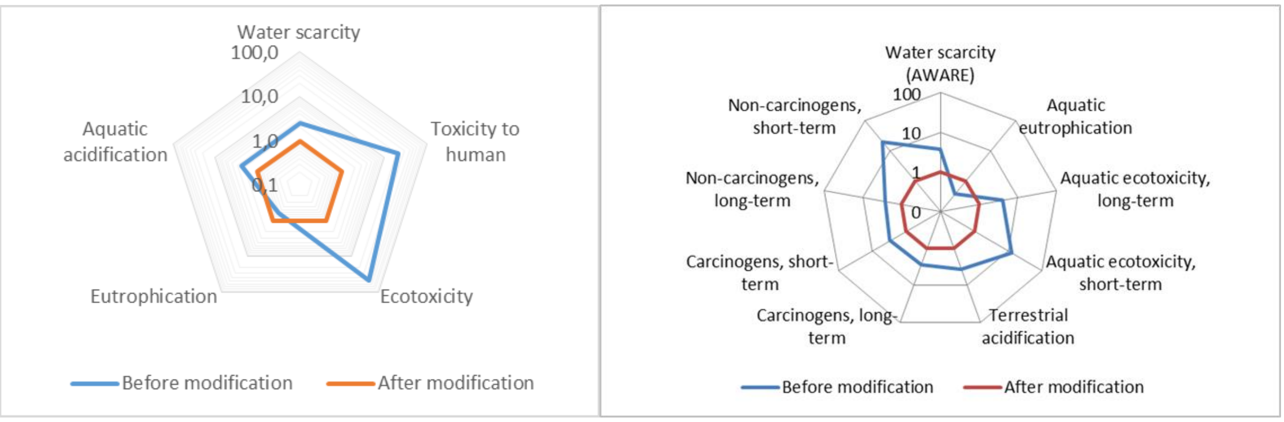

Figure 5. Spider diagram of the normalised midpoint impact indicator results for Waterlily tool (left), and for SULCA tool (right)

In Figure 6 results (extracted from SULCA) for selected impact categories are presented by life cycle stages. WWTP operation is the dominating contributor to aquatic eutrophication. In the case of aquatic ecotoxicity and terrestrial acidification, electricity production and reagents production are the biggest contributors.

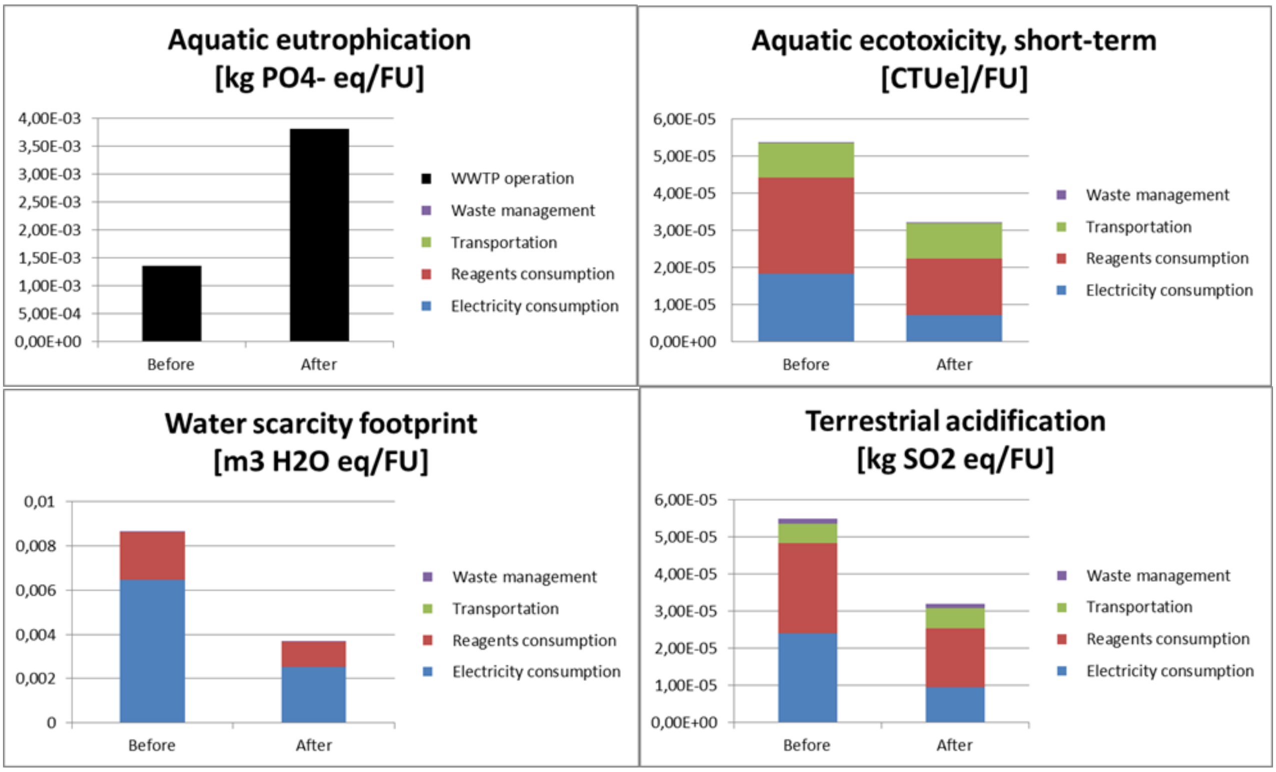

Figure 6. Impact assessment results for selected impact categories, extracted from SULCA.

In the water scarcity footprint assessment, energy production was identified as a major contributor to water consumption and impacts related to water use (see Figure 6). In order to identify and understand the impacts of energy production on the total water footprint in a more detailed level, the sensitivity of different energy production profiles could be analysed, and the specific data for the real local energy production profile should be identified[5].

Because the impact of energy production dominated so clearly, and because the purpose of this study was to test and compare the method itself, further sensitivity analyses for this specific case were not performed. The sensitivity of the regional effect was however tested by assuming the studied system to locate in Spain, which represents different water scarcity conditions. The analysis shows that the results increased by a factor of 10 in comparison with the original case study (see section French and Spanish scenarios in chapter 5.4).

The experiences from the case study highlight that finding the most relevant characterization models for different impact categories might not be straightforward, and testing available models would be preferential. Additionally, comparing the assumptions of different models might be challenging (See also the findings of from the integrated case study, reported in Appendix 1).

[5] According to the ISO14040 (2006), sensitivity analysis means systematic procedures for estimating the effects of the choices made regarding methods and data, on the outcome of the study.

5.3 Single-value weighted water footprint of "before and after" scenarios

The results above are reported as *water footprint profiles*, including indicators related both to water scarcity and water degradation. To obtain *a single-value water footprint*, (see chapter 4.5.1 and table 5), the Waterlily indicator results were aggregated into degradation water footprint and consumption water footprint results, and summed up, as reported in Table 10.

Table 10. Results of single-value weighted water footprint, expressed in litre of water equivalent (l H20-eq) per functional unit.

	L H_2O-eq/kg COD eliminated	L H_2O-eq/kg COD eliminated	L H_2O-eq/kg COD eliminated
Water Footprint	**Water footprint**	**Degradation Water Footprint**	**Consumption Water Footprint**
Before modification	**190**	188	1,7
After modification	**24**	23	0,7
Normalised values			
Before modification	**100**	99,1	0,9
After modification	**13**	12,3	0,4

The results show that the water degradation is the main contributor (99% of the impact in "before modification" situation, and 95% in "after modification", respectively) to the total water footprint caused by the service provided by the WWTP (Figure 7). It is important to note that the application of alternative weighting procedures could potentially change the relative importance of water consumed and water degraded in their contribution to the water footprint.

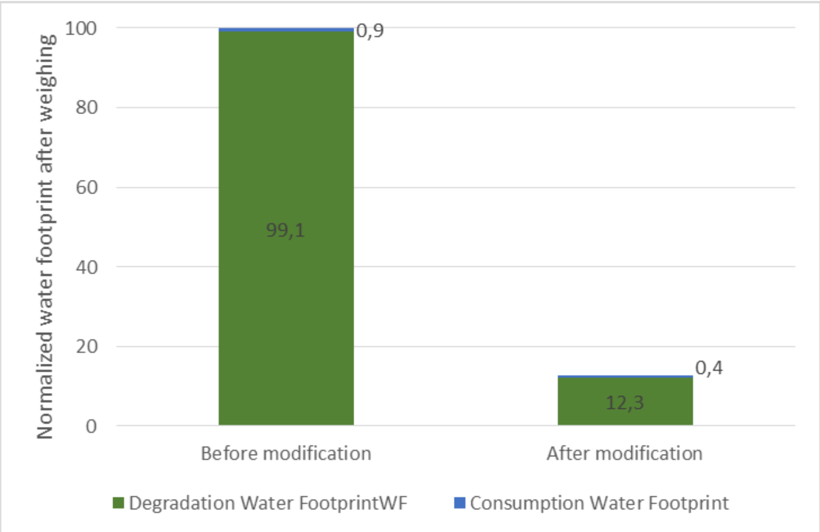

Figure 7. Normalized water footprint after weighing.

5.4 Water scarcity footprint of "French and Spanish" scenarios

When comparing the French and the Spanish scenarios, the results show that the water scarcity footprint of the service provided by WWTP depends greatly on its geographical location, more specifically the local water scarcity index defined for the specific region. The AWaRe factor (country average) for Spain is more than 13 times higher than the factor for France, and the results, presented in Figure 8, reflect this difference, too. In both French and Spanish cases, the greatest share (75 % and 71 % for "before" and 69 % and 70 % for "after", respectively) of water scarcity impact is caused by the electricity use at the WWTP. Rest of the impact is a result of the reagent production. Waste management (treatment of sludge) and transports of the reagents do not show significant impacts.

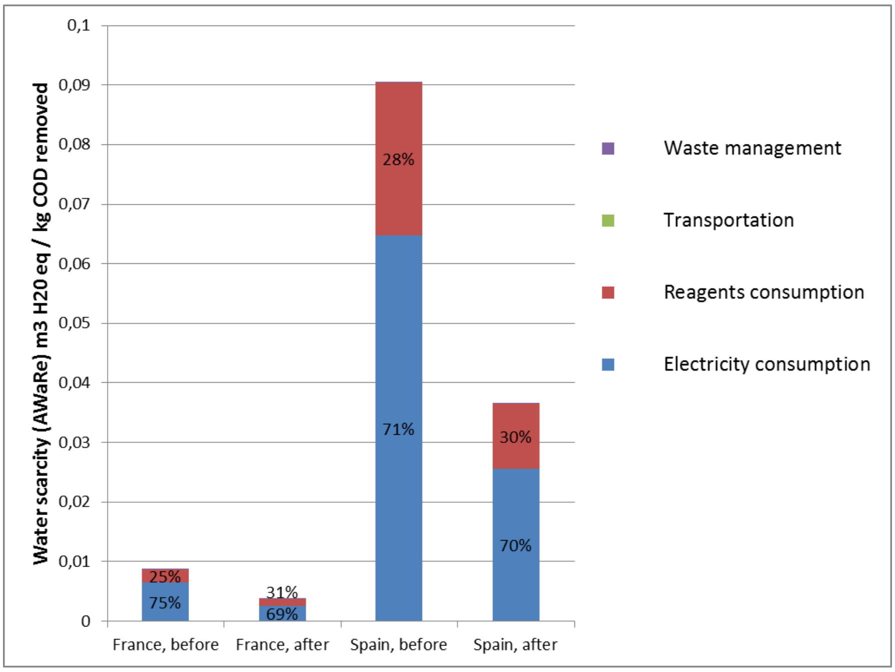

Figure 8.Comparison of the water scarcity footprint of the French and the Spanish cases

5.5 MIPS results

In addition to the water footprint assessment, impacts of the changes in the waste water treatment line were assessed using the MIPS methods, calculated based on the same inventory data and assumptions. The calculation has been prepared with OpenLCA 1.4.2 software using Ecoinvent 2.2 database and an impact assessment method prepared by Wuppertal Institute for the calculation of MIPS (Saurat and Ritthoff 2013). Additionally, data for one flocculant (one of the reagents) has been calculated on the basis of Ecoinvent 3.

The main results are presented in the following Table 11. Material Intensity of the WWT service and Figure 9.

Table 11. Material Intensity of the WWT service in Before (2014) and After (2015) scenarios

	2014 [kg/kg COD eliminated]	2015 [kg/kg COD eliminated]
Abiotic raw material	0.4771	0.2478
Biotic raw material	0.0039	0.0016
Erosion	N/A	N/A
TMR (∑ abiotic, biotic and erosion)	0.4810	0.2494
Water	8.91	3.71
Air	0.0787	0.0266

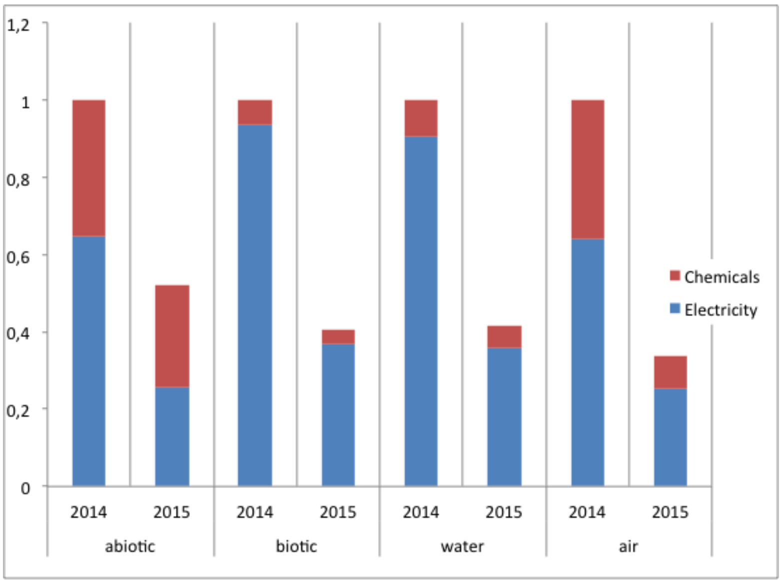

Figure 9. Relative material intensity for the waste water treatment plant in comparison

The changes in the process of wastewater treatment result in a clear reduction of material intensity in all categories. The reductions per functional unit (kg COD eliminated) range from 49 % for abiotic raw materials to 67 % for air consumption. Reductions are induced by savings of chemicals and transport as well as savings of electricity consumption.

Compared to the water footprint assessment, the results from the MIPS assessment indicate similar findings. Similarly to the water scarcity footprint results, electricity production seems to dominate the use of water resources. However, in the category abiotic resources, the impact of chemicals becomes almost as significant, especially in the after (2015) scenario.

5.6 Interpretation

The case study included a service water footprint of the wastewater treatment plant. The main goal of the case study was to test the water footprint assessment for the WWTP treatment plant by applying different available characterization factors for the impact assessment phase, and to consider potential challenges in conducting a comprehensive water footprint assessment according to ISO14046.

A water footprint was calculated for two scenarios that described situation at the WWTP before and after modifications done on the treatment line. One of the aims of the case study was to evaluate, how would the process changes be reflected in the water footprint, and if the WF assessment would bring additional value compared to other assessments and measurements conducted.

The findings of the case study and the scenario analysis using different tools, impact categories and impact assessment methods are quite clear. The modifications of the WWT process line lead to decreasing environmental impacts in all evaluated impact categories except from eutrophication, where a small increase in COD emissions occurs. While the WWT operation is the source of the eutrophication impact, electricity and reagents consumption are the main contributors to the other evaluated impact categories. Although the evaluated impact categories applied within the SULCA and the Waterlily tool are not identical or directly comparable as such, they show very similar results. However, the differences within the water scarcity results between the different characterization models might have an impact on the overall interpretation of the results. In this case, the AWaRe method reflects greater proportional benefit in the water scarcity indicator results between the before and after scenarios, compared to the Pfister et al. (2009) method, which was applied in the Waterlily tool.

The results of the water footprint inventory and the single value water footprint highlight that compared to impacts from water degradation, water consumption is in a minor role in this case. When considering the impacts of different life cycle stages, electricity consumption is the biggest contributor, followed by reagent consumption, in both water consumption and water degradation (except for the eutrophication impact).

The findings from the MIPS assessment related to resource intensity indicate very similar findings. Reduced energy consumption and reagent consumption in the After modifications (2015) scenario lead to resource savings in all evaluated resource categories. Also according to MIPS, electricity consumption and reagent consumption are major contributors in all resource use categories. Regarding water scarcity footprint, the comparison of the French and Spanish scenarios highlights the importance of taking into account local conditions: higher water scarcity index for Spain compared to France causes a significant increase in the results.

While the case study has been focused on assessing water related impacts and resource use, the results reveal a clear connection between use of water and other resources. Improved energy efficiency and reduced chemical consumption lead to reduced water consumption and decreasing environmental impacts in most of the assessed impact categories related to water, but also in other assessed resource categories. Thus it can be said that in this case, water footprint assessment and related scenario analysis were capable to highlight changes in water related environmental impact categories due to process modifications, and also to indicate potential changes in indirect impacts along the value chain. In areas with high water scarcity index, indicating these indirect impacts would become even more important. On the other hand, it is important to note that the locations of these impacts are different: the indirect impacts due to electricity and chemical production most likely occur in different geographical locations, and not within the site where the WWTP is located.

In the case study, water scarcity and water degradation footprints were assessed according to the guidelines of the ISO14046. The water availability footprint, as defined in the standard, was not included in the study, due to lack of relevant local data. To consider the potential significance of the COD emissions that show a slight increase in the 2015 scenario, water availability footprint would be an interesting next step in the analysis.

6 Conclusions and lessons learnt

6.1 Applicability and potential benefits and challenges related to the WF assessment

According to ISO 14046, water footprint assessment has been developed for better understanding of water related impacts. The outcome of the assessment should be used for improved water management. In addition to water footprint calculation, the aim of the case study was to learn about the methods, tools and databases currently available for water footprint assessment, and to highlight current good practices and development needs especially when considering the applicability of water footprint to support decision-making. When considering the potential added value that the water footprint assessment could bring for decision-making, the following conclusions can be made based on the assessed case study.

Compared to standard key performance indicators (KPI's), the strength of the life cycle based methods, such as water footprint, is the ability to point out also the indirect impacts within the value chain. In this case, many of the evaluated impacts were related to electricity consumption and reagents consumption. 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. In this case, the improvements in energy efficiency led to overall reduced water use in the value chain. Within the case study, this would be important especially in the Spanish scenario. These are aspects that might not be covered without specific water footprint assessment. As a consequence, when good quality data of the main processes is available, water footprint could even be used as a KPI, alongside the traditional economic ones, to include assessment of water related impacts in decision-making.

The assessment also pointed out an increase of COD emission, which in both scenarios stays below the discharge standard, but which might not be visible in case only the standard KPI's would be evaluated. On the other hand, the increasing COD emissions would be visible using standard LCA (without specific water footprint assessment), as eutrophication is commonly assessed as part of LCA, or in a basic input-output analysis of the plant data, since in this case, the impact was due to the operation of the plant.

Use of MIPS extends the point of view from water to other resource categories, from which the findings are somewhat similar to the actual water assessment. The MIPS assessment also clearly points out the significance of energy and reagent consumption in all assessed resource categories. Thus it can be said that both water footprint and MIPS can provide additional viewpoints to standard LCA results. On the other hand, a MIPS study or a water footprint study as stand-alone assessments (or together) are capable of bringing added value for decision-making, and especially for evaluating and communicating the impacts of process modifications in the case study.

Regarding the applicability of the new ISO14046 approach for water footprint assessment, and the available methods, tools and data demands, several remarks can be made based on the experiences gained during the case study.

At the moment, the WF approach as defined in the ISO14046 can be considered as "best practice" for water footprint assessment. However, as not many practical case studies applying the standard have been published yet, and some of the required impact assessment methods are still in development, the applicability and implementability of the standard in practice is still a bit uncertain. Overall, the conclusions of this study are in line with the findings of Boulay et al. (2015) in their laundry detergent water footprint case study. In their paper, Boulay et al. (2015) conclude that based on current information, ISO standard can already be applied to industrial products, creating water footprint profiles and identifying hotspots, although the results include uncertainty, and more work is still required both at inventory and impact assessment level for improving the robustness and confidence in the results.

The findings of this case study indicate that the requirements of the standard are comprehensive but as a consequence quite demanding. The comprehensiveness of the assessment increases the amount of information produced by the assessment and thus also the usability of the results, but also the amount of work required for the assessment. Clear benefits of the standard is the harmonization of terminology related to WF, as previously, many different types of assessments have been titled as water footprints. On the other hand, the standard includes a lot of new terminology to be added in the LCA dictionary. This might not be easy to communicate to non-experts, and requires attention from experts conducting the assessments. Additionally, the standard should harmonize approaches and presentation of results, by providing general guidelines for different type of water footprints.

Like the LCA standard (ISO 14044), the water footprint standard (ISO 14046) does not specify impact assessment methods or characterization models to be used, so it leaves a lot of room for method selection & case specific choices. As a consequence, finding the correct and most suitable method for each case might be challenging. This is an important point, as selection of appropriate impact categories relevant for the case study is very important for gaining meaningful results. The forthcoming ISO water footprint technical report (ISO TR14073, not yet published) with practical examples hopefully provides some assistance here. Along the water footprint standard construction, the last 10 years have been a reach for water specific impact assessment method development, in particular for impact related to water consumption. This development is still on-going as there is a willingness to have more and more regionalised characterization factors. As a consequence, good practice for the moment could be applying and testing different characterization models within the assessment. As such, adding 1-2 more characterization factors to a comprehensive water footprint assessment does not add too much work but might help understanding the impact of the assumptions and data used within different models.

The amount of work required (and the related costs occurred) depend of the complexity of the case study and the value chain in question. 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 many cases mean a lot of additional data collection and analysis. On the other hand, the results of the previous steps may be used as guidance when considering the need for this next step of the assessment.

To conclude, the added value provided by these assessments depends of the goal and scope and intended use of the assessment. In cases where water issues are considered as a strategic issue or important for the overall environmental performance (especially in areas with known scarcity or challenges in water availability in general), water footprint is a useful method providing different types of information related to water consumption, degradation and availability.

At the beginning, having WF information in a useful format most likely requires some work, and conducting several kinds of assessments, for finding the most essential messages, impact categories and characterization models. Although the databases are useful for indicating hotspots, availability of good quality primary data concerning key processes is essential, especially if the results are used for decision-making or research and development purposes (See Saurat et al. 2015). After appropriate impact categories and characterization factors have been implemented in LCA tools, applicability of the WF assessment is greatly improved.

It is important to note that in this case, the results of the assessment are quite clear, and the assessed value chain was not very long or complicated. With a more complicated value chain, the interpretation of the results would most likely become more difficult. Additionally, including different water resource types in the assessment (as recommended in the standard) could increase the complexity of the assessment to some extent, and would add additional demands related to communication of the results.

6.2 Identified specific challenges and needs related to available and applied methods and data

As the newly developed methods and updates to databases are emerging, a practical challenge is the incompatibility of the data files related to different impact assessment methods and databases. In case an assessment is conducted as cooperation with different actors along the value chain, extra effort is most likely required to find or to modify the files so that they would fit with the programs used by different actors. While the results of this case study showed that rather similar results could be achieved using different impact assessment methods and characterization factors, although some differences were indicated as well. In general, better transferability of the data files would be needed to make cooperation between different actors easier. Additionally, knowledge of the available characterization factors, or harmonized recommendations of the most potential ones for different kinds of cases would be needed.

In the context of the ISO standard, the WULCA recommendation for a consensus based water scarcity indicator is a good beginning towards a more harmonised approach. Consideration of the quality component of water availability would however be necessary in the future in order to capture the water use impacts in a more complete way.

Despite the fact that the water impacts modelled in water footprint assessments are local, the LCIA methodologies currently mainly offer generic characterisation factors that represent average conditions for a country or even a continent, and not accounting for the seasonal variations either. For water scarcity, there has been a lot of work done recently, and characterisation factors even at watershed level have been made available.

The IMPACT World+, used in the SULCA calculations in this study, is in its final testing phase, and is still a beta-version of the final product. It is an update to IMPACT 2002+ method that was applied in the Waterlily acidification impact category calculations. The project group is anxious to see the final version of this impact assessment method, because water use impacts are for the first time included in a comprehensive LCIA method and because regionalized characterisation factors exist e.g. for human and ecosystem toxic impacts, water use, acidification, and eutrophication.

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. In the earlier versions of Ecoinvent (v2.2), water data has been partially available: data has included water withdrawal, but the output exchanges have not been available. 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. Physical water flows recorded in ecoinvent v3 include: water inputs from sea, surface water, and groundwater and from air (precipitation); water outputs to sea, surface water and to air (evaporation). 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. Rationality does not however go beyond country level. Another useful data source is the Quantis Water Database. However, it is acknowledged that lack of relevant process data is still one of the main factors delimiting the scope and system boundaries of the assessments, also in this case study.

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

COORDINATION & SUPPORT ACTION

GRANT AGREEMENT NO. 636727

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SAMT Deliverable 2.2 – Appendix 3

Simulation methods

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Introduction

This Appendix provides a number of materials used as an input to implement the simulation methods. It has been subdivided in a number of sub-sections, as described below:

Section 1 provides a checklist including a number of questions designed to collect feedback on the relative relevance that partners assign to the different dimensions considered in the SAMT project, as reported by the SAMT D1.1 (Saurat et al., 2015b). The questionnaire that is presented in Section 1 has been answered by each industrial partner participating in the SAMT project.

Section 2 provides a template whose purpose has been to help characterise the different methods applied within the SAMT case studies across a number of relevant dimensions. For the sake of coherence, these dimensions are those previously introduced by Deliverable D.1.1 of the SAMT Project (Saurat et al., 2015b). This template shows what methods can do (in general). It has been filled by the RTOs for the three methods tested at the simulation level.

Section 3 builds on these characterisation criteria to provide insights into the practical implementation of methods within companies. Each of the criteria included in previous characterisation have been tested by means of a detailed questionnaire presented as a check-list in this Section. This check-list has been filled by Hydro, Neste and CEMEX for the LCAA, E-LCA and CF methods, respectively.

The combined application of the latter two templates within a realistic industrial scenario enabled incremental learning within the SAMT case studies. Whereas the first template provided an overview of the different methods, mainly useful for comparison, the second template provided a consistent platform for method testing. Synergies were sought and made operational through a one-to-one correspondence between the two templates.

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1. Relevance information

This Section provides a template that has been designed to compare the relevance that the dimensions connected to the implementation of sustainability assessment methods have for the companies participating in the project within their standard sustainability practice. The template has been filled by each industrial partner participating in the SAMT project.

If you had to decide on a sustainability assessment method to be applied within your companies, please rank the following characteristics from 1 (less important) to 5 (more important).

Low importance	Av.-low importance	Average importance	Av.-high importance	High importance	Decision criteria	Description/motivation/comments/references
Essence						
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Core idea: focus of the method; sustainability target*	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Status: degree of maturity of the method*	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Type of method (qualitative vs quantitative outputs)*	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Complexity of implementation*	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Availability and accessibility to support tools*	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Updating: continuity of development*	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Dynamics: possibility to produce scenarios*	
Scope						
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Number of sustainability aspects included (environment, economy, social issues)*	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Possibility to consider energy efficiency aspects*	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Possibility to consider material efficiency aspects*	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Economic scope*[1]	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Geographical scope*	

[1] Product, production site, company, branch, etc.

☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Application field along the supply chain*[2]	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Number of life cycle stages covered*	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Number of sectors that can be covered*	
Relevance						
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Relevance for decision making within your company*[3]	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Relevance for business decision* [4]	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Sectors inside the company*	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Disclosure*[5]	
Requirements[6]						
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Information systems needed*	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Input data needed*	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Competences / skills needed*	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Specific organisation structures needed*[7]	
Outcomes						
☐ 1	☐ 2	☐ 3	4	☐ 5	*Number and quality of outputs*	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Output formats: usability of outputs for communication purposes*	
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	*Usability of outputs for eco-labelling and certification of products*	

[2] Technical process optimization, management process optimization, supply chain optimization, life cycle wide optimization, ex-ante technology impact assessment, etc.

[3] Support management and investment decisions, support long-term process development inside a company, monitoring and reporting of sustainability performance, etc.

[4] Controlling, top-management, R&D, marketing, supply chain management, certification, product specification standards, communication, etc.

[5] Usable for complying with established sustainability benchmarks or frameworks such as e.g. GRI, CDP, DJSI.

[6] In this dimension you should think in terms of how the specific requirements of a given sustainability assessment method would refrain you or your company from implementing it. High scores (5 to 3) should be given to those criteria representing higher obstacles for selecting a method. Low scores should be given to those criteria that represent minor obstacles. For example, if the need of sophisticated skills would totally refrain your company from implementing a sustainable assessment method you should assign a 5 score to that specific criterion.

[7] This criterion refers to the degree to which the method could only be suitable for large companies or even companies with simpler organization structures could apply it. If for your company the absence of key organization structures could be a factor preventing the method from being implemented, this criterion should be scored 5.

2. Template for an in-depth characterisation of the simulation methods

This Section includes a template that has been designed to describe each sustainability assessment method across a number of relevant dimensions identified on previous steps of the SAMT project implementation. The template has been filled-in by the RTOs for the three simulation methods to be tested as part of the three case studies (namely, E-LCA, CF and LCAA). The filled document has been provided to the industrial partners participating in the project as an input for completing the questionnaire on these methods that is included in Section 3.

2.1.1 Basic information

2.1.1.1 Personal details

	Please, provide the following information
Name of the person(s) providing the information	…
Affiliation	…
Contact details	…
Date	…

2.1.1.2 Method being characterised

☐	CF
☐	MIPS
☐	E-LCA
☐	LCAA

2.1.1.3 Additional info on the method

	Please, provide the following information
Papers	…
Books, reports, thesis…	…
Webs	…

2.1.2 Essence

2.1.2.1 Core idea

General overview of the method
General description, goals, motivation, context, history, background information, etc.

2.1.2.2 Status

	Options	Description/motivation/comments/references
☐	*Established*	
☐	*Available*	
☐	*Under development*	

2.1.2.3 Type of method (outcome)

	Options	Description/motivation/comments/references
☐	*Quantitative*	
☐	*Semi-quantitative*	
☐	*Qualitative*	

2.1.2.4 Complexity

	Options (in comparison to a standard LCA)	Description/motivation/comments/references
☐	*Low*	
☐	*Medium*	
☐	*High*	

2.1.2.5 Access & costs of the support tools

	Options	Description/motivation/comments/references
☐	*Proprietary*	
☐	*Open source*	
☐	*High*	

2.1.2.6 Updating

	Options	Description/motivation/comments/references
☐	*On-going*	
☐	*Discontinued*	Please indicate the year when the method was interrupted

2.1.2.7 Replicability

	Options	Description/motivation/comments/references
☐	*Feasible if all analytical processes (e.g. setting boundaries, data compilation, aggregation, weighting and normalisation) are reported transparently,*	

	which could be done with ease	
☐	*Possible if all analytical processes (e.g. setting boundaries, data compilation, aggregation, weighting and normalisation) are reported transparently. However, this condition is difficult to satisfy in practice*	
☐	*Unlikely, even if all analytical processes (e.g. setting boundaries, data compilation, aggregation, weighting and normalisation) are reported transparently*	

2.1.2.8 Dynamics

	Options	**Description/motivation/comments/references**
☐	*Fully dynamic (systems are dynamically modelled)*	
☐	*Partially dynamic (some level of parameterisation is possible: what-if scenarios)*	
☐	*Static (scenarios cannot be built besides considering)*	

2.1.3 Scope

2.1.3.1 Sustainability aspects

	Options	**Description/motivation/comments/references**
☐	*Environmental*	
☐	*Social*	
☐	*Economic*	

2.1.3.2 Energy efficiency aspects

	Options	**Description/motivation/comments/references**
☐	*Directly: A direct measure of energy efficiency is provided by the method*	
☐	*Fully: All energy inputs are considered*	

☐	*Indirectly: Energy efficiency is not directly assessed by the method, but it can be estimated with the information provided by its implementation*	
☐	*Partially: Only a fraction of the energy inputs are considered in the assessment (only some energy sources or sectors are considered)*	
☐	*None: no information on energy efficiency is provided by the method*	

2.1.3.3 Material efficiency aspects

	Options	**Description/motivation/comments/references**
☐	*Directly: A direct measure of material efficiency is provided by the method*	
☐	*Fully: All material inputs are considered*	
☐	*Indirectly: Material efficiency is not directly assessed by the method, but it can be estimated with the information provided by its implementation*	
☐	*Partially: Only a fraction of the material inputs are considered in the assessment (only some materials or sectors are considered)*	
☐	*None: no information on material efficiency is provided by the method*	

2.1.3.4 Economic scope

	Options	**Description/motivation/comments/references**
☐	*Product*	
☐	*Component*	
☐	*Process*	
☐	*Technology*	
☐	*Production site*	
☐	*Company*	
☐	*Sector*	
☐	*Territory*	

☐	*Global systems*	
☐	*Non-applicable*	

2.1.3.5 Geographical scope

	Options	**Description/motivation/comments/references**
☐	*Sub-national*	
☐	*National*	
☐	*International*	
☐	*Non-applicable*	

2.1.3.6 Application field along the supply chain

	Options	**Description/motivation/comments/references**
☐	*Technical process optimisation*	
☐	*Management process optimisation*	
☐	*Supply chain optimisation*	
☐	*Life cycle wide optimisation*	
☐	*Ex-ante technology impact assessment*	
☐	*Other*	Please specify

2.1.3.7 Life Cycle stages

	Typical stages	**Description/motivation/comments/references**
☐	*Cradle to grave (i.e. from resource extraction to use phase and disposal phase)*	
☐	*Cradle to gate (i.e. the use phase and disposal phase are omitted)*	
☐	*Cradle-to-cradle (e.g. avoided burden method)*	
☐	*Gate-to-gate (e.g. looking at only one value-added process in the entire*	

	production chain)	
☐	*Other*	Please specify

2.1.3.8 Sectors

Sectors	Yes	No	Description/motivation/comments/references
All	☐	☐	
Process industry in general, of which:	☐	☐	
Chemical	☐	☐	
Cement	☐	☐	
Oil	☐	☐	
Metal	☐	☐	
Water	☐	☐	
Waste	☐	☐	
Mining and oil extraction	☐	☐	
Farming and forestry	☐	☐	
Service –oriented sectors	☐	☐	
Other (Please specify)	☐	☐	

2.1.4 Relevance

2.1.4.1 Relevance for decision making

	Options	Description/motivation/comments/references
☐	*Support management and investment decisions*	
☐	*Support long-term process development inside a company*	
☐	*Monitoring and reporting of sustainability performance*	
☐	*Other*	Please specify

2.1.4.2 Relevance for business

	Options	**Description/motivation/comments/references**
☐	*Controlling*	
☐	*Top-management*	
☐	*R&D*	
☐	*Marketing*	
☐	*Supply chain management*	
☐	*Other*	Please specify

2.1.4.3 Sectors inside a company

	Options	**Description/motivation/comments/references**
☐	*Certification*	
☐	*Product specification standards*	
☐	*Communication & external reporting*	
☐	*Other*	Please specify

2.1.4.4 Disclosure

Sustainability benchmarks or frameworks	**Required**	**Recommend.**	**Possible**	**Description/motivation/comments/references**
Carbon Disclosure Project (CDP)	☐	☐	☐	
Global Reporting Initiative (GRI)	☐	☐	☐	
Dow Jones Sustainability index (DJSI)	☐	☐	☐	
Other (Please specify)	☐	☐	☐	

2.1.5 Requirements

2.1.5.1 Information systems

	Options	**Description/motivation/comments/references**
☐	*Software or tool*	

☐	*Reporting system*	
☐	*Required standard*	
☐	*License fees*	
☐	*Other*	Please specify

2.1.5.2 Input data

	Required	**Recommend.**	**Possible**	**Description/motivation/comments/references**
Company internal data	☐	☐	☐	
Real supply chain data	☐	☐	☐	
Commercial or public databases, maps	☐	☐	☐	
Other (Please specify)	☐	☐	☐	

2.1.5.3 Competences and skills

	Options	**Description/motivation/comments/references**
☐	*Trained personnel needed (expert level)*	
☐	*Trained personnel needed (user level)*	
☐	*Anybody could apply the method*	
☐	*Other*	Please specify

2.1.5.4 Organisation

This dimension refers to the extent to which specific structures inside the company could be needed to apply the method.

	The method is suitable for companies with the following number of employees:	**Description/motivation/comments/references**
☐	*> 50000*	
☐	*25000 to 50000*	

☐	*10000 to 25000*	
☐	*5000 to 10000*	
☐	*1000 to 5000*	
☐	*500 to 1000*	
☐	*100 to 500*	
☐	*50 to 100*	
☐	*< 50*	

2.1.6 Outcome

2.1.6.1 Outputs

Output indicators	**Description/motivation/comments/references**
Environmental	
...	
...	
Economic	
...	
...	
Social	
...	
...	

2.1.6.2 Communication

	Output formats	**Description/motivation/comments/references**
☐	*Flow charts*	
☐	*Sankey diagrams*	
☐	*Risk scorecards*	
☐	*Spider diagrams*	
☐	*Other*	Please specify

2.1.6.3 Labelling and certification

	The outputs can be used to receive	**Description/motivation/comments/references**
☐	*EPD*	
☐	*Eco-label*	
☐	*Environmental certifications:*	
☐	*Carbon Trust Standard*	
☐	*EMAS*	

☐	*FSC*	
☐	*ISO 14001*	
☐	*MCERTS*	
☐	*Other*	Please specify

3. Template for an in-depth questionnaire on the applicability of simulation methods within companies

This Section bases on the characterisation criteria presented in Section 2 to provide insights into the practical implementation of methods within companies. Each of the criteria included in previous characterisation were tested by means of a detailed questionnaire presented as a check-list in this Section. There is a one-to-one correspondence between the templates presented on both Sections.

The following check-list has been filled by Hydro, Neste and CEMEX for the LCAA, E-LCA and CF methods, respectively.

3.1.1 Basic information

3.1.1.1 Personal details

	Please, provide the following information
Name of the person(s) filling the questionnaire	…
Affiliation	…
Contact details	…
Date	…

3.1.1.2 Case Study

	Please, select one of the above
☐	BASF
☐	BAYER
☐	SUEZ

3.1.1.3 Method being tested

☐	CF
☐	MIPS
☐	E-LCA
☐	LCAA

3.1.1.4 Current practice

Please list below the methods that have been used to assess the sustainability of processes and products within your company.

Methods	**Description/motivation/comments/references**

Please specify	
Please specify	
Please specify	

According to your experience, please provide some information on the dimensions that the methods that are currently being implemented within your companies fail to address.

Methods	Challenges/drawbacks/issues
Please specify	
Please specify	
Please specify	

3.1.2 Essence

3.1.2.1 Core idea

General perception on the method: According to the description of this method, would it fill any strategic or operational need related to sustainability assessment within your company?

	Options	Description/motivation/comments/references
☐	*Very fitted to our current or expected needs*	
☐	*Partially fitted to our current or expected needs*	
☐	*Marginally fitted to our current or expected needs*	
☐	*Unknown / uncertain*	

3.1.2.2 Status

Did you know about the existence of this method before taking part in the SAMT project?

	Options	Description/motivation/comments/references
☐	*Yes*	
☐	*No*	

To your current knowledge, has your company considered the application of this method on any of its products/processes?

	Options	Description/motivation/comments/references
☐	*Yes*	
☐	*No*	
☐	*Uncertain*	

To your current knowledge, has this method being implemented before within your company?

	Options	If yes, please specify on which product/process
☐	*Yes*	
☐	*No*	
☐	*Uncertain*	

If yes, please rank the degree to which this method has fulfilled the expectations

	Options	Has the previous experience with the application of this method fulfilled the expectations?
☐	*Yes*	
☐	*Partially*	
☐	*No*	

3.1.2.3 Type of method (outcome)

Which one(s) of the following types of methods could be more useful for assessing sustainability of your products/processes? Why? Does the method being tested satisfy your requirements from this point of view?

	Options	Description/motivation/comments/references
☐	*Quantitative*	
☐	*Semi-quantitative*	
☐	*Qualitative*	

3.1.2.4 Complexity

How would you rank this method in terms of complexity, as compared to a standard LCA?

	Options	Description/motivation/comments/references
☐	*Low*	
☐	*Medium*	
☐	*High*	

Do you consider that it would be necessary to hire someone or train someone within your company in order to apply this method to any of your products/processes?

		Description/motivation/comments/references
☐	*Training needed (external / professional)*	
☐	*Training needed (internal / self-education)*	
☐	*No training needed*	
☐	*Uncertain*	

3.1.2.5 Access & costs of the support tools

Does your company have any specific policy or restriction regarding the use of third party software? Please specify

Yes	**No**	**Types**	**Description/motivation/comments/references**
☐	☐	*Proprietary*	
☐	☐	*Open source*	
☐	☐	*High*	
☐	☐	*Other*	Please specify

How much do you consider that your company would accept to pay for a software tool designed to enable or simplify the application of this method?

	In thousands of Euros	**Description/motivation/comments/references**
☐	*< 1*	
☐	*1 - 3*	
☐	*3 - 5*	
☐	*5 - 10*	
☐	*10 - 30*	
☐	*30 - 50*	
☐	*> 50*	

Which department within your company would have to accept the acquisition of a software tool designed for the application of this method?

	Options	Description/motivation/comments/references
☐	*Procurement Department*	
☐	*ICT Department*	
☐	*Corporate Responsibility Department*	
☐	*Other*	Please specify
☐	*Uncertain*	

3.1.2.6 Updating

According to the information you have on this specific method, do you consider that it is updated with a sufficient frequency, according to your needs or expectations?

		Description/motivation/comments/references
☐	*Yes (on-going)*	
☐	*No (discontinued)*	
☐	*Uncertain*	

Do you deem important that the sustainability assessment methods applied within your company are regularly updated by their developers / community of users?

	Options	Description/motivation/comments/references
☐	*Yes, we (would) only apply methods that are updated on a regular basis*	
☐	*No, we could apply methods that were discontinued some time ago. Our interests lay on the relevance and usefulness of the methods rather than on their update rates*	
☐	*Uncertain*	

3.1.2.7 Replicability

According to the information you have on this specific method and to the knowledge you have on the implications of the analytical processes for your company, do you consider that replicability and comparability of results could be granted within your company in this method is applied?

	Options	Description/motivation/comments/references
☐	*Feasible if all analytical processes (e.g. boundary setting, data compilation,*	

	aggregation, weighting and normalisation) are reported transparently, which could be done with ease	
☐	*Possible if all analytical processes (e.g. boundary setting, data compilation, aggregation, weighting and normalisation) are reported transparently. However, this condition is difficult to satisfy in practice*	
☐	*Unlikely, even if all analytical processes (e.g. boundary setting, data compilation, aggregation, weighting and normalisation) are reported transparently*	

How would you rank replicability of the method within your company along each one of the following data-driven dimensions? I.e. rank the method according to the degree to which data could be reported with transparency across processes, production sites, periods, etc.

Replicability issue / dimension	**Yes**	**No**	**Uncertain**	**Description/motivation/comments/references**
Sustainability experts within your company would have access to all the sensitive / confidential data needed for the application of this method	☐	☐	☐	
The data provided by different processes, production sites, for different time periods or processes within your company would be accessible under the same formats	☐	☐	☐	
Access to the external data needed for the implementation of this method, if any, would be possible	☐	☐	☐	
Other (please specify)	☐	☐	☐	

How would you rank replicability of the method within your company along each one of the following methodological steps?

Replicability issue / dimension	**Transparent**	**Opaque / unclear**	**Unknown / Uncertain**	**Description/motivation/comments/references**
Data compilation	☐	☐	☐	
Data aggregation	☐	☐	☐	
Data weighting	☐	☐	☐	
Data normalisation	☐	☐	☐	
Other (please specify)	☐	☐	☐	

3.1.2.8 Dynamics

According to the information you have on this method and the expectations or practical needs you currently have within your company, how would you judge the degree of dynamism of this method?

	Options	**Description/motivation/comments/references**
☐	*Fully dynamic (our products, production systems could be modelled with this method)*	
☐	*Partially dynamic (we could build what-if scenarios to model our products or processes)*	
☐	*Static (we could only obtain static information following to the implementation of the method)*	

3.1.3 Scope

3.1.3.1 Sustainability aspects

According to the information you have on this method and the expectations or practical needs you currently have within your company, how do you consider this method takes account for the following sustainability dimensions?

Satisfactorily	**Partially**	**Unsatisfactorily**	**Sustainability aspects**	**Description/motivation/comments/references**
☐	☐	☐	*Environmental*	

☐	☐	☐	*Social*	
☐	☐	☐	*Economic*	

3.1.3.2 Energy efficiency aspects

According to the information you have on this method and the expectations or practical needs you currently have within your company, how do you consider this method takes account for the energy efficiency dimension?

Satisfactorily	**Partially**	**Unsatisfactorily**	**Efficiency dimensions**	**Description/motivation/comments/references**
☐	☐	☐	*Energy efficiency*	

3.1.3.3 Material efficiency aspects

According to the information you have on this method and the expectations or practical needs you currently have within your company, how do you consider this method takes account for the material efficiency dimension?

Satisfactorily	**Partially**	**Unsatisfactorily**	**Efficiency dimensions**	**Description/motivation/comments/references**
☐	☐	☐	*Material efficiency*	

3.1.3.4 Economic scope

According to the information you have on this method and the expectations or practical needs you currently have within your company, how do you consider this method takes account for the economic aspects?

Satisfactorily	**Partially**	**Unsatisfactorily**	**Options**	**Description/motivation/comments/references**

☐	☐	☐	*Product*	
☐	☐	☐	*Component*	
☐	☐	☐	*Process*	
☐	☐	☐	*Technology*	
☐	☐	☐	*Production site*	
☐	☐	☐	*Company*	
☐	☐	☐	*Sector*	
☐	☐	☐	*Territory*	
☐	☐	☐	*Global systems*	
☐	☐	☐	*Non-applicable*	

3.1.3.5 Geographical scope

According to the information you have on this method and the expectations or practical needs you currently have within your company, how do you consider this method takes account for the geographic aspects?

Satisfactorily	**Partially**	**Unsatisfactorily**	**Options**	**Description/motivation/comments/references**
☐	☐	☐	*Sub-national*	
☐	☐	☐	*National*	
☐	☐	☐	*International*	
☐	☐	☐	*Non-applicable*	

3.1.3.6 Application field along the supply chain

According to the information you have on this method and the expectations or practical needs you currently have within your company, how do you consider this method takes account for the application field along the supply chain?

Satisfactorily	**Partially**	**Unsatisfactorily**	**Options**	**Description/motivation/comments/references**
☐	☐	☐	*Technical process optimisation*	
☐	☐	☐	*Management process*	

			optimisation	
☐	☐	☐	*Supply chain optimisation*	
☐	☐	☐	*Life cycle wide optimisation*	
☐	☐	☐	*Ex-ante technology impact assessment*	
☐	☐	☐	*Other*	Please specify

3.1.3.7 Life cycle stages

According to the information you have on this method and the expectations or practical needs you currently have within your company, how do you consider this method takes account for the life cycle stages?

Satisfactorily	**Partially**	**Unsatisfactorily**	**Typical LCA stages**	**Description/motivation/comments/references**
☐	☐	☐	*Cradle to grave (i.e. from resource extraction to use phase and disposal phase)*	
☐	☐	☐	*Cradle to gate (i.e. the use phase and disposal phase are omitted)*	
☐	☐	☐	*Cradle-to-cradle (e.g. avoided burden method)*	
☐	☐	☐	*Gate-to-gate (e.g. looking at only one value-added process in the entire production chain)*	
☐	☐	☐	*Other*	Please specify

3.1.3.8 Sectors

According to the information you have on this method and the expectations or practical needs you currently have within your company, please indicate below the sectors where you would be interested in applying this method?

Yes	**No**	**Sectors**	**Description/motivation/comments/references**
☐	☐	*All*	
☐	☐	*Process industry in general, of which:*	

☐	☐	*Chemical*	
☐	☐	*Cement*	
☐	☐	*Oil*	
☐	☐	*Metal*	
☐	☐	*Water*	
☐	☐	*Waste*	
☐	☐	*Mining and oil extraction*	
☐	☐	*Farming and forestry*	
☐	☐	*Service-oriented sectors*	
☐	☐	*Other (Please specify)*	

According to the information you have on this method and the expectations or practical needs you currently have within your company, please indicate below the sectors where you deem feasible applying this method, even if your company is not directly involved in them?

Yes	No	Sectors	Description/motivation/comments/references
☐	☐	*All*	
☐	☐	*Process industry in general, of which:*	
☐	☐	*Chemical*	
☐	☐	*Cement*	
☐	☐	*Oil*	
☐	☐	*Metal*	
☐	☐	*Water*	
☐	☐	*Waste*	
☐	☐	*Mining and oil extraction*	
☐	☐	*Farming and forestry*	
☐	☐	*Service-oriented sectors*	
☐	☐	*Other (Please specify)*	

3.1.4 Relevance

3.1.4.1 Relevance for decision making

According to the information you have on this method and the expectations or practical needs you currently have within your company, please indicate below the decision making areas where this method could be helpful?

Decision areas	**Relevant**	**Partially relevant**	**Not relevant**	**Description/motivation/comments/references**
Support management and investment decisions	☐	☐	☐	
Support long-term process development inside a company	☐	☐	☐	
Monitoring and reporting of sustainability performance	☐	☐	☐	
Other	☐	☐	☐	Please specify

3.1.4.2 Relevance for business

According to the information you have on this method and the expectations or practical needs you currently have within your company, please indicate below the business areas where this method could be helpful?

Business areas	**Relevant**	**Partially relevant**	**Not relevant**	**Description/motivation/comments/references**
Controlling	☐	☐	☐	
Top-management	☐	☐	☐	
R&D	☐	☐	☐	
Marketing	☐	☐	☐	
Supply chain management	☐	☐	☐	
Other	☐	☐	☐	Please specify

3.1.4.3 Sectors inside a company

According to the information you have on this method and the expectations or practical needs you currently have within your company, please indicate below the sectors inside a company where this method could be helpful?

Sectors inside a company	**Relevant**	**Partially relevant**	**Not relevant**	**Description/motivation/comments/references**
Certification	☐	☐	☐	
Product specification standards	☐	☐	☐	
Communication	☐	☐	☐	
Other	☐	☐	☐	Please specify

3.1.4.4 Disclosure

According to the information you have on this method and the practical or expected needs you currently have within your company, please indicate below the Sustainability benchmarks or frameworks where this method could be helpful?

Sustainability benchmarks or frameworks	**Yes**	**No**	**Description/motivation/comments/references**
Carbon Disclosure Project (CDP)	☐	☐	
Global Reporting Initiative (GRI)	☐	☐	
Dow Jones Sustainability index (DJSI)	☐	☐	
Other (Please specify)	☐	☐	

3.1.5 Requirements

3.1.5.1 Information systems

According to the information you have on this method and the expectations or practical needs you currently have within your company, please indicate below the perceived difficulty to comply with the method requests over the following dimensions:

	High	Average	Low	Description/motivation/comments/references
Software or tool	☐	☐	☐	
Reporting system	☐	☐	☐	
Required standard	☐	☐	☐	
License fees	☐	☐	☐	
Other (please specify)	☐	☐	☐	

3.1.5.2 Input data

According to the information you have on this method and the practical or expected needs you currently have within your company, please indicate below the feasibility to satisfy the data needs linked to the implementation of this method:

	Accessible	Partially accessible	Not accessible	Description/motivation/comments/references
Company internal data	☐	☐	☐	
Real supply chain data	☐	☐	☐	
Commercial or public databases, maps	☐	☐	☐	
Other (Please specify)	☐	☐	☐	

According to the information you have on this method and your past experience, please indicate the estimated time need to collect all the information required for a successful implementation of this method within your company:

Number of weeks	< 1	1 - 2	2-4	4-8	8-24	24-48	> 48	Data not needed	Description/motivation/comments/references
Company internal data	☐	☐	☐	☐	☐	☐	☐	☐	

Real supply chain data	☐	☐	☐	☐	☐	☐	☐	☐	
Commercial or public databases, maps	☐	☐	☐	☐	☒	☐	☐	☐	
Other (Please specify)	☐	☐	☐	☐	☐	☐	☐	☐	

3.1.5.3 Competences and skills

According to the information you have on this method and the practical or expected needs you currently have within your company, please indicate below the expected training needs to apply the method within your company:

	Options	**Description/motivation/comments/references**
☐	*External training would be needed*	
☐	*Internal training would be needed*	
☐	*Training would not be necessary*	
☐	*Other*	Please specify

Would your company be willing to train staff for the implementation of this method?

	Options	**Description/motivation/comments/references**
☐	*Yes*	
☐	*No*	
☐	*Under specific conditions only (please specify)*	

3.1.5.4 Organisation

According to the information you have on this method and the practical or expected needs you currently have within your company, please indicate below the expected organisational changes needed for a correct application of this method within your company:

	Options	**Description/motivation/comments/references**
☐	*Your company already has the specific structures that would be needed (e.g. a stable sustainability team, a work*	

	group or a task force) for a successful implementation of this method	
☐	*Your company lacks of the specific structures that would be needed (e.g. a stable sustainability team, a work group or a task force) for a successful implementation of this method*	
☐	*The method does not require specific structures (e.g. a stable sustainability team, a work group or a task force) for a successful implementation*	

If your company lacks of the specific structures, do you consider that the mangers within your company would be willing to accept an internal reorganisation designed for the sole purpose of achieving a successful implementation of this method?

	Options	**Description/motivation/comments/references**
☐	*Yes*	
☐	*No*	
☐	*Under specific conditions (please specify)*	

3.1.6 Outcome

3.1.6.1 Outputs

According to the information you have on this method and the practical or expected needs you currently have within your company, please indicate below which of the following types of outputs provided by this method would be relevant for decision making your company:

Output indicators	**Low relevance**	**Average relevance**	**High relevance**	**Description/motivation/comments/references**
Environmental				
...	☐	☐	☐	
...	☐	☐	☐	
Economic				
...	☐	☐	☐	
...	☐	☐	☐	
Social				

...	☐	☐	☐	
...	☐	☐	☐	

3.1.6.2 Communication

According to the information you have on this method and the practical or expected needs you currently have within your company, please indicate below to what extent the formats of the outputs provided by the method are adequate for operational use within your company:

Output indicators	Low	Average	High	Description/motivation/comments/references
Flow charts	☐	☐	☐	
Sankey diagrams	☐	☐	☐	
Risk scorecards	☐	☐	☐	
Spider diagrams	☐	☐	☐	
Other (please specify)	☐	☐	☐	

According to the information you have on this method and your past experience, please indicate below the potential difficulties in communicating to the non-experts the following aspects linked to the implementation of this method:

Communication challenges	Low	Average	High	Description/motivation/comments/references
What is done in the assessment	☐	☐	☐	
What the results mean	☐	☐	☐	
Why results are important	☐	☐	☐	
Why results are trustworthy	☐	☐	☐	
Other (please specify)	☐	☐	☐	

According to the information you have on this method and your past experience, please indicate below the potential risk that results from this method are misused:

Risk of misuse	**Low**	**Average**	**High**	**Description/motivation/comments/references**
Risk of misuse within the company	☐	☐	☐	
Risk of misuse outside the company	☐	☐	☐	
Other (please specify)	☐	☐	☐	

3.1.6.3 Labelling and certification

According to the information you have on this method and the practical or expected needs you currently have within your company, please indicate below to what extent your company would consider applying for any of the following certifications basing on the outputs delivered by this method:

	The outputs can be used to receive	**Description/motivation/comments/references**
☐	*EPD*	
☐	*Eco-label*	
☐	*Environmental certifications:*	
☐	*Carbon Trust Standard*	
☐	*EMAS*	
☐	*FSC*	
☐	*ISO 14001*	
☐	*MCERTS*	
☐	*Other*	Please specify