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

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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 on 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, Ecocinvent (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 FOOTPRINT; LIFE CYCLE ASSESSMENT, SUSTAINABILITY ASSESSMENT, RESOURCE USE
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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 factors1 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 standard.

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.)

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).

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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](image)

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

<table>
<thead>
<tr>
<th></th>
<th>2014 (Before)</th>
<th>2015 (After)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional unit</td>
<td>1 kg COD removed</td>
<td>1 kg COD removed</td>
</tr>
<tr>
<td>Energy consumption/FU</td>
<td>Reference case</td>
<td>-61%</td>
</tr>
<tr>
<td>Waste water quantity/FU</td>
<td>-11%</td>
<td></td>
</tr>
<tr>
<td>Total amount of reagents/FU</td>
<td>-48%</td>
<td></td>
</tr>
<tr>
<td>Incoming waste water quality</td>
<td>+70% organic load</td>
<td>+40% grease</td>
</tr>
</tbody>
</table>

(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

<table>
<thead>
<tr>
<th></th>
<th>France</th>
<th>Spain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.315</td>
<td>31.49</td>
</tr>
</tbody>
</table>

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.

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

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 water4. 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.

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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 endpoint 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

<table>
<thead>
<tr>
<th>Type of indicator</th>
<th>Impact category (midpoint)</th>
<th>Characterisation model</th>
<th>Area of protection (endpoint)</th>
<th>Characterisation model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumptive water use</td>
<td>Water scarcity</td>
<td>Water scarcity index from Pfister et al. (2009)</td>
<td>Ecosystems</td>
<td>Water deprivation effect to ecosystems from Pfister et al. (2009)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Human Health</td>
<td>Water deprivation effect to human health from Pfister et al. (2009)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Resources</td>
<td>Water deprivation effect to resources from Pfister et al. (2009)</td>
</tr>
<tr>
<td>Water degradation</td>
<td>Freshwater eutrophication</td>
<td>ReCiPe (Goedkoop et al. 2009)</td>
<td>Ecosystems</td>
<td>ReCiPe (Goedkoop et al. 2009)</td>
</tr>
<tr>
<td></td>
<td>Marine eutrophication</td>
<td>ReCiPe (Goedkoop et al. 2009)</td>
<td></td>
<td>ReCiPe (Goedkoop et al. 2009)</td>
</tr>
<tr>
<td></td>
<td>Freshwater ecotoxicity</td>
<td>USEtox (Rosenbaum et al. 2008)</td>
<td></td>
<td>USEtox (Rosenbaum et al. 2008)</td>
</tr>
<tr>
<td></td>
<td>Toxicity to Human</td>
<td>USEtox (Rosenbaum et al. 2008)</td>
<td>Human Health</td>
<td>USEtox (Rosenbaum et al. 2008)</td>
</tr>
</tbody>
</table>

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 H₂O-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

<table>
<thead>
<tr>
<th></th>
<th>Degradative water use</th>
<th>Consumptive water use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquatic eutrophication</td>
<td>53</td>
<td>-</td>
</tr>
<tr>
<td>Aquatic acidification</td>
<td>2,5x10⁻²</td>
<td>-</td>
</tr>
<tr>
<td>Freshwater ecotoxicity</td>
<td>1,0x10⁻²</td>
<td>-</td>
</tr>
<tr>
<td>Human toxicity</td>
<td>9,2x10⁻⁷ (cancer)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2,2x10⁻⁷ (non-cancer)</td>
<td>-</td>
</tr>
<tr>
<td>Water scarcity</td>
<td>-</td>
<td>1,7</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>WATER FOOTPRINT</th>
<th>Type of indicators</th>
<th>Impact category (Midpoint)</th>
<th>Characterisation model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waterlily</td>
<td>Consumptive water use</td>
<td>Water scarcity</td>
<td>Water scarcity index from Pfister et al. (2009)</td>
</tr>
<tr>
<td></td>
<td>Water degradation</td>
<td>Freshwater eutrophication</td>
<td>ReCiPe (Goedkoop et al. 2009)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marine eutrophication</td>
<td>ReCiPe (Goedkoop et al. 2009)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Freshwater acidification</td>
<td>IMPACT 2002+ (Jolliet et al. 2003)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Freshwater ecotoxicity</td>
<td>USEtox (Rosenbaum et al. 2008)</td>
</tr>
<tr>
<td>SULCA</td>
<td>Consumptive water use</td>
<td>Water scarcity</td>
<td>WULCA / AWaRe, 2016</td>
</tr>
<tr>
<td></td>
<td>Water degradation</td>
<td>Aquatic eutrophication</td>
<td>ImpactWorld+, 2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aquatic ecotoxicity, long-term</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aquatic ecotoxicity, short-term</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Terrestrial acidification</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Carcinogens, long-term</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Carcinogens, short-term</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-carcinogens, long-term</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-carcinogens, short-term</td>
<td></td>
</tr>
<tr>
<td>MIPS</td>
<td>Resource use</td>
<td>Abiotic raw materials</td>
<td>Saurat &amp; Ritthoff 2013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Biotic raw materials</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Earth movement in agriculture and silviculture</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Air</td>
<td></td>
</tr>
</tbody>
</table>

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 m³ before modification and 1.5 m³ 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 0.0037m³/FU before modification and 0.0017 m³/FU after modification.
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.

<table>
<thead>
<tr>
<th></th>
<th>BEFORE MODIFICATION</th>
<th></th>
<th>AFTER MODIFICATION</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Withdrawal</td>
<td>Discharge</td>
<td>Consumption</td>
<td>Withdrawal</td>
</tr>
<tr>
<td>WWTP</td>
<td>1,6 %</td>
<td>1,6 %</td>
<td>0 %</td>
<td>3,5 %</td>
</tr>
<tr>
<td>Reagents consumption</td>
<td>2,9 %</td>
<td>2,9 %</td>
<td>23,1 %</td>
<td>4,8 %</td>
</tr>
<tr>
<td>Electricity consumption at WWTP</td>
<td>95 %</td>
<td>95 %</td>
<td>75,9 %</td>
<td>90,6 %</td>
</tr>
<tr>
<td>Transportation</td>
<td>0,3 %</td>
<td>0,3 %</td>
<td>0,9 %</td>
<td>0,7 %</td>
</tr>
<tr>
<td>Waste management</td>
<td>0,2 %</td>
<td>0,2 %</td>
<td>0,2 %</td>
<td>0,4 %</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Midpoint</th>
<th>Water scarcity</th>
<th>Toxicity to human</th>
<th>Ecotoxicity</th>
<th>Eutrophication</th>
<th>Aquatic acidification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before modification</td>
<td>2,5</td>
<td>21</td>
<td>46</td>
<td>0,6</td>
<td>2,4</td>
</tr>
<tr>
<td>After modification</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Midpoint</th>
<th>Water scarcity, AWARE</th>
<th>Eutrophication</th>
<th>Aquatic ecotoxicity, long-term</th>
<th>Aquatic ecotoxicity, short-term</th>
<th>Terrestrial acidification</th>
<th>Carcinogen, long-term</th>
<th>Carcinogen, short-term</th>
<th>Non-carcinogen, long-term</th>
<th>Non-carcinogen, short-term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>3,6</td>
<td>0,4</td>
<td>4,1</td>
<td>13</td>
<td>3,7</td>
<td>2,7</td>
<td>3,1</td>
<td>2,7</td>
<td>19</td>
</tr>
<tr>
<td>After</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

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.

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.
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).

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

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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 H2O-eq) per functional unit.

<table>
<thead>
<tr>
<th>Water Footprint</th>
<th>L H2O-eq/kg COD eliminated</th>
<th>L H2O-eq/kg COD eliminated</th>
<th>L H2O-eq/kg COD eliminated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water footprint</td>
<td>190</td>
<td>188</td>
<td>1.7</td>
</tr>
<tr>
<td>Degradation Water Footprint</td>
<td>24</td>
<td>23</td>
<td>0.7</td>
</tr>
<tr>
<td>Consumption Water Footprint</td>
<td>100</td>
<td>99.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Normalised values</td>
<td>13</td>
<td>12.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>

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.

![Normalized water footprint after weighing](image)

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](image)

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

<table>
<thead>
<tr>
<th></th>
<th>2014 [kg/kg COD eliminated]</th>
<th>2015 [kg/kg COD eliminated]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abiotic raw material</td>
<td>0.4771</td>
<td>0.2478</td>
</tr>
<tr>
<td>Biotic raw material</td>
<td>0.0039</td>
<td>0.0016</td>
</tr>
<tr>
<td>Erosion</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>TMR (Σ abiotic, biotic and erosion)</td>
<td>0.4810</td>
<td>0.2494</td>
</tr>
<tr>
<td>Water</td>
<td>8.91</td>
<td>3.71</td>
</tr>
<tr>
<td>Air</td>
<td>0.0787</td>
<td>0.0266</td>
</tr>
</tbody>
</table>

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.
7 References

http://www.impactworldplus.org/en/

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