Assessing the Social Performance and Social Risks of Wastewater Treatment Systems Through Social Life Cycle Assessment

A Case Study of the Water Mining Project in Spain

Master of Science

International Master's Programme on Circular Economy

Student

Akemi Kokubo

Supervisors

Dr John Posada
Dr Carlos Blanco
Dr George Tsalidis

August 2022

Executive Summary

Water scarcity problems will continue to aggravate in many parts of the world as the climate changes, the population grows, water demand increases, and the quality of water bodies declines. These challenges, hampered by the competition for water between different regions, cities, and economic sectors, urge society to mitigate or adapt. In so doing, water resources previously not exploited start to gain relevance and efforts to increase their use proliferates. One such resource is municipal wastewater, which is produced at a constant rate and is to some extent not affected by climate conditions.

Wastewater treatment technologies are typically assessed environmentally and techno-economically, yet similar to other products and services; their social implications are often disregarded. Therefore, this thesis research project aims to measure and evaluate the social impacts of wastewater treatment (WWT) systems potentially stemming from the social performance of organizations and social risks in the value chain. One of the studied WWT facilities is located in La Llagosta, Barcelona, Spain, serving a population of 138 thousand. The other system is formed by one of the Water Mining project case studies (Water Mining, 2020b), which implements a new train of technologies to treat municipal wastewater and recover phosphorus, sludge for agriculture, and water for agriculture and industries.

The social life cycle assessment (S-LCA) methodology is implemented to achieve the goals mentioned above, evaluating the systems' social effects on Workers, Consumers, Local community, Society, and Value chain actors. The social performances of the case study operator and its first-tier suppliers are evaluated in a site-specific assessment using the Reference Scale approach for impact assessment. In addition, the social risks along the value chain of both product systems are assessed in a generic assessment via the use of the S-LCA database, PSILCA. Activity variables are employed in both assessments to link the organizations' performances (site-specific assessment) and the country-specific sectors' social flows (generic assessment) with the product system at hand. Furthermore, economic allocation is used to solve multifunctionality issues in both systems and types of assessments.

The results indicate that the organizations included performed relatively well in both systems in relation to the performance reference points considered. However, improvements are needed in the subcategories "Safe and healthy living conditions", "Local employment", "Public commitment to sustainability issues", and "Promoting social responsibility". In addition, improvements are needed in "Equal opportunities/discrimination" in the system representing the WWT plant currently operating in La Llagosta. The above refers to the overall organization's social performance. Nevertheless, after using activity variables and solving multifunctionality, organizations' social performances are deficient in only two subcategories: "Safe and healthy conditions" and "Local employment". For each organization that did not achieve the acceptable level (Basic Requirement), suggestions for improvement are offered.

Regarding the generic assessment, most social risks are associated with the subcategories "Access to material resources", "Fair salary", "Freedom of association and collective bargaining", "Corruption", and "Contribution to economic development" for both WWT systems and their value chains. Furthermore, the contributions of each WWT process to the total social risks are determined as well as those from the processes in Spain. Nevertheless, most social risks originate upstream of the supply chain.

The biggest challenge faced in the site-specific assessment concerns the accessibility and availability of site-specific data. On the other hand, the most challenging aspect of the generic assessment was creating a waste treatment process and solving for multifunctionality. Besides the challenge of using the database, the latter concerns inherent limitations of assessing a system that is not yet implemented at full scale since many assumptions were made. As for S-LCA, linking social performances with a product and solving for multifunctionality is possible, yet in practice, they remain abstract for the most part. Indeed, solving theoretical and methodological problems does not make them more real in practice. Nevertheless, S-LCA application delivers its purpose since measuring and evaluating the social performances of organizations along the value chain is facilitated, and opportunities to spot negative areas and implement improvement strategies can be identified.

Further research is still needed in S-LCA, especially in comparing products in the linear economy with those in the circular economy. Research on the social implications of WWT systems should also advance as additional (new) subcategories, and social indicators can be included. Furthermore, as WWT systems transition to water resource recovery systems and contribute to a circular economy, it is essential to determine whether they will bring about impacts or benefits to the stakeholders affected. If the social aspect of circular economy and circular economy systems is not considered, their contributions to challenging the status quo in this path of unsustainability will be pretty limited.

Acknowledgements

I would like to thank all my three supervisors for their pieces of advice and support in this academic process. I thank George Tsalidis, my daily supervisor, for the immense amount of time and patience he invested in my learning and for supporting me in the data collection process. I also thank my first supervisor, John Posada, for providing a more general and practical perspective on my work and findings. Additionally, many thanks to my second supervisor, Carlos Blanco, who helped me have critical eyes on the method and its outcomes.

I would also like to thank Daniel Dias and Joao Ribeiro for their valuable help in data gathering for the Water Mining case study. This research also benefitted from the assistance of Teresa de la Torre Garcia, who put a lot of time and effort into facilitating physical and social data about the systems studied. Calculating my results would have been much more of a hassle if it were not for the inputs from the representatives of the organizations studied. Many thanks to them for taking the time to answer my emails and fill out the questionnaires.

A heartfelt thank you to my family and friends for their invaluable support. Thank you to my mom (Juana), grandma (Carmen), sister (Silvia), and Gabi Wippler for always encouraging me and trusting in my abilities. Thank you to Maria Myridinas and Sandy Indriana for their emotional support and constant reminders that all will work out for good. Last but absolutely not least, thank you to Thomas Wippler for always being there, believing in me, supporting me, and making sure that I take enough breaks.

List of contents

List of figures

List of tables

List of abbreviations

AHP	Analytical Hierarchy Process
BES	Bioelectrochemical system
BR	Basic Requirement
CS	Case study
CSR	Corporate Social Responsibility
CSRD	Corporate Sustainability Reporting Directive
CSS	Country-specific sector
E-LCA	Environmental Life Cycle Assessment
IA	Impact assessment
IOA	Input-Output Analysis
IP	Impact Pathway
LCSA	Life Cycle Sustainability Assessment
mrh	Medium risk hours
PRP	Performance Reference Point
PSIA	Product Social Impact Assessment
RS	Reference scale
S-LCA	Social Life Cycle Assessment
S-LCIA	Social Life Cycle Impact Assessment
S-LCI	Social Life Cycle Inventory
SAM	Subcategory Assessment Method
SETAC	Society of Environmental Toxicology & Chemistry
SO-LCA	Social Organizational Life Cycle Assessment
SDGs	Sustainable Development Goals
TBL	Triple Bottom Line
UNEP	United Nations Environment Programme
WCEP	World Commission on Environment and Development
WM	Water Mining
WWT	Wastewater treatment
WWTP	Wastewater treatment plant

1. Introduction

The first chapter of this thesis gives a brief overview of its background regarding the main challenges in society and the problems and research gap it aims to address. Additionally, the research object, goals, main research question, and sub-questions will be introduced. The chapter then concludes with a discussion on how the topic and methodology of this thesis are relevant to the Industrial Ecology field and society.

1.1. Introduction to study

As the global population grows and moves to cities, water scarcity will not stop increasing and will continue to be aggravated by climate change (He et al., 2021; Richter et al., 2013). He et al. (2021) analysed the severity of water scarcity in cities and made future projections. One of their results indicates that half of the urban population in 2050 will live in regions with water scarcity.

Some solutions to the water scarcity problem are obtaining water from unconventional water resources and implementing measures for its more efficient use (e.g., by reusing urban and industrial water) (He et al., 2021; Karimidastenaei et al., 2022). Regarding the latter, and in order to address water scarcity in cities, it is crucial to promote water conservation through, for example, the use of technologies that save water (He et al., 2021). Moreover, urbanization and population growth increase the demand for water treatment facilities. In addition to providing a basic societal service, municipal wastewater treatment plants (WWTPs) not only recover water but also have the potential to recover additional valuable resources. Urban wastewater treatment (WWT) also aims at preventing the release of nitrogen and phosphorous to surface water resources, which contributes to their preservation of environmental quality (Kehrein et al., 2020).

However, since solutions to global urban water scarcity come at the expense of severe impacts on the environment, the economy, and society (He et al., 2021), the organizations in charge of their development and implementation need to ensure that those technologies actually contribute to sustainable development. Contrary to the common practice of mainly focusing on technologies' environmental and techno-economic assessment, the above requires a more holistic perspective.

In this regard, a development that ensures and maintains environmental quality and social equity can be considered one of this century's most important goals. Sustainability has often been interpreted as a multidimensional concept comprising environmental, social, and economic goals, and many different societal actors have adopted it. However, trade-offs between the different pillars of sustainability exist, and some scholars argue that when tensions appear, organizations often prioritize the economic aspect (Avesani, 2020). Furthermore, not only have technologies not been assessed from a social sustainability perspective, but also organizations have paid less attention to the social aspects of their operations compared to the environmental and economic ones (Vallance et al., 2011 and Lehtonen, 2004, as cited in Meseguer-Sánchez et al., 2021; Malandrakis et al., 2019; Vavik & Keitsch, 2010).

The situation described above might be changing. Organizations are facing increasing pressure from different stakeholders to consider the impacts of their operations on society (Labuschagne et al., 2005; Yawar & Seuring, 2015). Furthermore, international guidance documents and regional legislation have been implemented for companies to consider their operations' societal and environmental aspects and report on them (e.g., ISO 26000, Non-Financial Reporting Directive). Additionally, for the first time, the private sector's contribution was and is explicitly relied upon for progress toward the sustainable development agenda for 2030 through the Sustainable Development Goals (SDGs) (Pedersen, 2018). As a response, businesses have adopted the SDGs to different extents, and have been implementing strategies to act and report on issues relevant to sustainability (van der Waal & Thijssens, 2020).

1.2. Research problem

However, although organizations may be engaged in sustainable practices, implementing corporate social responsibility (CSR), and adopting the SDGs into their business strategies, there are not many adequate tools and frameworks available that allow for measuring social sustainability in businesses' operations and their value chains (Schönherr et al., 2017; Weingaertner & Moberg, 2014). Moreover, relying on what businesses disclose in their sustainability reports has proven not to be enough to assess their contributions to sustainable development and has been questioned by researchers as to whether these efforts demonstrate a change in business-as-usual (Milne & Gray, 2013; van der Waal & Thijssens, 2020).

- First problem statement: Organizations' contributions to social sustainability are difficult to assess, and CSR initiatives are considered insufficient to achieve actual progress in this pillar. There are few tools and methodologies to empirically measure social sustainability performance along the supply chain of products.

Social life cycle assessment (S-LCA) is a framework that helps overcome the challenges mentioned above since it facilitates measuring the social performance of products and services along their life cycles (i.e., value chains) and avoids shifting social problems from one process or point in time to another (Mazzi, 2020). Guidelines on applying this methodology were prepared and published in 2009 (UNEP/SETAC Life Cycle Initiative, 2009), and an updated version was released in 2020 (UNEP, 2020)[1]. Additionally, a document encompassing detailed impact subcategory descriptions and sets of relevant social indicators was published in 2013 (UNEP/SETAC, 2013), and an updated version in 2021 (UNEP, 2021). Another effort made by the United Nations Environment Programme (UNEP) in collaboration with industries and other organizations has been implementing and testing the new version of the Guidelines in different case studies published earlier this year (Life Cycle Initiative & Social Life Cycle Alliance, 2022). These documents and initiatives indicate the growing interest that this framework has been receiving and the many efforts put into its development and adoption in different sectors.

However, as indicated by the initiatives mentioned above, S-LCA is still being developed and has not yet achieved standardization. Thus, many limitations to its application exist, such as the difficulty in accessing (up-to-date) data for some indicators and different actors in the value chain, the availability and quality of that data, the qualitative nature of social indicators, the development of reference scales, and the communication of results (Blom & Solmar, 2009; Life Cycle Initiative & Social Life Cycle Alliance, 2022; Mesa Alvarez & Ligthart, 2021).

- Second problem statement: S-LCA is still an immature methodology, and its application in more case studies is needed to improve the framework and advance its standardization.

[1] Hereinafter referred to as *Guidelines*

As for the assessment of technologies aiming to address water scarcity, there are a few studies assessing the environmental and economic impacts of conventional WWTPs, although similar studies are scarcer in the case of retrofitted WWTPs (also called water resource recovery facilities) (Faragò et al., 2021). In line with this, Hao et al. (2019) conducted an LCA of both a conventional WWTP and a WWTP with energy and resource recovery, where the latter had fewer negative impacts. Some examples of other studies assessing the environmental impacts and costs of WWTPs are those from Daskiran et al. (2022), Gallego-Valero et al. (2021), Lorenzo-Toja et al. (2016), Pesqueira et al. (2020) and Shanmugam et al. (2022).

Some authors argue that the social impacts of wastewater treatment systems are often overlooked, and the use of S-LCA is minimal (García-Sánchez & Güereca, 2019; Muhammad Anwar et al., 2021; Opher et al., 2018; Padilla-Rivera et al., 2016; Serreli et al., 2021; Tsalidis et al., 2020; Tsalidis & Korevaar, 2019), particularly, in resource recovery technologies in the wastewater sector (Foglia et al., 2021), indicating a research gap.

- Third problem statement: There is a lack of evaluations on the social impacts of wastewater treatment systems; hence, measuring and understanding how these systems affect the social well-being of stakeholders is needed.

1.3. Research object

The Water Mining (WM) project is a consortium of public and private enterprises from 12 European countries. Its primary purpose is to facilitate water reuse, thus, making water use and consumption more sustainable. Specifically, the project aims to demonstrate innovative approaches to recover energy, clean water, and secondary resources from municipal and industrial wastewater and seawater, following the EU Water Framework Directive. Additionally, since one of the goals is to put the recovered secondary materials back into the economy (Water Mining, 2020b; Wetsus, 2020), the systems under study showcase the application of circular economy principles in the water sector (Marcal et al., 2021; Water Mining, 2020b).

The WM project proposes redesigning the water cycle by treating water as an essential part of the circular economy. It is important to identify water as a product, resource, or infrastructure system to achieve a circular economy in water management (Stuchtey, 2015). Moreover, Stuchtey (2015) argues that from the product perspective, water can be considered either consumable or durable. Consumable products typically have short life spans and, in a circular economy, should be used as much and as long as possible before being discarded. Water is treated as a consumable if it is kept free from hazardous substances and is only mixed with materials that can then be recovered (Stuchtey, 2015).

On the other hand, durable products have long life spans and must be reused not to lose their value (Stuchtey, 2015). An example of water as durable is when water is reused as much as possible in the same facility in water-scarce regions. Water as a resource implies that it should be used only to the extent that it can be regenerated (keeping withdrawal or abstraction at natural replenishment rates). Finally, water as an infrastructure system refers to maximizing the benefits of water infrastructure facilities (e.g., energy-efficient operations in utilities) (Stuchtey, 2015).

Water classified in each form has its own set of obstacles and drivers and implies the consideration of different business models, stakeholders, infrastructures, and policies (Water

Mining, 2020a). Therefore, in the WM project, the full potential of water in the circular economy is captured through different case studies (Water Mining, 2020a). Six case studies are included in the project, currently being tested for four years in Italy, Spain, Portugal, Cyprus and the Netherlands. In particular, the WM case study considered in this thesis regards water as consumable since it promotes water reuse and the recovery of value-added materials (Water Mining, 2020a). This case study is an urban WWTP located in La Llagosta, Barcelona, Spain, that has been redesigned to facilitate water reuse and recover phosphorous and energy from urban wastewater (Water Mining, 2020b).

In addition to assessing the technical feasibility of the case studies, their performance should be evaluated from a sustainability perspective, encompassing environmental, economic, and social considerations. The environmental and economic life cycle consequences of the case studies are being evaluated through environmental life cycle assessment (E-LCA) and life cycle costing (LCC). Similarly, the social implications of the case studies will be evaluated through S-LCA. Thus, this thesis project aims to fulfill the latter, specifically assessing the social performance and risks along the value chain of the WM case study in La Llagosta.

1.4. Research goals

The main goal of this thesis is to assess the social effects of a WM case study in Spain and evaluate them in relation to the current WWT system operating in La Llagosta. These goals will be achieved by applying the S-LCA framework described in the latest S-LCA Guidelines (UNEP, 2020) and the Methodological Sheets (UNEP, 2021). Hence, this methodology's applicability and usefulness will be tested, aiming to advance its development.

The S-LCA will serve to (i) determine the social performance of the WM case study vis-à-vis the current WWTP in La Llagosta by evaluating the potential effects of their life cycles on stakeholders such as workers, value chain actors, the local community, and the broader society; (ii) identify the activities in the life cycle of the above mentioned WWT systems where negative social performances and social risks could take place (hotspots), and (iii) spot opportunities and suggest measures to minimize those adverse social risks and improve the life cycle social performance of the studied systems. Therefore, the S-LCA will provide information about the social aspects of the project for decision-making, and it will contribute to improving the social performance of such water resource recovery systems and their value chain.

1.5. Research question and sub-questions

In light of the above, the main research question that this thesis project will aim to answer is the following:

What are the potential social impacts of a Water Mining municipal wastewater treatment system in relation to the wastewater treatment plant currently operating in La Llagosta, Barcelona, Spain?

The main research question calls for applying the S-LCA framework to assess and compare the social consequences of a new train of technologies to treat wastewater, proposed as a case study of the WM project, with those of the current WWTP. Three sub-questions are proposed to assist in answering the main research question:

1. What is the academic state of the art in social life cycle assessment, and how has it been applied in the water sector?

Before applying S-LCA, current developments in the methodology need to be reviewed to identify the main barriers to its application. Moreover, it is particularly relevant to perform this in light of previous S-LCA studies on wastewater treatment systems. Thus, assessing the current state of the art of S-LCA in the water sector can provide an overview of the main issues found and approaches to overcome them can be implemented. Consequently, this thesis can aid in advancing research in this field.

2. How does the social performance of the Water Mining case study treating municipal wastewater compare to that of the wastewater treatment plant currently operating in La Llagosta, Barcelona, Spain, and how can negative social performances be improved?

Social impacts can stem from the way organizations operate. Evaluating how organizations' behavior affects stakeholders means assessing their social performance. In this study, the social performance of the WM case study and the current WWTP will be assessed through a site-specific S-LCA. The site-specific assessment will require evaluating the behavior of the case study operator and its suppliers, providing a life cycle perspective. Furthermore, suggestions will be proposed to improve those areas where the social performance of the organizations is poor.

3. What are the social risks along the value chain of the Water Mining case study treating municipal wastewater, and how do they compare to those from the current WWTP?

While a site-specific analysis is limited in terms of the extent of the life cycle that can be assessed, a generic S-LCA performed through a database allows for the evaluation of entire value chains. This generic analysis will be carried out through an S-LCA database called Product Social Impact Life Cycle Assessment (PSILCA). Moreover, the impact subcategories and social indicators with the highest social risks will be identified, as well as the processes that contribute to them. Consequently, the organizations in the product system will be able to learn from potential social risks in their value chains and ensure that their activities do not reinforce those social risks.

1.6. Research relevance to IE and society

Industrial ecology (IE) studies the interactions between industrial and natural systems (Garner & Keoleian, 1995). It is concerned with tracing and quantifying material inputs and wastes produced in a system (Duchin & Levine, 2008; Garner & Keoleian, 1995). Consequently, by identifying those flows, efforts can be made to reduce environmental impacts and optimize resource use. In addition, one of the main goals of IE is the change from a linear to a closed-loop system, where wastes from a product system can be reused as inputs for other product systems (Duchin & Levine, 2008; Garner & Keoleian, 1995).

In the research object described above, waste from a particular system (i.e., a city) enters another system (i.e., industry), is treated, and other materials are recovered, which then enter other (industrial) systems. By reusing water and using waste as an input to recover or generate other resources, loops are being closed, waste produced is minimized, extraction of raw materials is decreased, and most likely, the overall environmental burdens are decreased.

Moreover, an LCA approach will be used to study the effects of the whole life cycle of WWT systems on human well-being. Life cycle assessment, as life cycle design, material flow analysis, and input-output analysis (IOA), is one of the tools of IE. Therefore, the object of study and the assessment tool used in this thesis are both intrinsic to the IE concept.

It is important to note that IE aims to promote sustainable development (Garner & Keoleian, 1995). Sustainable development, a term defined in the Brundtland Report in 1987 (World Commission on Environment and Development, 1987), implies intergenerational equity regarding resource use. Furthermore, the United Nations' SDGs encompass an urgent call to action to end poverty and strengthen the need to take a holistic approach to sustainability (Ekener, Hansson, Larsson, et al., 2018) by including the economic, social, and environmental dimensions of sustainable development (UN General Assembly, 2015). Interestingly, although a significant share of SDGs is related to social sustainability (Ekener, Hansson, Larsson, et al., 2018), when it comes to sustainability impact assessments, the social aspect is considered to a lesser extent (Rafiaani et al., 2018). Therefore, the S-LCA assessment approach offers opportunities to empirically assess the impacts of products and services on society and allows for a complete and holistic consideration of sustainability when combined with existing environmental and economic assessment tools, such as in the Life Cycle Sustainability Assessment (LCSA).

According to the S-LCA Guidelines (UNEP, 2020), social or human well-being is the Area of Protection of S-LCA, based on which the social impacts can be determined (Ekener, Hansson, & Gustavsson, 2018). Thus, the negative and positive social impacts of the urban WWTPs to be studied will indicate how this project affects the well-being of its relevant stakeholders.

The results of this study will be essential to demonstrate the potential social benefits of similar (retrofitted) WWT systems, suggest areas of improvement, promote further research in the field, and promote the development of the S-LCA methodology. Thus, it is clear that the objective of this thesis has an essential contribution to the well-being of society, and the topic itself is closely related to the industrial ecology concept.

1.7. Research structure

The thesis structure can be visualized in Figure 1. The two main topics that form the background of this thesis are water scarcity and social sustainability, which will be introduced in the second chapter. In the context of social sustainability assessment, S-LCA will also be introduced in Chapter 2. Next, the state of the art in each phase of S-LCA and the literature review results in S-LCA in the water sector will be discussed in Chapter 3. Thus, the first research sub-question is addressed in that chapter.

The S-LCA methodology applied in this thesis is presented and discussed in Chapter 4, including the phases Goal and Scope definition and Life Cycle Inventory. Then, the impact assessment results in terms of social performance and social risks are presented in Chapter 5, as is the Interpretation phase. A critical discussion on the central issues encountered along the application of S-LCA in this study is presented in Chapter 6. Straight answers to the research (sub)questions, research reliability and validity, and recommendations for further research are presented in Chapter 7.

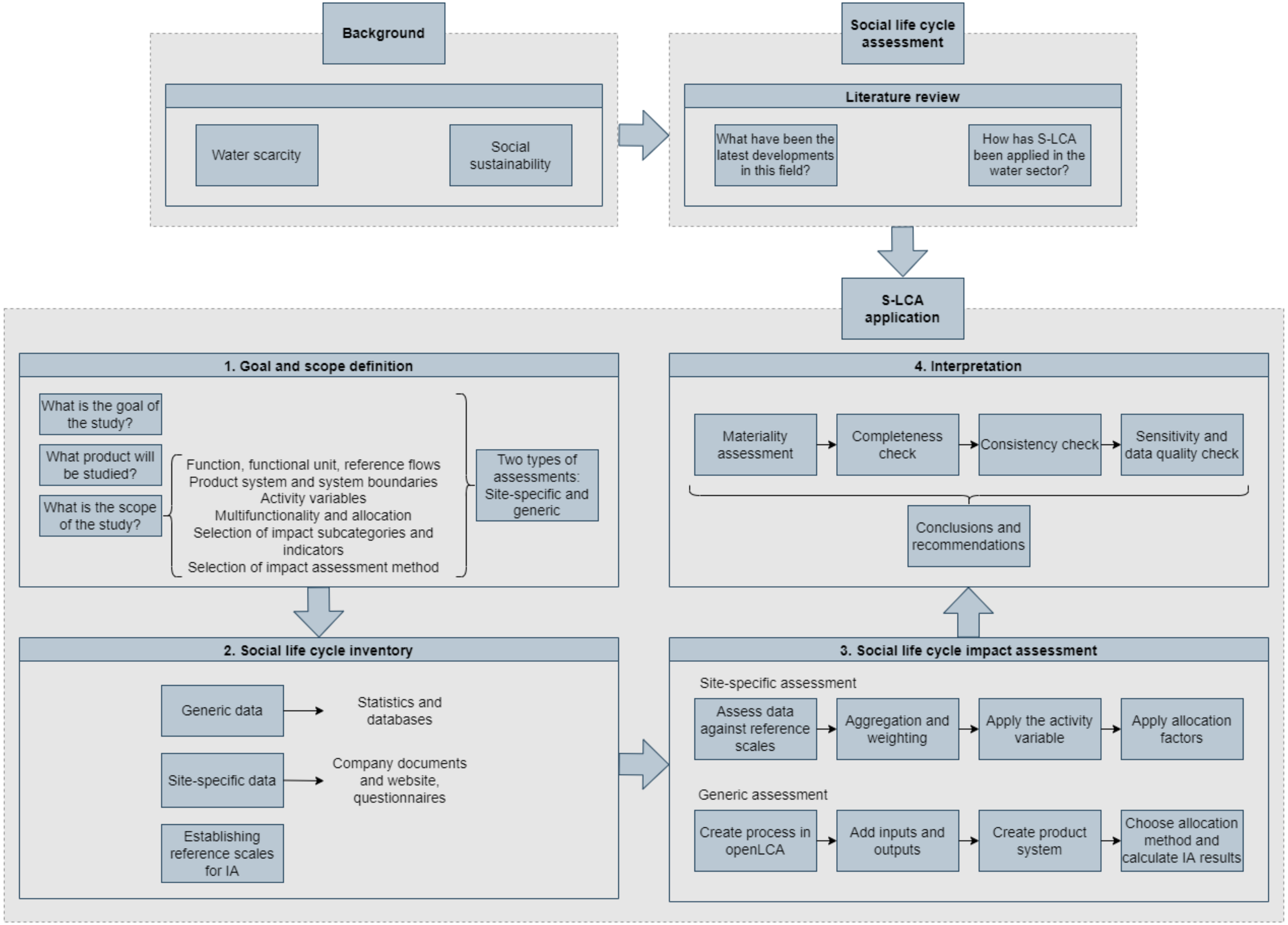

Figure 1: Research structure

2. Thesis background and introduction to S-LCA

The previous chapter briefly mentioned the topics on which this thesis is built. This chapter will address those topics in more detail and present the S-LCA methodology, which is at the heart of this research project. Specifically, water scarcity, sustainability, and S-LCA will be discussed.

2.1. Water scarcity

Water use impacts water supply capacity and quality, which may lead to the inability to satisfy water demand from different sectors and the environment (Liu et al., 2017). The long-term condition of unfulfilled water demand due to insufficient water resources is often defined as physical water scarcity (Gude, 2017; Omer et al., 2020). Furthermore, when it is specific to blue water, water scarcity can be classified into water shortage and stress. The first refers to the lack of water availability per person, i.e., when large populations rely on finite water resources, and thus, it can be understood as population-driven scarcity (Kummu et al., 2016). On the other hand, water stress or demand-driven scarcity occurs when water use (e.g., consumption, abstraction) is too large compared to its availability (Kummu et al., 2016). Garcia and Pargament (2015) highlight that water scarcity and stress are related to quantities of water resources and their inability to satisfy a population's demand. Water scarcity can also be "economic" if the population does not possess enough mechanisms to access clean water in the region (Gude, 2017).

Regarding populations living in cities, it is estimated that this will increase from nearly 55% as of today to 60-90% by the end of this century (Flörke et al., 2018). Subsequently, urbanization coupled with population growth will cause domestic water use and urban water demand to continue to increase in the coming decades, exacerbating pressures on water resources (Flörke et al., 2018; Garcia & Pargament, 2015; Gosling & Arnell, 2016). Other authors note that in addition to population growth, economic growth and climate change are the main drivers of freshwater demand and future water scarcity (Distefano & Kelly, 2017; Gude, 2017). Climate change will have significant impacts not only on water quality but also on water quantity; for example, more regions will be exposed to water scarcity (Gosling & Arnell, 2016; Ricart et al., 2021).

In most water scarcity hotspot regions in the world, such as the Middle East, China, Mexico, the Mediterranean, and India, water scarcity is linked to the inadequate quantity and quality of water (van Vliet et al., 2021). Moreover, when accounting only for water quality, the water scarcity problem worsens in South America and Africa (van Vliet et al., 2021). Water scarcity in these regions and other communities leads to environmental and economic consequences (Hristov et al., 2021). Therefore, as Kummu et al. (2016) indicate, understanding how to adapt to water scarcity and finding sustainable pathways will become increasingly relevant.

Water scarcity is also linked to social conflicts between and within countries, which arise from different interests of water-scarce and water-rich regions (Gude, 2017; Karimidastenaei et al., 2022). For example, Flörke et al. (2018) highlight that there will be less water security for people living near basins from which water is withdrawn and transferred to cities. The increase in water demand will also lead to competition for water use between different sectors such as the urban, industry, agriculture, and tourism sectors (Flörke et al., 2018; Hristov et al., 2021). Regarding agriculture, it is the sector with the most significant water consumption in the world;

hence, sustainable agriculture practices and food security are additional challenges to be solved in the near future (Kummu et al., 2016; Ricart et al., 2021).

2.1.1. Tackling the water scarcity problem

A few water scarcity mitigation options exist. Demand-side adaptation solutions can be implemented in high per capita water consumption situations. These might include enhancing water productivity in the different economic sectors, implementing water conservation strategies, shifting to goods with a lower water footprint, diminishing virtual water exports, and promoting responsible user behavior (Gude, 2017; Kummu et al., 2016). For example, utilities could control water demand through pricing (Gude, 2017). Other strategies include increased public awareness and education, restrictions on water supply, and technological improvements (Gude, 2017). Increasing water use efficiency in irrigation by 10% would benefit 236 million people in overcoming water scarcity (Flörke et al., 2018).

In situations where there is not enough water to satisfy water demand, supply-side adaptations are necessary, such as increasing the availability of water (Kummu et al., 2016; van Vliet et al., 2021). This could be done by transferring water across regions; however, as mentioned previously, this could lead to water dependency on other regions and political stress (Gude, 2017). Other approaches may include obtaining freshwater suitable for use from other sources. Unconventional water resources are those water flows that need additional specialized processes to be considered suitable for use (Karimidastenaei et al., 2022). Karimidastenaei et al. (2022) identified many forms of unconventional water resources such as fog water, fossil water, rainwater, desalinated water, and treated greywater and wastewater. In an attempt to showcase the latter's potential, van Vliet et al. (2021) noted that globally expanding desalination capacity and increasing treated wastewater reuse can substantially reduce water scarcity and the population affected (from 40% to 14%). Nevertheless, desalination is related to environmental damage, high energy consumption, and high costs (Karimidastenaei et al., 2022; Ricart et al., 2021).

2.1.2. Wastewater as a water resource

Wastewater is water used in domestic, commercial, industrial, and agricultural activities (Karimidastenaei et al., 2022). Treated wastewater currently comprises a small fraction of globally used unconventional water resources (Karimidastenaei et al., 2022). Nevertheless, water reuse is increasingly being used in water-scarce regions such as South Africa, North America, France, Spain, Italy, China, and Australia (Karimidastenaei et al., 2022; Müller et al., 2020).

Treated wastewater can be given non-potable or potable uses, especially when water resources are too limited (Gude, 2017; Ricart et al., 2021). Treated wastewater can also be reused in landscape irrigation, agriculture, industries, and water bodies' restoration (Garcia & Pargament, 2015; Karimidastenaei et al., 2022). This resource is often used indirectly when water is abstracted from surface or groundwater resources that previously received treated wastewater (Garcia & Pargament, 2015).

There are many advantages of using reclaimed water. For instance, indirectly reusing treated wastewater increases the availability of water resources and improves the ecological conditions of the receiving water bodies (Garcia & Pargament, 2015). Indeed, treated wastewater is beneficial to the environment since wastewater discharge is controlled, and strategies like the artificial recharge of aquifers are developed (Ricart et al., 2021). Other advantages are its high availability and high nutrient content, allowing farmers to save on fertilization costs (Ricart et al., 2021).

However, many barriers need to be overcome to increase the use of reclaimed water. The main barriers are related to environmental and human risks in agricultural and urban uses (Garcia & Pargament, 2015; van Vliet et al., 2021). The quality and chemical composition of the reclaimed water may affect soil properties and crop production due to heavy metal concentration, high conductivity, and high salinity (Müller et al., 2020; Ricart et al., 2021). Furthermore, despite the high efficiency of wastewater treatment plants in eliminating conventional pollutants, pharmaceuticals are more difficult to remove even if tertiary treatment is applied (Ricart et al., 2021). Additionally, if ingested, pathogens and hazardous substances in treated wastewater can affect human health (Müller et al., 2020). Another barrier is the lack of public acceptance and support for the use of reclaimed water; however, this has been overcome in regions with long dry periods and water deficits (Garcia & Pargament, 2015; Karimidastenaei et al., 2022). Water reuse is also limited by the high costs of treatment technologies and regulations (Gude, 2017; Hristov et al., 2021; Karimidastenaei et al., 2022).

In order to overcome the barriers mentioned above and foster the use of reclaimed water, improved regulation frameworks, investments in wastewater treatment plants, promotion of community participation, and incentives such as quotas on treated wastewater are necessary (Karimidastenaei et al., 2022; Müller et al., 2020; Ricart et al., 2021). From an economic perspective, recovering resources from wastewater may help reduce costs and improve resource efficiency (Müller et al., 2020; van Vliet et al., 2021). Regarding environmental sustainability, treated wastewater use contributes to the conservation of water resources and allows for their more efficient use (Müller et al., 2020). Moreover, water reuse can ensure the fulfillment of social needs and, thus, favor social well-being by providing water suitable for use (Müller et al., 2020).

Lastly, despite the geographic, economic, and political limitations to using unconventional water resources, they are of utmost importance in satisfying increasing water demands and reducing water scarcity (Karimidastenaei et al., 2022). Furthermore, unconventional water resources are essential for achieving the SDGs, particularly SDG 6, “Clean water and sanitation for all” (Karimidastenaei et al., 2022; Ricart et al., 2021).

2.2. Sustainability

2.2.1. Sustainable development

In the World Commission on Environment and Development’s (WCED) report “Our Common Future”, sustainable development was described as a “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987, p. 41). This is the most popular definition of sustainable development; however, given its ubiquitous nature, different societal actors have elaborated their own interpretations (Avesani, 2020; Giovannoni & Fabietti, 2013). Thus, to some extent, the concept of sustainability remains global and somewhat abstract (Milne & Gray, 2013).

The term “sustainable development” has received much attention in the last decades due to social and environmental issues and the lack of considerable progress that ensures human well-being and respects planetary boundaries (Avesani, 2020; Giovannoni & Fabietti, 2013). Sustainable development enhances the quality of life of every person without compromising the planet's boundaries in regenerating resources and assimilating wastes so that future generations have the same possibilities to achieve the same welfare that populations today enjoy (Mazzi, 2020). Similarly, Dyllick and Hockerts (2002) defined sustainability by stating that it implies evolving to a more prosperous and more equitable world where society's cultural accomplishments and the natural environment have been conserved for generations to come. The above means that human and economic development are not limitless and that sustainability requires a systems-level approach; hence, different societal actors must act by setting adequate policies, changing production and consumption patterns, and challenging business-as-usual (Mazzi, 2020; Milne & Gray, 2013).

2.2.1.1. The triple bottom line

There are many approaches to sustainable development. One of them is the three-pillar approach which considers sustainable development as formed by three dimensions (i.e., the social, economic, and environmental dimensions) that are interdependent, have equal importance and must be addressed simultaneously (Avesani, 2020; Mazzi, 2020; Steurer et al., 2005). This approach is also referred to as the "triple bottom line" (TBL), which was coined in the business community by John Elkington in 1997 (Elkington, 1999; Mazzi, 2020). The TBL concept aims to go beyond businesses' economic focus and consider the social and environmental benefits and costs those businesses create in society (Avesani, 2020).

The environmental pillar concerns the relationship between people and nature (Giovannoni & Fabietti, 2013). Despite the multidimensionality of sustainability, for many decades, it has been treated as an entirely environmental issue (Drexhage & Murphy, 2010).

Regarding the social pillar, the WCED's sustainable development definition focuses on the social dimension of sustainability by emphasizing social equity in the present generation and between the present and future generations (i.e., intragenerational and intergenerational equity) (Giovannoni & Fabietti, 2013; Steurer et al., 2005). From a business perspective, the social dimension regards the company's relations with its stakeholders and its impacts on the social systems where it carries out operations (Labuschagne et al., 2005). It has been argued that sustainability's ethical and social aspects have not received special attention from businesses because the benefits are more immaterial (Mazzi, 2020; Yawar & Seuring, 2015). Nevertheless, due to increasing pressure from external stakeholders, more attention is paid to managing social issues in the supply chain (Yawar & Seuring, 2015). The third pillar concerns the economic dimension of sustainability, which relates to the global economy and business operations (Greenland et al., 2022). Economic sustainability involves practices that emphasize long-term economic growth without compromising environmental quality and social well-being (Greenland et al., 2022).

The TBL concept has encountered criticism. Milne and Gray (2013) stated that the TBL is rather insufficient to achieve sustainability; hence, it is a profoundly problematic concept that may lead to reinforcing business-as-usual and even greater levels of unsustainability. They argued that many corporations use the TBL as the equivalent of corporate sustainability, confusing incomplete reporting with "being sustainable" or claims of "moving towards sustainability". Additionally, in an earlier study, they noted that where there are trade-offs between the three pillars, the economic dimension is weighed as the most important one indicating that the social and environmental pillars are dependent on their ability to create profits (Gray & Milne, 2002 as cited in Avesani, 2020). Furthermore, McDonough and Braungart (2002) noted that the TBL often leads businesses to narrowly focus on mitigating their negative (environmental) impacts by adopting end-of-pipe initiatives rather than designing products and processes that are sustainable from the very beginning.

2.2.2. Sustainable development and businesses

Companies, particularly large ones operating in different countries with different regulations, face increasing pressure to consider the environmental, social, and ethical issues stemming from their business (Kolk, 2016). Furthermore, companies should carefully consider the social issues of concern as long as they operate in a societal context and need to secure resources to continue their business (Steurer et al., 2005). Put differently, because firms depend on external stakeholders to obtain resources, stakeholders have leverage over a firm (Frooman, 1999). Therefore, organizations ought to take actions to advance toward sustainable development, and superficial activities such as philanthropic initiatives or volunteering are no longer considered sufficient by stakeholders in this regard (Schönherr et al., 2017).

2.2.2.1. Corporate sustainability

In line with the above, businesses have a responsibility in the route to sustainability (Avesani, 2020). Subsequently, the sustainable development concept has been adopted by the business world. Some authors argue that a company is sustainable when it produces benefits for its shareholders in such a way that the environment is protected and the lives of other stakeholders are improved (Savitz & Weber, 2006 as cited in Meseguer-Sánchez et al., 2021). The most popular definition of business or corporate sustainability is the one constructed from the sustainable development definition by the WCED: implementing activities and strategies that allow for meeting the needs of the firm and its stakeholders today, while the human and natural resources that will be demanded in the future are protected and sustained (IISD Deloitte and Touche, WBCSD, 1992 as cited in Steurer et al., 2005).

However, some researchers note that nothing in the nature of businesses and capitalism can ensure that people have access to the environmental services necessary to meet their needs (Milne & Gray, 2013). In other words, large corporations may find it challenging to reconcile creating value for the common good with creating value for shareholders (van der Waal & Thijssens, 2020). Therefore, the concept of sustainable development may be decoupled from corporate sustainability because the first regards global challenges at the macro level, and the second is more focused on activities that generate business value at the business or micro level (Dyllick & Muff, 2015).

2.2.2.2. Corporate social responsibility

Under the CSR heading, increasing attention has been put on the social, ethical, and environmental aspects of business activities (Kolk, 2016). According to Avesani (2020), companies use CSR as a tool to take responsibility for their environmental and social impacts. The Corporate Social Responsibility Pyramid proposed by Carroll (1991) is one of the most popular understandings of the concept. The pyramid has a base of economic, legal, and ethical business responsibilities, while philanthropic responsibilities form the pinnacle. Schönherr et al. (2017) expanded this concept by considering the following principles. First, following Porter and Kramer's theory of "creating shared value" (Porter & Kramer, 2011), creating value for shareholders and other groups of society may facilitate progress toward sustainable development, as the connection between business and society is emphasized. Although this theory has been criticized for being superficial and ignoring the tensions between economic and social goals (Crane et al., 2014), it has redrawn attention to the consideration of business purpose in society (beyond mere philanthropic contributions) while also considering the impacts on other stakeholders (Schönherr et al., 2017).

The second expansion to the CSR concept considered by Schönherr and colleagues regards the work of Whiteman et al. (2013). They affirmed that CSR must address impacts on society and link business operations to ecological processes and planetary boundary conditions. Nevertheless, it seems that most management theories linked to sustainability tend to ignore the obvious fact that all organizations are entrenched within the environment (Starik & Kanashiro, 2013). Realizing this, and in line with the concepts of sustainable development presented above, it is necessary to understand businesses' contributions to sustainable development (Schönherr et al., 2017). Therefore, this extended CSR concept links the CSR activities of organizations with their impacts on the broader society and the environment.

The above indicates that corporations need to have a good understanding of both their direct and indirect impacts on society and the environment. Although many tools are available for measuring and reporting social sustainability issues, these tools and management systems need to consider the impacts of organizations' activities *and* those that occur along the value chain (Schönherr et al., 2017; Weingaertner & Moberg, 2014). This is not an easy task since it requires access to up-to-date data (Schönherr et al., 2017) and an adequate framework to capture those impacts. An approach that meets this requirement is that of the life cycle approach. Through life cycle thinking, organizations can consider all the impacts that accrue along the whole life cycle of products, i.e. including the impacts along the value chain.

2.2.3. Social sustainability assessment through life cycle thinking

Most management tools consider social problems from one point of view alone (i.e., that of the single organization), while social issues are created by many different subjects and processes that together contribute to the overall social impacts related to a product. In this regard, the life cycle approach helps to avoid shifting problems from an organization or process to another one up- or downstream the supply chain or to another point in time (Mazzi, 2020). In life cycle assessment, S-LCA concerns the evaluation of social impacts. Compared to similar social assessment tools, S-LCA provides a more holistic perspective due to the inclusion of the entire life cycle of a product or service. Furthermore, assessing a product with a life cycle approach allows for identifying stages in the life cycle where improvements can be implemented, enhancing the entire product's social performance (Mazzi, 2020). Therefore, sustainable production and consumption processes necessary for sustainable development can be promoted.

Given the increased interest in social issues and life cycle thinking (Petti et al., 2018), S-LCA can be an attractive solution to organizations' needs to evaluate their social impacts since it represents the best available science to collect data and report on positive and negative impacts of products' life cycles (Norris, 2012). Like E-LCA, S-LCA can be used to assess technology alternatives regarding social impacts and for sustainability management and labelling (Chhipi-Shrestha et al., 2015). Additionally, S-LCA can be used as a decision-support tool facilitating the comparison of products (Huertas-Valdivia et al., 2020; Jørgensen et al., 2012; Petti et al., 2018). However, some authors argue that S-LCA cannot contribute to product comparisons due to uncertainties in the assessment (Benoît-Norris, 2014). This may be related to the difficulty in reporting results for a given functional unit (RS approach), as the results do not represent product-specific information (Zanchi et al., 2018). If not based on a functional unit, the impacts of different products' life cycles cannot be compared.

Despite the above limitation, S-LCA can still be used as a decision-support tool to reduce potential negative impacts on people's well-being resulting from different organizations' activities (Dreyer et al., 2006; Fan et al., 2015; Pollok et al., 2021). As such, S-LCA is a managerial decision-support tool with growing importance since it can assist in evaluating social risks along the value chain, assessing social consequences of investment choices, and in the verification of ethical compliance of suppliers (Huertas-Valdivia et al., 2020). In light of all the aspects discussed above, S-LCA supports improving the social aspects of a product's life cycle, thereby contributing to more socially sustainable products.

2.3. Introduction to Social Life Cycle Assessment (S-LCA)

Along the life cycle of products (Figure 2), social impacts are produced, and these impacts must be measured and mitigated if a company wishes to improve its social sustainability performance. S-LCA is described as a methodology or framework for evaluating and communicating such impacts (Norris, 2012). In fact, it is aimed that with the use of S-LCA, the improvement of social conditions, as well as that of the social performance of a product throughout its life cycle, will be achieved (García-Sánchez & Güereca, 2019; Huertas-Valdivia et al., 2020; Opher et al., 2018; UNEP, 2020).

Since S-LCA is about protecting stakeholders (Dreyer et al., 2006), it is crucial to understand how social impacts are produced. Zamagni et al. (2011) note that, based on the broad definition in the Guidelines, social impacts may be linked both to companies' behavior and socioeconomic processes. Lehmann et al. (2013) go a step further by classifying social impacts into those that originate due to a project or policy, the technologies themselves, and the conduct of companies.

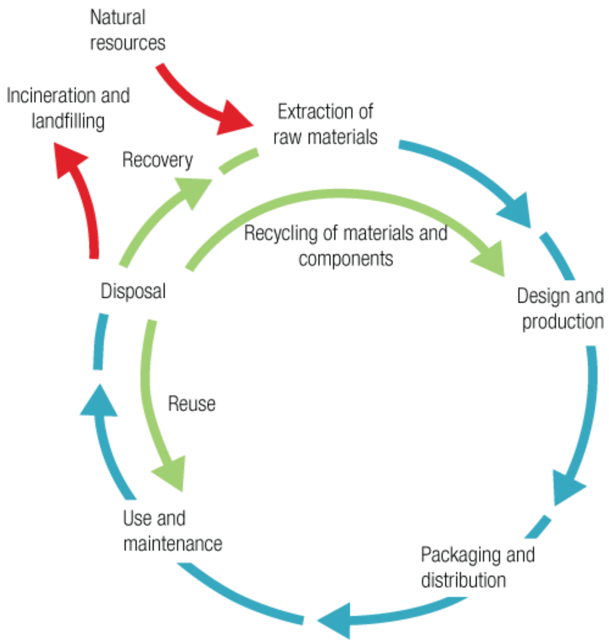

Figure 2: Product life cycle diagram (Life Cycle Initiative, n.d.)

Social impacts can be negative or positive, such as the high rates of accidents while manufacturing a product or the creation of more job positions due to a new packaging line. Another classification of social impacts is that of potential and actual social impacts. The first relates to the likelihood of social impacts resulting either from the behavior of companies in the product's life cycle or from the product's consumption (UNEP, 2020). The second is an impact that results from a causal relationship between a given activity and a component of human well-being (UNEP, 2020).

The modeling characteristics and systematic approach of E-LCA are the base for evaluating social impacts in S-LCA (Norris, 2012). Furthermore, S-LCA is a tool that uses a mix of methods, representation models, and data on the product system and its social impacts (Huertas-Valdivia et al., 2020; UNEP, 2020). The S-LCA framework follows the Life Cycle Assessment standards ISO 14040-14044 (UNEP, 2020), with some adaptations to cover social aspects (Parent et al., 2010) since it lacks formalization in the form of an international standard (Arcese et al., 2013; Shemfe et al., 2018). Thus, S-LCA is composed of four iterative phases: (1) goal and scope definition; (2) life cycle inventory; (3) life cycle impact assessment; and (4) interpretation (Figure 3).

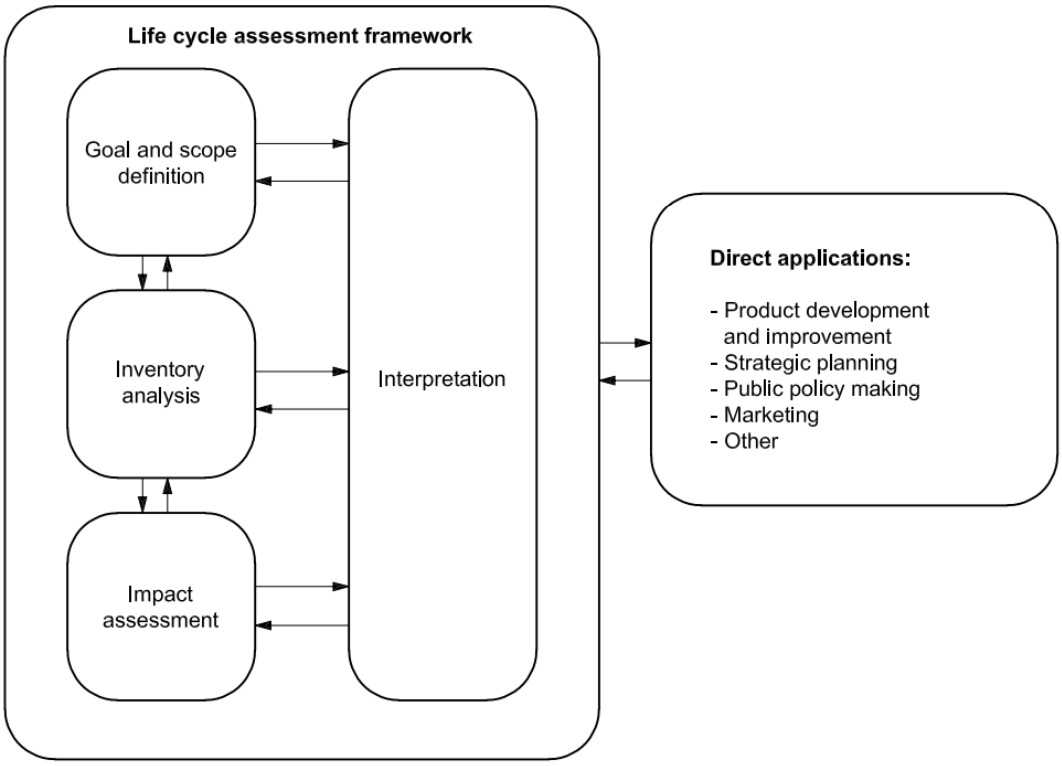

Figure 3: Stages of Life Cycle Assessment (ISO, 2006)

2.3.1. Historical development

In 1996, the Social and Environmental Life Cycle Assessment (SELCA) concept was introduced, emphasizing the difficulty of integrating social considerations in LCA assessment methods (O'Brien et al., 1996). As discussions about integrating social aspects in LCA increased, the UNEP and SETAC partnership launched the Life Cycle Initiative in 2002 (Huertas-Valdivia et al., 2020). Subsequently, a task force was formed to fulfill the following objectives: convert the LCA tool into a sustainable development tool; include socio-economic benefits into LCA through a framework; determine the implications for the life cycle inventory and impact assessment phases; and facilitate a forum for sharing experiences in the inclusion of social aspects into LCA (UNEP/SETAC Life Cycle Initiative, 2009).

Some of the initiative's objectives were met by providing a forum where experts could exchange information and ideas (Norris, 2012) and by conducting a feasibility study in 2006 (Grießhammer et al., 2006). The results of this study pointed out that it is feasible to assess social aspects into the framework of LCA, but that considerable hurdles exist, particularly with regards to the goal and scope definition, categorization and classification of indicators, and most importantly, the characterization models (Grießhammer et al., 2006).

The rest of the objectives were achieved by the preparation and publication of the first Guidelines for Social Life Cycle Assessment of Products in 2009 (UNEP/SETAC Life Cycle Initiative, 2009) and the Methodological Sheets for Subcategories in Social Life Cycle Assessment published in 2013 (Norris, 2012; UNEP/SETAC Life Cycle Initiative, 2009). In 2020, a new version of the Guidelines was published. A new methodological development called social organizational LCA (SO-LCA) was introduced, and a new stakeholder category and impact subcategories were added to the Guidelines (UNEP, 2020). Similarly, a new version of the Methodological Sheets was published in 2021 (UNEP, 2021) to serve as an operative tool in applying S-LCA.

Another effort to establish methodological guidelines for carrying out S-LCA is the work by PRé Sustainability BV and the Roundtable for Product Social Metrics, who have prepared the Handbook for Product Social Impact Assessment (PSIA) since 2013 (M.J. Goedkoop, de Beer, Harmens, Saling, Morris, Florea, Hettinger, Indrane, Visser, Morao, Musoke-Flores, Alvarado, Rawat, et al., 2020). The social impact assessment proposed in PSIA is a more industry-oriented approach. Mesa Alvarez and Ligthart (2021) provide a comparison of the Guidelines and PSIA.

After the publication of the Guidelines and the Methodological Sheets, research in S-LCA has grown exponentially (Huertas-Valdivia et al., 2020), both in terms of stand-alone S-LCA studies and studies within more comprehensive sustainability assessments (such as LCSA) (Zanchi et al., 2018). Although S-LCAs have been performed in a broad diversity of sectors, research in the field is highly fragmented as various goals and scopes prompt researchers to develop different approaches or methods (Benoît-Norris, 2014; Huertas-Valdivia et al., 2020). Thus, even after years of the publication of the first Guidelines, S-LCA is the least mature methodology in LCSA (Furness et al., 2021; Valdivia et al., 2021), and hence, the research field is still developing (Benoît-Norris, 2014). As the results of Huertas-Valdivia et al. (2020) point out, research in S-LCA is expected to continue to grow in the coming years.

3. Social life cycle assessment

In the third chapter, the four LCA stages are discussed. Special attention is given to the main issues regarding S-LCA's application in the literature. The chapter ends with a literature review of S-LCA case studies in the water sector.

3.1. Goal and scope definition

"Goal and scope definition" is the first of four phases that make up an S-LCA, in which the study's purpose, object, and extent are defined (UNEP, 2020). A clear delineation of the goal of a study is crucial because it will determine how the S-LCA will be carried out in the following phases (Parent et al., 2010; UNEP, 2020).

3.1.1. Goal definition

As Jørgensen et al. (2012) noted, S-LCA is primarily concerned with enhancing the social conditions of the stakeholders affected along the life cycle of products. Although this is the underlying goal of all S-LCA studies, the Guidelines suggest answering a set of questions to specify further what, by whom, and how the results will be used. These questions are about the study's goal, planned use, target audience, and affected stakeholder (UNEP, 2020). One of the main elements that affect S-LCA applications is the perspective from which the study is conducted, which is determined by whoever is responsible for the consequences of a decision or action (Zanchi et al., 2018). Dreyer et al. (2006) highlighted that since S-LCAs assist businesses in operating in a socially responsible way, they are developed from a company perspective. In contrast, a tool developed from a societal perspective will be different.

Furthermore, since S-LCA is often used to support decision making, considering who the user of the study results and which information they are interested in is relevant (Zanchi et al., 2018). However, researchers often do not address or provide enough details about these goal-definition questions and do not question some of the features that complicate the application of S-LCA, such as the functional unit and scope definition (Zanchi et al., 2018).

3.1.2. Scope definition

The methodological framework must be determined based on the established goal. Thus, during the scope definition, the system is pre-defined to a certain degree by considering many elements that constitute its foundation, such as the product system itself, the system boundaries, the function and the functional unit (UNEP, 2020). In the following sub-sections, each of these elements will be discussed in further detail.

3.1.2.1. Product system

The product system is defined by all the processes that make up the life cycle of a product. A shortcut to identifying all the life cycle processes of a product may be the use of databases or Input-Output tables that identify all the inputs an industry needs from other economic sectors to produce one unit of output (Parent et al., 2010).

In E-LCA, the environmental impacts or the changes in the quality of the environment are closely linked with the physical inputs or outputs of a process; thus, the environmental impacts of a product's life cycle are determined by the performance of the processes included (Dreyer et al., 2006). In contrast, social impacts assessed in S-LCA are related to how a product's life cycle affects people's well-being; hence, those activities that create these impacts are the focus of attention in S-LCA (Dreyer et al., 2006). Furthermore, the impacts of those activities depend on where they occur and are more related to the companies that undertake these activities than the technological systems they adopt (Zanchi et al., 2018). Therefore, an assessment at a process level is less reasonable in S-LCA because, in most cases, the physical conditions of the processes will not cause impacts on people (except for some direct health impacts); instead, these will originate from the conduct of the companies involved in the product's life cycle (Dreyer et al., 2006).

The emphasis on company conduct is also endorsed in the publications that establish the methodological framework of S-LCA: the Guidelines and the PSIA Handbook (M.J. Goedkoop, de Beer, Harmens, Saling, Morris, Florea, Hettinger, Indrane, Visser, Morao, Musoke-Flores, Alvarado, Rawat, et al., 2020; Opher et al., 2018). Therefore, the social impacts in S-LCA are strongly connected to a product's value chain and the behavior of the organizations involved (Opher et al., 2018; Zamagni et al., 2011).

Zamagni et al. (2011) argue that social impacts not only can be caused by the conduct of the companies but also by the socioeconomic processes in place. Regarding the former, some indicators are entirely derived from how a company manages social aspects along the supply chain (Zamagni et al., 2011). Lehmann et al. (2013) made a similar observation by emphasizing that the impacts on the stakeholders "Society", "Consumers", and "Value chain actors" are mainly determined by a company's behavior.

Regarding the latter, some indicators assess the social context of the unit processes by considering the social conditions of a region or economic sector (generic indicators). This suggests that social stressors (and thus, social impacts) are created in the Sociosphere and have an organizational nature rather than a technical one (Parent et al., 2010). Moreover, some impacts may be originated from the unit processes in the Technosphere (Parent et al., 2010). For example, working hours can be inferred straight from the unit process' output (Hunkeler, 2006) without considering the organizational perspective. Although the number of hours worked can be determined by managerial decisions, the time required by the workforce to produce an output is determined at a technical level (Parent et al., 2010). Nevertheless, as noted above, it is crucial to recognize that most of the social impacts in S-LCA are not dependent on the physical conditions of the unit processes (Dreyer et al., 2006).

Therefore, focusing on social impacts calls for serious consideration of how the product system is developed and modelled (Dreyer et al., 2006). This is why there is a lack of agreement on how the product system should be defined (Zanchi et al., 2018). A combination of a technology-oriented approach with an organization-oriented approach would be ideal as all the technological unit processes along the product's life cycle and the individual companies responsible for them would be included (Zanchi et al., 2018). This way, the inclusion of all the sources of impacts can be ensured since no process or organization in the life cycle is left out. Furthermore, as expected, this type of product system will have implications on the system boundaries; they should also reflect the two natures of the system under study.

3.1.2.2. Functional unit

The functional unit is at the heart of LCA, given LCA's focus on a product (Zamagni et al., 2011). Mainly, since the function of a product is the object of analysis of an E-LCA, all the unit processes necessary to fulfill the functional unit constitute the product system and are the source of the environmental flows responsible for the impacts (Parent et al., 2010). Since in S-

LCA, the impacts are analyzed at the organizational level instead of the process level, the connection between the impacts and the product and its function is somewhat lost due to the difficulty of linking a company's conduct with the product under study (Dreyer et al., 2006).

For example, consider a company producing a single product with policies encouraging equal opportunities among workers. Expanding its product line to include a second or third product will likely have a negligible effect on the company's measures to promote equal opportunities. Therefore, whether this company has policies in place regarding this social aspect is independent of the products it commercializes. Another example is a company that decides to optimize its processes so that its final product has a lower carbon footprint. In an environmental LCA, this modification of processes will produce different results considering the same functional unit. However, using less or more efficient technologies will not change a company's initiatives to promote sustainability in its value chain. These examples illustrate that conflict arises when the functional unit and a company perspective are applied in the same framework. Consequently, the following question comes up: if the goal is to improve the social aspects of a given product system, is the same application of the functional unit in LCA suitable in S-LCA? (Zamagni et al., 2011).

Therefore, while environmental impacts have a direct link with the inputs/outputs of the processes necessary to deliver the functional unit (R. Wu et al., 2014), and thus, the relationship between the impacts and the functional unit is clear, socioeconomic impacts are caused by the behavior of the companies that are part of a product's life cycle, and hence, the relation between the impacts and the product becomes indirect and less quantifiable (Dreyer et al., 2006). However, the fact that social impacts are linked with the behavior of organizations and not with the function of a given product is of great importance, as demonstrated by the many boycott campaigns started by different stakeholders when the conduct of a company—and not its products per se—was deemed unethical and wrongful (Zamagni et al., 2011).

The next big issue in using a functional unit in S-LCA is apparent –the link of social inventory data (information about the behavior of a company) to the product system becomes a challenge (Zamagni et al., 2011). For this reason, it is arguably necessary to find a method that facilitates a meaningful connection between the social profiles of organizations and the product under study (Dreyer et al., 2006). In order to make the indicator results proportional to the product system, the practitioner can either relate the elementary flows or social stressors to the process outputs (like in E-LCA) or use an activity variable to grant different levels of relative importance to each unit context in the product system (Parent et al., 2010; Zanchi et al., 2018). In the first approach, an impact pathway implicitly carries the different processes' weights so that the indicator result indicates the functional unit's impact, whereas, in the second approach, the importance of each context unit in the product system is given by relative weights (Parent et al., 2010). In other words, a "share factor" can be used to reflect the importance of a company's social performance in the overall life cycle (Dreyer et al., 2006). Additionally, an activity variable also entails information about the scope (e.g., the share of the supply chain that has attribute X) and is an alternative to the functional unit, which is necessary to model the product system but might not always be used as a way to present the results (Benoît-Norris, 2014; Zanchi et al., 2018). Most S-LCA studies define a functional unit (Petti et al., 2018, 2014), especially when they are part of a broader sustainability assessment, as is LCSA and the results of E-LCA, LCC, and S-LCA must be aligned or at least consistent (Zanchi et al., 2018).

Some researchers acknowledged the issues above by questioning whether there are other meaningful ways to represent the social aspects of a product's function, apart from trying to quantitatively link the indicator results with the functional unit (Parent et al., 2010). One emerging methodology aiming to keep the organization-oriented perspective with the product approach is Organizational LCA, as the social aspects are evaluated vis-à-vis an organization's behavior and its product portfolio (Zanchi et al., 2018).

3.1.2.3. System boundaries and cut-off criteria

The system boundaries define which processes will be covered in a product system based on the study's goal (Guinée et al., 2002). The identification of system boundaries is facilitated through the initial delineation of the product system. The system boundaries could be defined by the level of influence that the company performing the assessment (e.g., product manufacturer) has on the other parts of the life cycle (Dreyer et al., 2006). Alternately, the entire life cycle could be included, except for those processes whose influence on the results is insignificant (Zanchi et al., 2018). For instance, Ekener-Petersen et al.'s (2014) study on fossil fuels and biofuels for vehicles includes the production of feedstock, intermediate processes and transport but leaves out the use phase.

Furthermore, the relevance of a process and its degree of influence also form the base for the distinction between foreground and background processes and determine the data requirements (Martínez-Blanco et al., 2014). However, the way to determine if a process is relevant or not is unclear (i.e., how to determine how much is significant enough?). Researchers may use a physical or economic approach or other criteria, such as the number of hours worked (R. Wu et al., 2014; Zanchi et al., 2018). Consequently, the Guidelines classify different cut-off criteria into three types: social significance, identical elements, and available resources (UNEP, 2020). The first includes quantitative and qualitative approaches such as the amount of materials used (Ekener-Petersen & Finnveden, 2013) and the consideration of the social context, respectively. The second applies to comparative S-LCAs where identical processes in the same location or organization could be excluded. Finally, the third refers to the availability of data and time (Franze & Ciroth, 2011).

The delineation of a product system determines the type of data required and the system boundaries or the extent of the analysis (Zanchi et al., 2018). As mentioned above, a two-layer product system will have implications for the system boundaries, indicating that these should also share that dual nature. An effect-oriented approach concerns the extent to which a life cycle phase or process influences stakeholders, whereas a technology-oriented approach is related to the physical unit processes within the product system (Zanchi et al., 2018). A double-layer system boundary is relevant for identifying and including all the stakeholders linked to the product system and all the life cycle phases.

3.1.2.4. Stakeholder categories

Because the goal of S-LCA is to improve the social conditions of stakeholders, the Guidelines propose a method that mainly focuses on six groups of stakeholders: Workers, Local community, Society, Consumers, Value chain actors, and Children (UNEP, 2020). Decisions on whether to include or exclude stakeholder groups from the assessment are part of the scope definition; for example, a study can focus only on one particular stakeholder group (Norris, 2012).

The results of some S-LCA review studies highlight that the stakeholder category "Workers" has been receiving the most attention (Di Cesare et al., 2018; Huertas-Valdivia et al., 2020; Kühnen & Hahn, 2017; R. Wu et al., 2014). In contrast, the stakeholders Consumers, Value chain actors, and Local community are the least evaluated in S-LCA studies (Huertas-Valdivia et al., 2020; R. Wu et al., 2014). The Guidelines suggest including new stakeholder categories or regrouping the existing ones depending on the impacts a product may have (UNEP, 2020).

3.1.2.5. Impact categories, impact subcategories, and indicators

An impact category represents important social issues to stakeholders; in practice, they represent logical groupings of subcategory results (UNEP, 2020). Impact subcategories are socially relevant themes and are classified according to stakeholder groups (Worker, Local community, Society, Value chain actor, Consumer, or Children) and/or impact categories (Human Rights, Working Conditions, Cultural Heritage, Governance, and Socio-economic repercussions) (Norris, 2012; UNEP, 2020).

Social indicators link social data, impact subcategories, and impact categories (R. Wu et al., 2014) (Figure 4). They can be compared to E-LCA's elementary flows and referred to as social stressors when used similarly (Parent et al., 2010). In addition, social indicators can be qualitative, quantitative, and semi-quantitative (UNEP, 2020). In an analysis of 46 case studies, Di Cesare et al. (2018) identified 569 indicators, most of them being semi-quantitative (57%) and qualitative (25%).

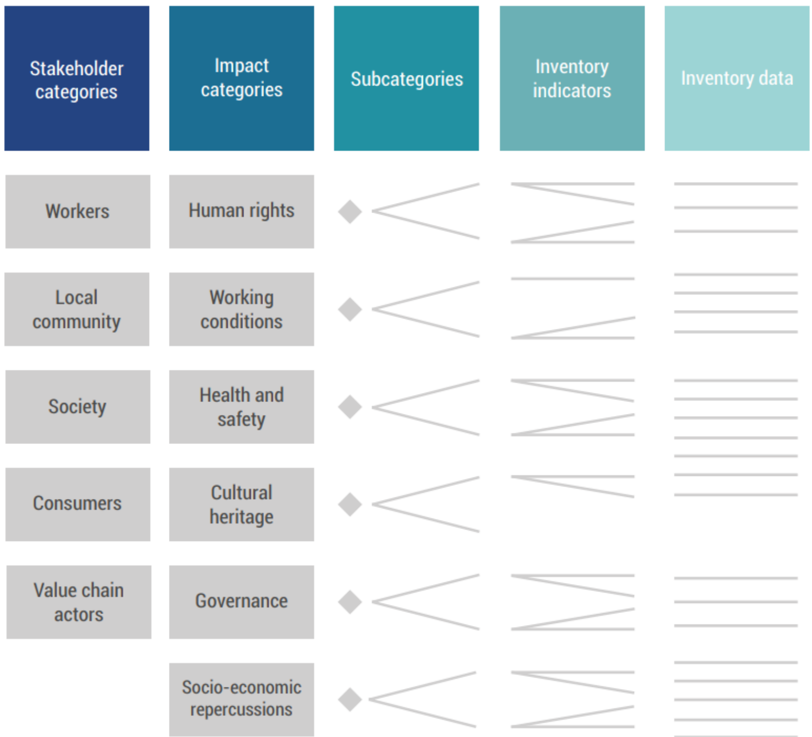

Figure 4: Relationship between stakeholder categories, impact categories, subcategories, indicators and inventory data (UNEP, 2020)

However, one of the biggest challenges in applying S-LCA is the selection of indicators (Zanchi et al., 2018). Although indicator selection is rarely discussed in S-LCAs, most indicators are selected due to their relevance in a particular sector, based on literature review, or generic analysis results. In this context, two approaches for indicator selection can be identified: 1) the bottom-up approach, where indicators are selected based on their relevance to the stakeholders, data availability, and the business context (Dreyer et al., 2006; Kruse et al., 2008), and; 2) the top-down approach, which is based on what is valuable to society hence, international conventions and guidelines are used as references (Dreyer et al., 2006; Zanchi et al., 2018). Lastly, as pointed out in the feasibility study by Grießhammer et al. (2006), more case studies should be conducted to overcome the hurdles of S-LCA application, which would conduct to the formation of a clear and generally accepted list of social indicators.

3.2.Life cycle inventory

The life cycle inventory phase involves collecting and organising data for all the unit processes included in the system boundaries and obtaining LCI results (Norris, 2012; Parent et al., 2010; UNEP, 2020). Data drives LCA, and its source and quality are pivotal to the results as the amount of information needed is considerable (Curran, 2012; Zanchi et al., 2018). Data collection, or LCI, is the most time-consuming, energy-intensive and daunting step of a (social) LCA (Benoît-Norris, 2014; Curran, 2012; Huertas-Valdivia et al., 2020; Norris, 2012). Indeed, the need for and lack of data and the difficulty of quantifying some indicators are some of the aspects that limit the applicability of S-LCA (Benoît-Norris, 2014; Huertas-Valdivia et al., 2020). When S-LCA is carried out from an organizational perspective, the company's behavior towards its stakeholders is examined in the inventory step (Dreyer et al., 2006).

Three types of data are emphasized in the Guidelines (UNEP, 2020): the activity variable, the inventory data, and the data for the Performance Reference Points (PRPs) used in the Type 1 or Reference Scale approach in the impact assessment. In addition, the fourth type of data is contextual data which reflects the average social situation of a country or an economic sector (Benoît-Norris, 2014).

The same entity of elementary flows is aggregated into LCI results in an E-LCA. However, in S-LCA, that is not always possible because social impacts are site-specific, which means that the indicator result is arrived at not only by the company's conduct but also by the local context (Dreyer et al., 2006; Parent et al., 2010). It is important to highlight the importance of location information in S-LCA since social impacts are linked to the particular geographical and cultural context where they occur; the same product produced in different parts of the globe may generate different social impacts (Zamagni et al., 2011). Nevertheless, in some cases, the technology or industry type may play a more prominent role than the location of the processes, and there are even some subcategories that are less sensitive to the geographical location than others, such as "Public commitment to sustainability issues" (Norris, 2012).

Furthermore, based on the goal of the study, generic or site-specific data may be required, and different data collection methods may be used (Norris, 2012; R. Wu et al., 2014). The types of data used may also depend on the product system, i.e., foreground and background processes (Zanchi et al., 2018). Specifically, foreground processes may require site-specific data, while generic data may suffice for background processes (Zanchi et al., 2018).

Additionally, it can be noted that when a product system is not defined to its fullest extent or the study does not have a specific case or product at hand, life cycle inventory databases are used as the primary data source (Ekener-Petersen et al., 2014). It can also be the case that an S-LCA is carried out for product design or product development and little information is available on the supply chain; in this scenario, the use of a database may make more sense than performing a site-specific analysis (Norris, 2012). On the other hand, a detailed data collection strategy must be employed when a case-specific study is at hand or at least some information about the supply chain is available (Blom & Solmar, 2009; Norris, 2012).

When data is not readily available, the behavior of a company can be deducted from sectoral information in a given country (Dreyer et al., 2006). Generic data may be used in S-LCAs as statistical data and input-output models (R. Wu et al., 2014). However, because social performances rely more on the geographical context and the behavior of companies, the use of databases in S-LCA seems to be more delicate than in E-LCA (Zanchi et al., 2018). Furthermore, a couple of databases (e.g., the Social Hotspot Database, SHDB; and the Product Social Impact Life Cycle Assessment, PSILCA) have been created to calculate and analyse the social impacts of products over their life cycles (Huertas-Valdivia et al., 2020). These two databases were developed in compliance with the Guidelines and are the first to directly conduct hotspot assessments and S-LCAs of products (UNEP, 2020).

Using databases (e.g. SHDB) facilitates the screening of social risks or opportunities in the value chain and assist in the prioritization of data collection activities; for instance, more thorough data collection efforts can be directed to the high-risk sectors identified (Norris, 2012). Additionally, databases can perform general assessments of a product category instead of one specific to a product chain (R. Wu et al., 2014). Therefore, databases can be used to gain a better understanding of the social conditions in a country or sector and are a valuable source to look for indicators for which there is generic data available (Benoît-Norris, 2014; Norris, 2012; UNEP, 2020).

The following section will provide further information on the PSILCA Database.

3.2.1. PSILCA database

Developed by the consultancy GreenDelta, PSILCA database is based on a multi-regional input-output database called Eora (Huertas-Valdivia et al., 2020). The database contains social data specific to 189 countries and approximately 15,000 economic sectors (Maister et al., 2020). Eora uses a heterogeneous classification to keep the national classification of sectors in IO or Supply-Use tables; however, when national IO tables are unavailable or have a less detailed sectoral classification, the database adopts a 26-sector classification (Maister et al., 2020). Therefore, it can be said that PSILCA is a comprehensive database.

The selection of stakeholders and indicators in PSILCA was based on the Methodological Sheets (UNEP/SETAC, 2013) and an S-LCA study of a notebook computer by Ciroth and Franze (2011). Four stakeholder categories are included (Workers, Local Community, Society, and Value Chain Actors), for which there are 25 social and socioeconomic subcategories and 69 qualitative and quantitative indicators (Maister et al., 2020).

Thanks to the MRIO database, it is possible to have estimates of the product supply chains of different country-specific sectors (Benoît-Norris, 2014). Social data in the database were retrieved from statistical agencies (e.g., World Bank, International Labor Organization, United Nations), restricted and open access databases, and own case studies and investigations (Maister et al., 2020). The database also contains information regarding worker hours for each sector in the supply chain (Benoît-Norris, 2014). The worker hours correspond to 1 USD of sector output and were calculated based on the equation below, with data from Eora satellite accounts (compensation of employees), Eora MRIO table (gross outputs), and the International Labor Organization (mean hourly labor cost).

$$Worker\ hour = \frac{Unit\ labor\ costs}{Mean\ hourly\ labor\ cost}$$

The unit labor costs refer to the compensation of employees in a sector per unit of its output (USD), and the mean hourly labor cost refers to the average remuneration for the work performed in a given country and sector (Maister et al., 2020; Serreli et al., 2021). Thus, the final result is in hours per unit of sector output (USD).

For some indicators, the data needed to be normalized. This means that when the data on an indicator is proportional to the size of a sector or the economy, it needs to be normalized by the number of employees, total output, or the population of a country so that the values are comparable across different countries and sectors (Maister et al., 2020). For example, the indicator "Rates of non-fatal accidents at workplace" indicates the number of non-fatal accidents per 100,000 employees per year.

Furthermore, the indicators also carry contextual information since they are risk-assessed or "characterized" by assigning a level of risk (Benoît-Norris, 2014). For each indicator type, an ordinal level is assigned to the observed indicator value; on a negative (risk) scale, there are six levels between very low to very high risk (see Table 1) (Maister et al., 2020). On the other hand, for indicators that may indicate positive social impacts ("Contribution of the sector to economic development"), an opportunity scale is used (Maister et al., 2020). The basis for assigning risk levels to the indicator values are characterization models that use distributions of data from international conventions and norms, labor regulations, expert judgements and personal experience (Benoît-Norris, 2014; Maister et al., 2020). However, due to the subjectivity of this step, the database allows the user to modify these selections in case studies.

Table 1: Risk assessment example for the indicator "Social security expenditures"

Risk assessment	**Distribution of % of GDP**
Very high risk	0-2.5
High risk	2.5-7.5
Medium risk	7.5-15
Low risk	15-20
Very low risk	>20
No data	n.a.

The impact assessment method used in PSILCA is the "Social Impacts Weighting Method". This method assigns values (i.e., impact factors or characterization factors) to different risk or opportunity levels. The impact factor for the medium risk level is given a value of 1, and the impact factors of the levels above (very high risk and high risk) and below (low risk and very low risk) are assigned values to the powers of ten, i.e., 100, 10, 0.1, 0,01, respectively (Table 2). Therefore, the indicator results are calculated by multiplying the characterization factor by the worker hours. The results are expressed in relation to the medium risk level, with "medium risk hour" (mrh) as the unit. As for the social risks along the whole supply chain, the indicator results are determined by the price and quantity of inputs, worker hours per unit of output, and characterization factors (Maister et al., 2020). Therefore, the results obtained are very comprehensive top-down results but with reduced granularity compared with process-level data (Benoît-Norris, 2014).

Table 2: Risk and opportunity levels in PSILCA with their corresponding characterization factors

Risk level	**Characterization factor**	**Opportunity level**	**Characterization factor**
Very high risk	100	High opportunity	10
High risk	10	Medium opportunity	1
Medium risk	1	Low opportunity	0.1
Low risk	0.1	No opportunity	0
Very low risk	0.01	No data	0.1
No data	0.1		

3.3.Life cycle impact assessment

Like in E-LCA, in the Social Life Cycle Impact Assessment (S-LCIA) phase, the inventory data collected in the inventory stage are used to determine the social impacts corresponding to different impact categories (Parent et al., 2010). Notably, from an organizational perspective, this regards the social implications of companies' conduct on stakeholders (Dreyer et al., 2006).

The framework for IA presented in the Guidelines is composed of a set of impact categories, which are formed by a collection of subcategories, which in turn are represented by a group of indicators (Norris, 2012) (Figure 4). Thus, the connection between inventory data and impact categories and subcategories is first established (termed "classification"), and then the subcategory indicators or endpoints are calculated (termed "characterization") (Chhipi-Shrestha et al., 2015; García-Sánchez & Güereca, 2019).

According to Parent et al. (2010), the definition of the IA phase in the Guidelines is broad in that it includes the works of several researchers allowing for the use of different methods. Indeed, after the first publication of the Guidelines in 2009, the number of IA frameworks has proliferated as researchers proposed their own methods based on their project objectives (Chhipi-Shrestha et al., 2015; Petti et al., 2018; Subramanian et al., 2018). Chhipi-Shrestha et al. (2015) and Petti et al. (2018) also note that the variety of methods for IA might be because the Guidelines do not provide a concrete list of methods or characterization models for the IA phase. Therefore, there is currently no internationally accepted IA method in S-LCA (Franze & Ciroth, 2011), and the existing methods still need to be scientifically improved (Chhipi-Shrestha et al., 2015). Nevertheless, the new version of the Guidelines states that there is no one-size-fits-all characterization model and suggests that practitioners use existing ones (UNEP, 2020, p. 97).

In general, there are two main approaches to performing S-LCIA: the Reference Scale (RS) or Type I approach and the Impact Pathway (IP) or Type II approach (UNEP, 2020). Some authors argue that these two approaches can also be referred to as characterization models (Parent et al., 2010; R. Wu et al., 2014). However, it is essential to highlight that "characterization models" in the RS approach are not the same as those in E-LCA. When addressing the process of translating qualitative information into a semi-quantitative form or the process of assigning a score to inventory data (which is what is done in the RS approach), Sureau et al. (2020) suggest using the term "referencing" instead of "characterization". The word "referencing" will be adopted in this thesis.

The RS and IP approaches have advantages and disadvantages (R. Wu et al., 2014), but neither is promoted over the other in the literature (Subramanian et al., 2018). The main difference between the RS and IP approaches is the evaluation systems used to assess the indicator results, which produce different outcomes: social performances and social impacts, respectively (Huertas-Valdivia et al., 2020; Parent et al., 2010; Russo Garrido et al., 2018). In turn, those outcomes are produced from social stressors (social flows) that have different origins (i.e., the technical or the organizational nature of the product system) (Parent et al., 2010). This indicates that each IA approach needs different data types (Jørgensen et al., 2010).

The choice between these two classes of IA approaches is based on the availability of suitable methods and indicators (Parent et al., 2010). As indicated by Petti et al. (2018), this phase of S-LCA is the one with the most divergence, and many different methods exist for each type of IA approach (Ramos Huarachi et al., 2020). Accordingly, the following two subsections will expand on the differences between the approaches addressed above and provide an overview of what each entails.

3.3.1. Type I or Reference Scale approach

In S-LCIA, the most used IA technique is the RS approach (Subramanian et al., 2018). The RS approach concerns the measurement or the evaluation of the social performance of organizations or processes, which in turn represents the condition of an aspect of the social context in each organization (Parent et al., 2010; Pollok et al., 2021; S. R. Wu et al., 2015). In the RS approach, the inventory indicators are aggregated into subcategories and stakeholder categories, following a scoring and weighting process (Chhipi-Shrestha et al., 2015; Parent et al., 2010). S. R. Wu et al. (2015) note that in some works, this is done by following the classification of indicators into subcategories and/or stakeholder categories presented in the Guidelines, while in others, the aggregation of the indicators is based on the authors' own judgement.

Under this IA approach, the inventory data is assessed through PRPs to evaluate organizations' social performance along a product's life cycle (Parent et al., 2010; Pollok et al., 2021; Ramos Huarachi et al., 2020). Therefore, the outcome of this IA approach is not representative of the social burdens of a given amount of a product (or the reference flow) (Parent et al., 2010). Moreover, this approach can arguably be related to social reporting, such as CSR standards (Sureau et al., 2020).

Researchers may use RS methods that vary greatly, but these methods can be broadly grouped into different categories: checklists, scoring, and database methods (Chhipi-Shrestha et al., 2015; Pollok et al., 2021). Checklists conventionally use the tick sign (✓) to indicate the presence of an impact (Chhipi-Shrestha et al., 2015). They can also be understood as RSs comprising only two scale levels (UNEP, 2020). This method does not assess the magnitude, but the sole presence or absence of an impact, which is why it can be helpful to prioritize data collection by limiting the list of possibly relevant subcategories (Pollok et al., 2021). On the other hand, S-LCA databases (SHDB, PSILCA) use social risks of countries and country-specific sectors (CSS) and a scoring method which is part of a more extensive database IA system (Chhipi-Shrestha et al., 2015; Pollok et al., 2021).

As its name suggests, the scoring IA methods assess impacts through scores denoting different impact levels (Chhipi-Shrestha et al., 2015). Scoring methods are based on reference scales, which are ordinal in nature, and each level is defined by PRPs (UNEP, 2020). RSs may describe only negative or positive impacts or both, and their levels may be associated with numbers or non-numerical characteristics such as colors, letters or tick signs (UNEP, 2020).

As mentioned previously, the inventory data is compared with PRPs (e.g., the minimum salary paid is compared with the living wage in that country), which is also helpful in translating qualitative data into semi-quantitative data (Opher et al., 2018; Parent et al., 2010; Sureau et al., 2020). A PRP is thus a benchmark, threshold, or target which could be taken from industry best practices, national legislation and international standards that designate different levels of social performance or social risk (Petti et al., 2018; Subramanian et al., 2018; UNEP, 2020). While these are normative PRPs, other reference points such as the sector's average value (UNEP, 2020) can also be used. Furthermore, PRPs are context-dependent (UNEP, 2020). Thus, RSs enable users and practitioners to estimate the significance of the inventory data and potential social impacts related to the organizations within the product system (UNEP, 2020).

The Guidelines specify six types of PRPs. Concretely, reference points can be based on (1) norms or industry best practices; (2) same as (1) but combined with the socio-economic context of the unit context; (3) expert knowledge and a generic RS; (4) sector average, median or distribution; (5) a combination of (1) and (4); and (6) a combination of expert knowledge and (4) (UNEP, 2020, p. 85).

There is a great variety of scoring methods or frameworks for the S-LCIA RS approach (the review by Ramos Huarachi et al. (2020) provides a good overview of this). This indicates that there is no well-accepted system (Chhipi-Shrestha et al., 2015; Pollok et al., 2021), and some researchers recommend the use of established frameworks so that the technique can be standardized (Ramos Huarachi et al., 2020). Other shortcomings include the lack of consideration of impacts accruing from the use of products, whether the indicators selected represent the corresponding subcategory fairly, and whether there is a clear linkage between indicators, subcategories and/or stakeholder categories (Subramanian et al., 2018; R. Wu et al., 2014; S. R. Wu et al., 2015).

Lastly, in contrast to the IP approach, causal links between social stressors and impacts on an area of protection are not used in the RS approach (Chhipi-Shrestha et al., 2015; Parent et al., 2010; Pollok et al., 2021; S. R. Wu et al., 2015), but more subcategories can be included in the assessment (Chhipi-Shrestha et al., 2015).

3.3.2. Type II or Impact Pathway approach

The second approach employed in S-LCIA is the Impact Pathway (IP) approach. IP methods are based on social mechanisms and use impact pathways to calculate the social impacts of a product system (Chhipi-Shrestha et al., 2015; Ramos Huarachi et al., 2020; UNEP, 2020; S. R. Wu et al., 2015). Social mechanisms describe cause-effect chains and, according to the Guidelines and in line with ISO 14044 (ISO, 2006b), they include characterization models (as in E-LCA), social impact categories and impact category indicators (UNEP, 2020). Thus, after classification, the inventory indicators are used to calculate the impact indicator results at midpoint or endpoint levels through characterization models based on impact pathways (Parent et al., 2010; UNEP, 2020) (Figure 5). A midpoint indicator is located at an intermediate point on the impact pathway between the inventory data and the end of the pathways, while an endpoint indicator is an attribute of human health or well-being that can be identified as an issue of concern (Chhipi-Shrestha et al., 2015).

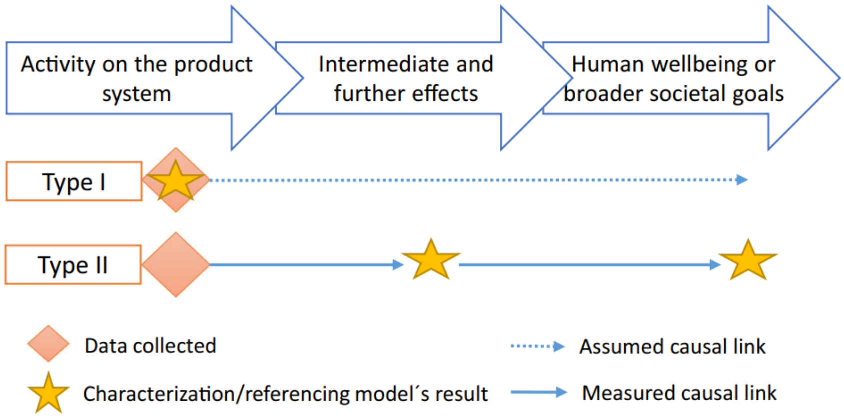

Figure 5: Position of inventory data and characterization/referencing results on the impact pathway in the S-LCA framework (adopted from Sureau et al., 2020, which is based on Russo Garrido et al., 2018)

IP methods are quantitative, experimental or statistical and hence, allow carrying out the impact assessment objectively (Chhipi-Shrestha et al., 2015; Pollok et al., 2021). Furthermore, the IP approach in S-LCA can be used to present the social impacts in relation to the functional unit and inventory data and to anticipate impacts from product life cycles or changes in it (Chhipi-Shrestha et al., 2015; Parent et al., 2010; Pollok et al., 2021; Sureau et al., 2020).

Different impact pathways have been proposed so far (a comprehensive overview of these can be found in the works of Ramos Huarachi et al. (2020) and Sureau et al. (2020)). Accordingly, different authors have attempted to provide different classifications of IP methods. For instance, IP methods have been classified into "multiple impact pathways methods" and "single impact pathways methods" by R. Wu et al. (2014) and into "empirical methods" and "environmental life cycle inventory (E-LCI) database methods" by Chhipi-Shrestha et al. (2015). Empirical methods assess social impacts based on formulas and rules using secondary or primary data, whereas, in the E-LCI database method, the social impacts are estimated using E-LCI databases (Chhipi-Shrestha et al., 2015). Regarding the latter, only a few social impacts are usually assessed with this method (e.g., employment and human health), and the impacts stemming from a particular company's behavior cannot be evaluated (Chhipi-Shrestha et al., 2015).

In a review by Sureau et al. (2020), the IP methods are distinguished between studies that (1) propose variables or single impact pathways or that identify several pathways (termed frameworks); (2) empirically examine or test known pathways, mainly those that link income values with health impacts; and (3) apply already known impact pathways or characterization models/factors in case studies. In the second classification, the idea is to prove the existence of pathways or to quantify the relationships between variables by finding correlations (via simple or multiple regression modelling) or causalities (via structural equation modelling) (Sureau et al., 2020).

A description of impact pathways is characteristic of studies that use the IP approach (UNEP, 2020). An impact pathway can be understood as a clearly established link representing the relation between a cause (social stressors resulting from an organization's activities) and its effect (Subramanian et al., 2018; UNEP, 2020). Furthermore, impact pathways can be built qualitatively or quantitatively (UNEP, 2020; S. R. Wu et al., 2015). Qualitative impact pathways identify social topics of concern and help explain the connections between social phenomena and certain areas of protection (UNEP, 2020). Notably, these pathways facilitate linking social activities with social topics, and although this may be limited to theoretical interrelations, it is necessary for well-grounded impact pathways (UNEP, 2020) (Figure 6). Qualitative impact pathways use findings from different social and natural sciences subjects and often integrate expert knowledge (UNEP, 2020; S. R. Wu et al., 2015).

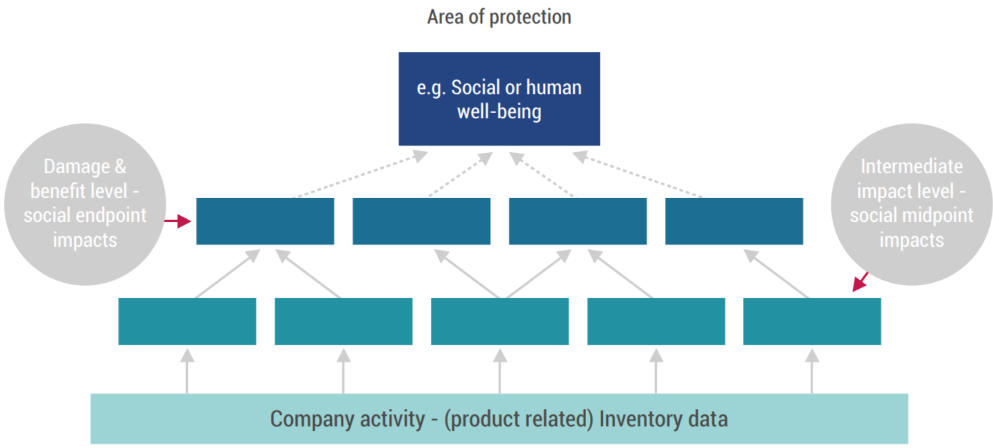

Figure 6: Representation of qualitative impact pathways where a company's operations are linked with social mid- and endpoint indicators (adopted from UNEP, 2020, which adapted it Dreyer et al., 2006)

Rather than presenting the bigger picture, quantitative pathways aim to explain different phenomena by focusing on quantifiable values (UNEP, 2020). The Guidelines distinguish quantitative impact pathways into those that follow a mechanistic modelling approach and those that follow a regression-based modelling approach (UNEP, 2020). The first type often uses the Disability Adjusted Life Years (DALYs) approach by linking emissions or social conditions with the probability of affecting people (UNEP, 2020). The second type of pathway identifies correlations based on economic regression modeling (e.g., the relationship between economic development and health improvements) (UNEP, 2020; S. R. Wu et al., 2015). Furthermore, it is essential to note that these correlations are often case-specific and are used to assess scenarios or changes in social conditions rather than the plain status of product systems (UNEP, 2020).

Finally, in contrast to the RS approach in S-LCIA, IP methods typically involve fewer subcategories and indicators; this may be because these methods require quantitative data to construct the cause-effect chains (Chhipi-Shrestha et al., 2015). Furthermore, quantitative data may not be readily available as cause-effect chains are not fully known or are very complex (Pollok et al., 2021).

3.4. Interpretation

Interpretation is the fourth and last phase of S-LCA. In this phase, the life cycle inventory analysis and the impact assessment results are evaluated to draw conclusions and recommendations and aid in decision-making based on the goal and scope of the study (ISO, 2006b; UNEP, 2020).

The interpretation of results is also an iterative process, as it may lead to the revision of the Goal and Scope of the study, further data collection and impact assessment (UNEP, 2020). The interpretation phase in S-LCA includes evaluations considering completeness, consistency, sensitivity and data quality checks, the materiality principle, conclusions, limitations and recommendations (ISO, 2006b; UNEP, 2020). Most of these steps can be carried out through qualitative methods (UNEP, 2020).

A brief description of the steps mentioned above is provided in Appendix I. Furthermore, the Guidelines provide sets of guiding questions for the completeness and consistency checks, which the researcher should attempt to answer.

3.5. S-LCA in the water sector

Having reviewed every S-LCA stage in detail, this section focuses on the review of literature on S-LCAs in the water sector. This literature review aims to assess the state-of-the-art development in S-LCA's application in the water sector and determine which stakeholder categories and impact subcategories are commonly assessed. The stakeholder groups and impact subcategories included in S-LCAs of WWT systems indicate the most affected stakeholders by such systems and the most relevant social effects they may have on those stakeholders. Therefore, only S-LCAs applied in case studies were included in this review.

The search for research articles was done through the Scopus database by inserting combinations of selected keywords in the field "TITLE-ABS-KEY" and using the "AND" Boolean operator. The period selected was from 2009 to the present since 2009 was when the UNEP/SETAC Guidelines were published, conceptualizing the S-LCA technique and addressing several research needs in the field (Ramos Huarachi et al., 2020). The keyword combinations that yielded the most results are: "social life cycle assessment" AND "water" and "social life cycle assessment" AND "wastewater". The abstracts of the research papers were screened to assess whether they met the requirement stated above. A total of 11 research articles applied the S-LCA methodology in case studies related to wastewater treatment, and thus, they were reviewed (Table 3).

Tsalidis and Korevaar (2019) applied a consequential approach in evaluating the societal effects of recovering materials from industrial wastewater treatment. They investigated the social implications of a Zero Brine project case study, which used Zero Liquid Discharge technologies to recover clean water, magnesium, and sodium from brine. Their results indicate that a change to the Zero Brine system would result in social benefits at the generic and site-specific levels, especially in the subcategories related to Workers ("Health and safety", "Freedom of association and collective bargaining", and "Fair salary" subcategories). Some of the main challenges faced were data collection and the use of the selected scoring system, as it may have included uncertainty when converting qualitative data to quantitative data.

The Zero Brine case study analyzed in the previous work was also included in another S-LCA, together with other three Zero Brine case studies. The S-LCA was done by Tsalidis et al. (2020), aiming to assist in decision-making concerning the purchase of equipment (via a hotspot or generic analysis) and identify the social impacts originating from the companies involved in the product systems (via a site-specific analysis). Regarding the first, for all case studies, the same hotspot was found in the endpoint indicator "Labor rights and decent work". As for the site-specific results, they found that the case study companies performed relatively well in all the impact subcategories, although some improvement was needed in the "Occupational accidents rate", "Water consumption", and "Organizational support for community initiatives" indicators.

Serreli et al. (2021) analyzed the social risks stemming from treating three types of industrial wastewater using the PSILCA database (version 2). They found that the highest social risks were associated with the "Local community" and "Value chain actors" and were related to processes upstream the supply chain. Indeed, including the entire supply chain evokes insights into how social risks could be managed in the life cycle of a product. One of the main limitations of this study is that although the functional unit aims to represent the new WWT system, it is used in a way that it is divided into three different functional units, each representing one line of WWT. This most likely leads to misinterpreting the results by considering each line independent of the other, as their presentation of results suggests. If the authors aimed at comparing the three lines, then a correction to the functional unit should have been addressed.

Six studies were found regarding the social assessment of urban wastewater systems or the reuse of treated wastewater. The first is a study examining the social benefits and impacts of four alternative urban wastewater reuse scenarios conducted by Opher et al. (2018). In this study, the authors followed the general S-LCA framework, with some adaptations—the use of the analytical hierarchy process (AHP). AHP was proven helpful in eliciting expert judgment regarding the relative importance of multiple social criteria and quantifying all social criteria in a common numeric scale. The authors developed impact subcategories and social indicators reflecting the local culture, perceptions, and views. The results highlight the benefits of municipal domestic water reuse, mainly due to "Water saving" and "Urban landscape", which received the highest weights. Other social benefits are "Community engagement" and "Consumer expenses". On the other hand, "Health concerns", "Convenience of use", and (lack of) "Water supply equivalence" are some of the disadvantages of water reuse. However, these results are not differentiated per life cycle stage or process. Moreover, this approach does not allow for the use of an organizational approach in S-LCA.

Another S-LCA that applied AHP was the one performed by Muhammad Anwar et al. (2021). They proposed a socio-eco-efficiency analysis framework and applied it to determine the most sustainable wastewater management alternative in a refugee camp in Jordan. In the S-LCA, the results from the expert survey indicated that the social indicators with the highest relative importance were "Lower incidence of water-related illnesses", "Increased diligence of residents in reducing damages", and "Adequate ownership of water, sanitation, and hygiene facilities". Regarding the socio-eco-efficiency framework results, in comparison with the original wastewater management system (Scenario 1) and the UN long-term plan, which comprises the distribution of water through a piped network (Scenario 2), Scenario 3 is the most beneficial in terms of environmental, social, and economic implications. Scenario 3 is the same as Scenario 2 but integrates non-potable water reuse. One of the limitations of the S-LCA is that experts were the data source and not the primary stakeholders affected.

The third study regards a comprehensive S-LCA of the urban water system in Mexico City by García-Sánchez and Güereca (2019). The study included all the processes in the life cycle of urban water and evaluated its social performance on workers. The results indicate that the overall social performance of the system is at a regular level, and improvements are needed in the "Health and safety" of working conditions. The transportation stage had the best social performance, whilst the storage stage had the worst overall social performance. The authors suggested reducing overtime work, constant personnel training, monitoring the workforce's health, paying fair salaries, and improving the facilities' safety. It is worth noting that, like the study of Opher et al. (2018), this study focused only on the foreground processes of the life cycle and measured the social performance per facility and life cycle stage rather than per organization. This might be because the public utility is in charge of operating all the processes.

A fourth study on the social implications of urban WWT facilities was performed by Padilla-Rivera et al. (2016). Although their primary goal was to propose a methodology for assessing the social implications of WWT facilities, their approach was implicitly based on the S-LCA framework. Their results suggest that the urban WWT facility achieved a better social performance than the rural WWT facility, especially for the stakeholder categories “Local community and society”, “Consumers”, and “Workers”. It was also found that for both facilities, improvement efforts must be directed to “Performance monitoring program”, “Health and safety” of workers and “Social acceptance”. The first refers to the lack of monitoring of the operation of the WWT facilities by the authorities. The second refers to the workers’ exposure to noise, bad smells, and facilities that are hard to access with high safety risks for workers. The reasons for the third social aspect were not made clear. Additionally, how the inventory data was converted into scores was not explained, and a good summary of the results was not provided.

Padilla-Rivera and Güereca (2019) proposed a sustainability assessment framework for WWTPs. They assessed environmental, social, and economic factors using the life cycle thinking approach, then implemented fuzzy logic analysis and constructed a global sustainability index to rank alternatives. The framework was applied to four WWTPs (two in Mexico and two in the USA). Regarding sustainability, the best alternative was the WWTP in Los Angeles, followed by the one in Phoenix. As for the assessment of social indicators, the normalized indicator results indicate that most WWTPs had a poor performance in “Safe and healthy living conditions” and “Promoting social responsibility”. On the other hand, better performance was achieved in “Local employment” and “Fair salary”.

Whilst not precisely an evaluation of a WWT system, Do Amaral et al. (2019) conducted a sustainability evaluation of four scenarios of sludge and biogas treatment, use, and disposal from WWTPs in Brazil. The study was included in this review as it concerns byproducts generated in the process of WWT. Thus, the stakeholder categories, subcategories, and indicators used and the results generated are relevant to assessments of WWTPs. The social aspect of the sustainability assessment was evaluated via S-LCA, using ten indicators specific to WWTPs. According to the results, all scenarios had a poor performance in the social indicators “Wages paid to workers”, “Capacity to generate employment”, “Noise level (workers)”, “Use of hazardous chemicals”, and “Odor emission”. In the sustainability assessment, the best score in the social dimension was achieved by Scenario 2 and the worst by Scenario 3. In Scenarios 2 and 3, the sludge is burned, and the heat is used for drying the dewatered sludge. Furthermore, the ashes are destined for agriculture (Scenario 2) or sanitary landfills (Scenario 3). The reference scales of the S-LCA impact assessment were not defined, leaving what represents each score of the social indicators unclear.

Foglia et al. (2021) assessed the impacts of innovative technologies (SMARTechs) that converted municipal WWTPs into water resource recovery facilities through a cost-benefit analysis and an S-LCA. Special attention was paid to the latter in this review. A total of nine wastewater resource recovery technologies were assessed through S-LCA. The results indicate that all the SMARTechs achieved positive performances in social acceptance and technical characteristics, especially those SMARTechs whose technologies were simple. Once more, the authors did not specify how the inventory data was converted to social performance scores and how the reference scale levels were defined. This hampers the interpretation of results since the difference between the lowest (worst) and highest (best) performance scores is unclear.

Shemfe et al. (2018) assessed the social risks of the components of bioelectrochemical systems (BESs) used to recover secondary materials from wastewater. The authors used the SHDB for the S-LCA. The results indicate that among all the social impact categories considered, "Labor Rights and Decent Work" resulted in the highest social risks for all the commodities included, mainly due to the inclusion of more social indicators. The authors also noted that larger trade values do not always imply higher social risks. For example, compared to other countries, polytetrafluoroethylene from India resulted in higher risks in all impact categories, although the imports of this commodity from India to the UK were the smallest in the sample. Additionally, they highlighted the difficulty in linking social indicators to the functional unit as the major limitation of their study.

3.5.1. Learnings from the literature review

Whereas functional units were defined in most research articles, the results were rarely presented in relation to them. Some authors acknowledged the difficulty of using functional units in S-LCA (Shemfe et al., 2018). For example, Shemfe et al. (2018, p. 3) defined two "ornamental" functional units as 1 kg of Cu recovered and 1 kg of formic acid production. Although their study aimed not to compare the social risks from the BESs' components' supply chain but to assess the social hotspots along them, those functional units could be described as reference flows. This is because those systems meet the function of recovering clean water and byproducts from wastewater. A similar example is that of Serreli et al. (2021). They defined a functional unit composed of three parts (Table 3), each representing one line of wastewater treated with a new technology at an electronics and semiconductor company. Since the results were calculated for each line treating different amounts of wastewater, unsurprisingly, the line treating the most wastewater had the largest social risks (line 1).

Furthermore, it was found that discussions about the selection of stakeholder categories and impact subcategories are often missing in S-LCA studies. When discussed, selections were based on findings from previous studies (García-Sánchez & Güereca, 2019; Opher et al., 2018).

Regarding impact assessment, although all the studies implemented the RS approach, various methods can be observed, indicating the lack of standardization. Some authors used existing methods (Subcategory Assessment Method by Ramirez et al., 2014), others applied a combination of approaches (García-Sánchez & Güereca, 2019), and some made their own by applying other methods to S-LCA (Opher et al., 2018). Nevertheless, the reference scales and how the scoring was performed were not reported transparently in many studies, which hampers understanding of how the results were achieved (see Do Amaral et al., 2019; Foglia et al., 2021; García-Sánchez & Güereca, 2019; Padilla-Rivera et al., 2016).

Finally, concerning reporting, not all studies presented the four stages of S-LCA in their research papers, and the interpretation phase was found to be commonly excluded. From the number of articles found, it is evident that research on the social implications of WWT systems is still limited; hence, the application of S-LCA in more case studies is encouraged.

Table 3: Reviewed S-LCA articles in the water sector

Reference	Goals of the study	Methodology	Functional unit
(Tsalidis & Korevaar, 2019)	Evaluation of the societal effects of a modified train of technologies in a demineralized water plant to recover clean water, magnesium, and sodium. A consequential approach was implemented, and its applicability in decision-making was evaluated.	S-LCA at a generic and site-specific level of analysis. Application of a modified version of the PROSA guidelines	1400 m^3 of ultra-pure demineralized water, 114 kg salt, and 0.92 kg magnesium
(Tsalidis et al., 2020)	Assessment of societal benefits and risks of industrial wastewater (brine) treatment systems under the Zero Brine project.	S-LCA at a generic and site-specific level of analysis using the SHDB and SAM (Ramirez et al., 2014), respectively.	1 Zero Brine demo plant
(Serreli et al., 2021)	Socioeconomic assessment of a full-scale industrial WWTP that treats three types of wastewater from a microelectronics company.	S-LCA through the PSILCA database	Current annual generated amounts for each kind of wastewater considered: 6300 t of wastewater with TMAH and photoresist (line 1), 435 t of wastewater with NH4F (BOE) (line 2), and 145 t of wastewater with nitrates, fluorides, phosphoric acid and acetic acid (SEZ) (line 3).
(Opher et al., 2018)	Comparison of the social impacts and benefits of four alternative approaches to urban water reuse to be implemented hypothetically in Israel.	General S-LCA framework in combination with an analytical hierarchy process (AHP)	Supply, reclamation, and reuse of water used in a city (approx. 200,000 inhabitants) for one year.
(Muhammad Anwar et al., 2021)	Development of a socio-eco-efficiency analysis framework and comparison of the economic, environmental, and social aspects related to different water, sanitation, and hygiene services in refugee camps in Jordan.	S-LCA, AHP	Not defined
(García-Sánchez & Güereca, 2019)	Evaluation and analysis of the social performance of the water system in Mexico city.	S-LCA, based on the method proposed by Padilla-Rivera et al. (2016), and nominal scales from Franze & Ciroth (2011) and Fontes (2016)	1 m^3 of water for human consumption (same FU as in the E-LCA)

(Padilla-Rivera et al., 2016)	Presentation of a new methodology to evaluate the social aspects related to wastewater treatment facilities (WWTFs). Additionally, the methodology was applied to two WWTFs in Mexico to test its applicability.	The authors proposed a new method, which follows the S-LCA approach (definition of goal and scope, development of evaluation criteria, data collection, scoring of indicators, and interpretation and application). It is based on the use of social indicators to measure the social performance of WWTFs.	Not defined
(Padilla-Rivera & Güereca, 2019)	Development of a sustainability assessment tool to evaluate the environmental, social, and economic performances of WWT facilities. The methodology was applied to four WWT facilities.	S-LCA, Padilla-Rivera et al. (2016)	1 m^3 of treated water
(Do Amaral et al., 2019)	Sustainability assessment of four scenarios of sludge and biogas treatment and use in a WWTP in Brazil, using E-LCA, LCC, and S-LCA.	S-LCA, using adaptations from Ramirez et al. (2014), Zortea et al. (2017) and Padilla-Rivera et al. (2016)	Management of byproducts produced from the treatment of 1m^3 of urban wastewater
(Foglia et al., 2021)	Assessment of the sustainability of innovative technologies (SMARTechs) in the context of water resource recovery facilities through a holistic approach including social, economic, and environmental indicators. S-LCA was applied to assess the Social Readiness Level of each SMARTech and their related products.	S-LCA, with a reference scale of five levels	Not defined
(Shemfe et al., 2018)	Evaluation of social risks related to the components necessary to build and operate bioelectrochemical systems (BESs) for wastewater treatment and resource recovery.	S-LCA, SHDB	1 kg of Cu recovery and; 1 kg formic acid production at the cathode, related to the organic WWT at the anode ("ornamental" FU)

4. Methodology

The fourth chapter starts by giving an overview of the Water Mining Case Study concerning this thesis—it describes the two product systems under consideration. Then, it describes three stages of the S-LCA applied to this thesis: Goal and scope definition, Inventory, and Impact assessment. In each phase, all the decisions and assumptions made are explained in detail in light of the two levels of S-LCA application: site-specific and generic. The output of the site-specific assessment is the social performance of each system, whereas that of the generic assessment is the social risks along their value chains.

4.1. Water Mining Case Study

As mentioned in the second chapter, alternative water sources such as wastewater represent an essential resource for regions with water scarcity. In contrast to the reclaimed water reuse levels reached in Israel, certain states of the USA, and Singapore, only 11% of the treated wastewater was reused in Spain in 2014 (PwC, 2018). Most of Spain's reused treated wastewater (70-80%) goes to the agricultural and recreational sectors (AEAS/ AGA, 2020; PwC, 2018). The following sub-sections will explain the main characteristics of the currently operating wastewater treatment plant and the WM case study in La Llagosta.

4.1.1. Case study description: reference system and original system

The WWTP in La Llagosta was built in 1994, comprising a physicochemical treatment, and it was expanded to include a biological treatment in 1998 (Consorci Besòs Tordera, 2022). It is estimated to serve a population of more than 130,000 and treat a daily flow of 43,000 m^3 (Consorci Besòs Tordera, 2022). Together with a sanitary sewer system of about 60 km, this WWTP forms the La Llagosta Sanitation System (Sorigué, n.d.).

Consorci Besòs Tordera (CBT) is the current owner and public utility of La Llagosta WWTP. However, its operation has been in charge of the WM case study (CS) operator since 2019 (Water Mining, 2020a). In the past years, expansion and improvement works have been carried out at the WWTP, including the installation of a new biological reactor (for nitrification/denitrification) and a third secondary decanter (Consorci Besòs Tordera, 2022; Sorigué, n.d.). These works aimed to enhance the removal of nutrients (i.e., nitrogen) so that the effluent water would meet the standards outlined in the European legislation (Sorigué, 2021). Thus, it is expected that the quality of the Besòs River will be improved.

The WM case study concerning this thesis research project is located in La Llagosta, Barcelona, Spain, currently being tested at a pilot scale, with a capacity of 400 l/h or 10 m^3/day. In this case study, by-products for industrial and agricultural purposes will be generated by the incorporation of a process train, including an anaerobic membrane bioreactor (AnMBR), a partial nitrification-anammox system, phosphorus recovery technologies and a reverse osmosis unit (Sorigué, 2020).

In the AnMBR, organic matter is removed from municipal wastewater via anaerobic digestion with granular biomass. More specifically, organic matter is transformed into biogas. Additionally, stabilized sludge suitable for agricultural purposes is produced in this process. In order to obtain water for agriculture or effluent water with low nitrogen concentrations, nitrogen can be removed through biological nitrogen removal. Conventionally, the two processes used in WWTPs are nitrification and denitrification (Ruscalleda Beylier et al., 2011).

In the first, ammonium is oxidized to nitrite, and nitrite is then oxidized to nitrate via ammonium-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB), respectively (Ma et al., 2016). This is achieved under aerobic conditions, which require a significant amount of energy (Lackner et al., 2014; Ma et al., 2016).

In denitrification, denitrifiers (heterotrophic bacteria) grow on organic substrates under anaerobic conditions to reduce the oxidized N species into nitrogen gas (N_2) (Inglett et al., 2005; Ruscalleda Beylier et al., 2011). However, since this reduces the amount of organic matter available for energy production and/or the amount of available biodegradable organic carbon in water is already limited to allow for this conventional process, autotrophic nitrogen removal methods are preferred in WWT (Ma et al., 2016; Ruscalleda Beylier et al., 2011). Thus, instead of the conventional method for nitrogen removal, partial nitritation and anaerobic ammonium oxidation (anammox) are used in this case study. Partial nitritation consists of oxidizing ammonium to nitrite while limiting the oxidation of nitrite into nitrate (Lackner et al., 2014; Ruscalleda Beylier et al., 2011). This helps to reduce the treatment costs as less aeration is needed (Ruscalleda Beylier et al., 2011). Then, in the anammox process, ammonium is oxidized to nitrogen gas and some nitrate by anaerobic ammonium-oxidizing bacteria (AnAOB), using nitrite as an electron acceptor (Lackner et al., 2014; Ma et al., 2016; Ruscalleda Beylier et al., 2011).

Furthermore, phosphorus can be removed from the water line of WWTPs. Phosphorus removal can be combined with crystallization to obtain struvite, vivianite or hydroxyapatite (Zhang et al., 2022). In this case study, P recovery as vivianite is being tested by implementing the new P-recovery technologies ViviCryst® and BioPhree®. The ViviCryst® technology is based on a fluidized bed reactor and is used to produce large vivianite crystals from treated wastewater (van Hooijdonk, 2020). Vivianite can be used as fertilizer and has a higher market value than conventional struvite (Zhang et al., 2022). BioPhree®, on the other hand, consists of using adsorbents based on iron oxide to remove phosphorus from wastewater to very low concentration levels (10-50 ppb). The adsorbents can be reused and regenerated, and phosphorus can be recovered from the regeneration liquid (Aquacare, 2022; Wetsus, 2020). Finally, the effluent from the P recovery technologies can be treated with reverse osmosis to produce ultrapure water suitable for industrial applications.

As the effluent of the current WWTP in La Llagosta is disposed of directly into the Besòs River, no treated wastewater is reused. However, this situation will be substantially improved with the WM system, which is estimated to reuse ca. 70% of the water for environmental, industrial, and urban purposes (Water Mining, 2020a). Table 4 shows the different outputs of the reference and original systems.

Table 4: Outputs of the reference system and the original system

Product system	**Output**
Reference system	Clean water
	Biogas
	Sludge for agricultural use
Original system	Water for agriculture
	Water for industries
	Sludge for agricultural use
	Vivianite

4.2. Social life cycle assessment

4.2.1. Goal and scope definition

4.2.1.1. Goal definition

This study aims to assess the social performance of a new arrangement of wastewater treatment technologies and compare it with that of the current WWTP in La Llagosta, Barcelona, Spain. Similarly, the second goal is to identify the social risks along the value chain of these product systems. Subsequently, pinpointing the areas where a company needs to direct more efforts to improve and where most social risks occur—also referred to as social hotspots, constitutes the third goal of this study. Finally, regarding the social hotspots in the social performance of the product systems, recommendations to improve can be formulated for each of the companies within the system boundaries. All these goals underline the main objective of S-LCA, which is the reduction of social impacts on those stakeholders affected by an organization's conduct.

Accordingly, it is expected that this study's results will shed light on the social performance of technologies that emphasize circular economy principles, such as resource efficiency and recovery in a country like Spain, where water resources are becoming increasingly scarce. Moreover, the results might also be used for decision-making within the assessed organizations, thus improving the systems' social performance. The object of study is one of the case studies from the WM project; thus, the project partners and organizations studied (notably, the CS operator) form the target audience of this research.

Given the type of question that this assessment (indirectly) aims to answer ("what are the impacts of the life cycle of a product as is?"), this S-LCA fits the objectives, characteristics and structure of an attributional LCA. While, in the consequential approach, the focus lies on changes in the physical flows resulting from different decisions or actions taken, in the attributional approach, the product system and its elementary and economic flows are described as they are (Finnveden et al., 2009; Rebitzer et al., 2004).

4.2.1.2. Scope definition

In this phase of the S-LCA, the system under study must be determined. The set of decisions made while setting the scope regards the identification of the function, functional unit, and reference flows; the definition of the product system and the delimitation of its system boundaries; the selection of an activity variable; the identification of relevant stakeholders impact (sub)categories and indicators; and the selection of the impact assessment method. Each of these will be further detailed below.

4.2.1.3. Scope definition: definition of the function, functional unit, and the reference flows

The first step in defining the scope of the study is determining the system's function, that is, what is offered or delivered by the object of the study. Therefore, the primary function of the systems under consideration is to treat municipal wastewater so that it meets environmental standards before being reused or disposed of in the receiving water resources.

In the previous chapter (section 3.1.2.2), the issues in linking social impacts to the functional unit in S-LCA have been described. In this study, defining a functional unit is deemed relevant for three reasons:

a. It is the base for a fair comparison of the social impacts of different products.

b. It is the initial step for the calculation of activity variables.
c. It is one of the essential elements of LCAs since it is the starting point for the construction of the product system.

Therefore, the functional unit, which translates a product's function into quantitative terms, is the treatment of 1 m^3 of municipal wastewater. The reference flows are the following:

a. Treatment of 1 m^3 of municipal wastewater in the current WWTP in La Llagosta, Barcelona, Spain
b. Treatment of 1 m^3 of municipal wastewater in a new train of technologies proposed in one of the case studies of the WM project in La Llagosta, Barcelona, Spain

4.2.1.4. Scope definition: definition of the product system

As social stressors may originate from the conduct of companies, socioeconomic processes, or the technical nature of processes, it was suggested to apply a double-layer approach in the delineation of the product system (see Product system section). This entails considering the product system from both an organizational level and a technical level to include all the organizations and the technological unit processes involved in the life cycle of a product.

For the fulfillment of the goals of this S-LCA, two types of analyses are performed (site-specific analysis and generic analysis), each comparing the current WWTP (reference system) with the WM case study (original system). Therefore, two main types of product systems can be differentiated: one for the site-specific analysis and one for the generic analysis. This is relevant since the generic analysis is performed with the PSILCA database, which implies that country-specific sectors and not companies are included in the assessment. Additionally, when a database is used, all the processes (sectors) that are further upstream in the value chain of a product are included in the calculations of social risks.

Figure 7 shows a representation of a product system for the site-specific analysis, while Figure 8 shows a representation of a product system for the generic analysis. The main rectangles in red and blue represent different spheres: the Sociosphere and the Technosphere, respectively. The Sociosphere aims to represent the social aspect of the triple bottom line (the "people" element); hence, it concerns human society and social networks (Frederick, 2018; Irimie et al., 2014). The Technosphere, on the other side, is understood as a system that includes all man-made resources (Crenna et al., 2018; Zalasiewicz, 2018). Accordingly, all the organizations (light blue boxes in Figure 7) that are linked to the product in a certain way are identified. These organizations are part of the Sociosphere since they are formed by, interact with, and affect people. Thus, the red arrows representing social stressors are generated in the Sociosphere (mainly by the conduct of organizations) and affect different groups of stakeholders (red boxes).

Furthermore, organizations produce the required inputs for the operation of the WWTPs, which qualifies them (via the production processes that they operate) also to be considered a part of the Technosphere. This is represented, for example, by the blue box (organization: CS operator) that contains a dark grey box (unit process: wastewater treatment) (Figure 7).

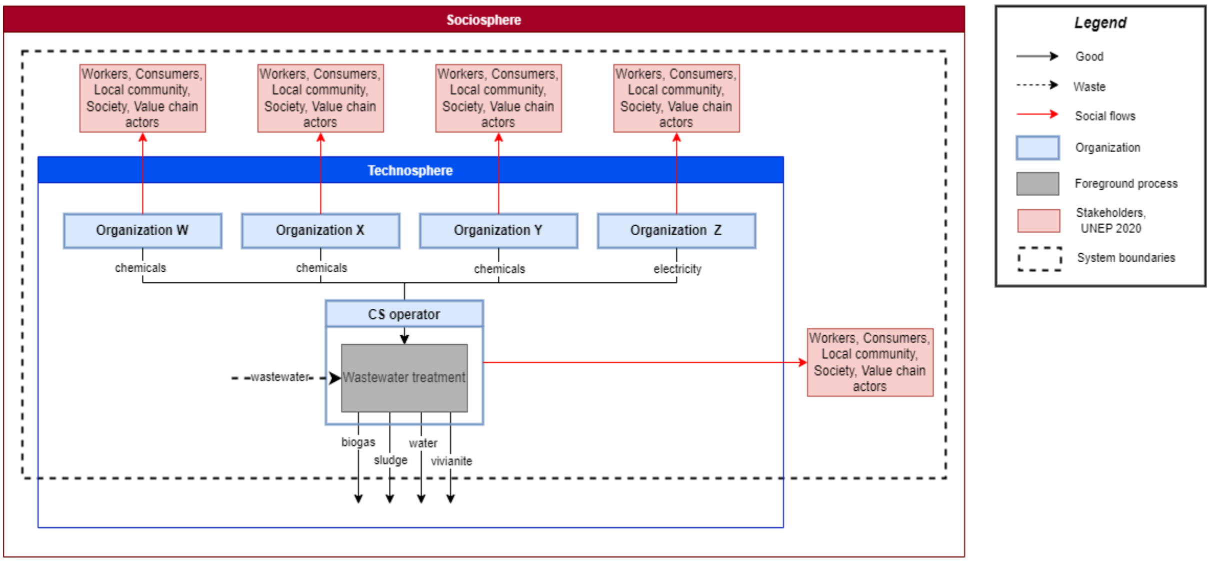

Figure 7: General representation of a product system for site-specific analysis

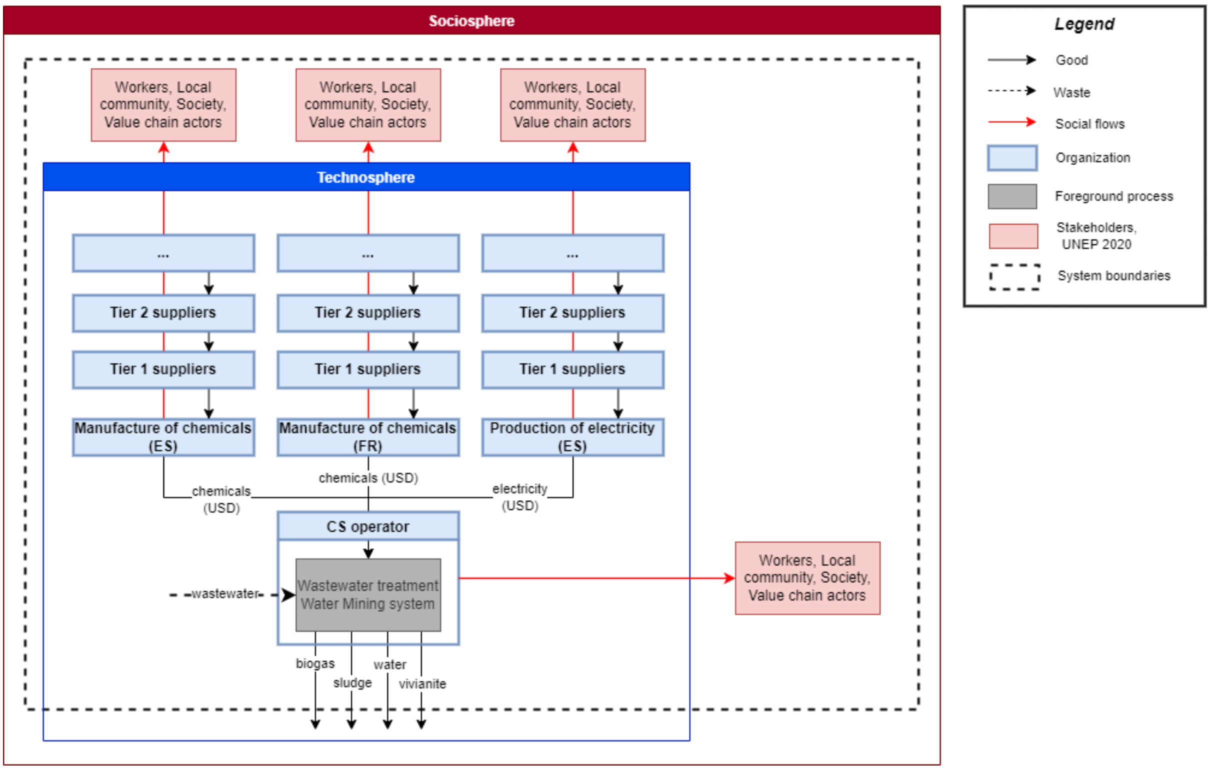

Figure 8: General representation of a product system for generic analysis in the PSILCA database

4.2.1.5. Scope definition: definition of the system boundaries (and cut-off criteria)

Setting the system boundaries is related to answering the question, "which processes (organizations) of the life cycle of a product should be included in the product system?". Given its name, LCAs ideally should cover the entire life cycle of a product, including all the processes that take place within the product system (cradle-to-grave) (Guinée et al., 2002; UNEP, 2020). However, this is (almost) impossible to do in practice, mainly due to limitations on resources and data availability (Guinée et al., 2002; UNEP, 2020). Therefore, setting boundaries to the product system and establishing cut-off criteria are necessary scoping steps.

Before describing the systems under study, it is helpful to consider the life cycle of water in urban environments. This can be briefly described as follows. Water is first abstracted from natural resources such as surface or underground water bodies and is stored and treated before use (Biosphere to Technosphere). After treatment, the water is suitable for its intended use and is distributed to final consumers. The resulting wastewater is then collected and directed to treatment facilities. Finally, after treatment, the water is returned to nature (Technosphere to Biosphere) or reused in agriculture, industries, or urban environments. A simplified graphical representation is shown in Figure 9.

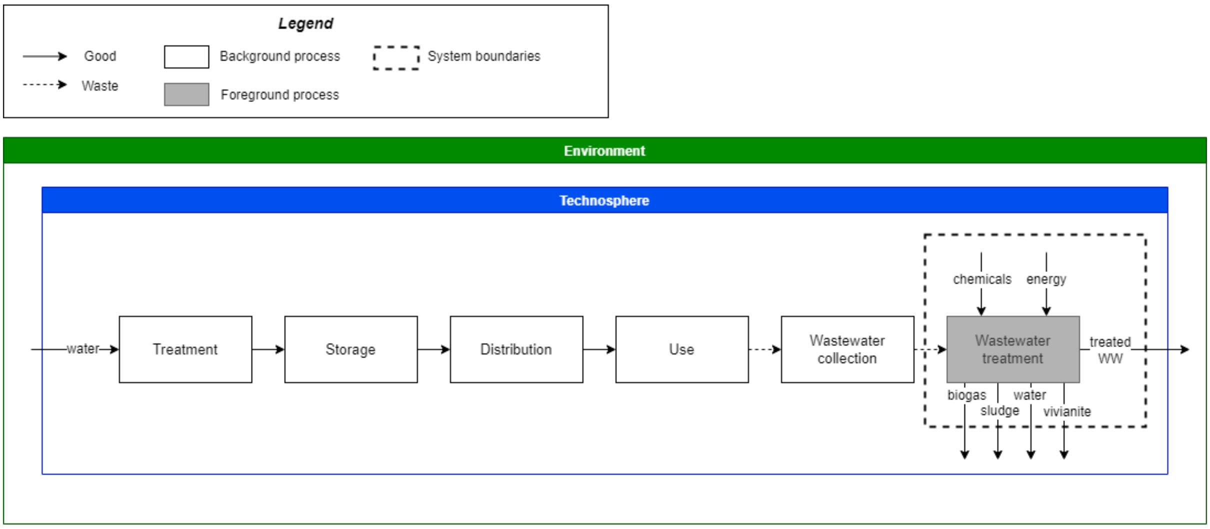

Figure 9: The urban water cycle

Considering the object of the study and the goals of this S-LCA, the only life cycle stage of the urban water cycle included in the product system is that of waste treatment. Furthermore, considering that two product systems are compared, the identical processes that occur before the WWT can be omitted. Therefore, the system boundaries of this study are gate-to-grave (reference system) and gate-to-gate (original system). A gate-to-grave approach includes all the upstream and end-of-life processes that occur after production and consumption (Preethi et al., 2020; Silva & Sanjuán, 2019). When the scope is limited to a specialized unit process that receives raw materials and transforms them into a final product (value-added or core process), then the scope of the LCA is deemed from gate-to-gate (Cao, 2017; Preethi et al., 2020; Silva & Sanjuán, 2019).

Therefore, the reference system's scope is from gate to grave because the focus is placed on the (waste)water received after being used (gate of the WWTP) and its treatment. Then, after treatment, the water returns to the environment (grave). In the original system (gate-to-gate approach), the same is true with the exception that instead of releasing the treated wastewater to the environment, it is reused in other product systems (agriculture or industries). Since the treated wastewater for reuse is not followed upstream, the scope is limited to the point until it leaves the WWTP (gate) to be used elsewhere.

When deciding which processes or organizations to include within the system boundaries, the availability of resources is the primary practical limitation. Regarding the site-specific analysis, access to site-specific data is essential for the assessment. Therefore, it is critical that the data collector or the S-LCA practitioner has access and can exert some influence on an organization to obtain that data (Dreyer et al., 2006). Since the CS operator is running the WWTP, it has some influence on its closest suppliers, facilitating access to data from these organizations. However, this influence dissipates further upstream and downstream in the value chain (Dreyer et al., 2006). Thus, the focal organization and its first-tier suppliers are included within the system boundaries (Table 5), as well as the stakeholder groups that they may affect. It is important to note that the impacts of first-tier suppliers' behaviors on their own suppliers are considered in this assessment (stakeholder "Value chain actors"), which can be understood as an indirect, partial inclusion of further upstream suppliers. However, this does not mean that second or third-tier suppliers' social performance is included in this S-LCA. Another critical issue to acknowledge is that in some situations, the significant social impacts occur further upstream in the supply chain (Dreyer et al., 2006).

Table 5: Organizations included in the system boundaries

Product system	**Organizations**	**Role**
WWTP in La Llagosta (reference system)	CS operator	CS operator
	Organization A	Chemical supplier
	Organization B	Chemical supplier
	Organization C	Chemical supplier
	Organization D	Chemical supplier
	Organization E	Electricity provider
WM system (original system)	CS operator	CS operator
	Organization F (proxy)	Chemical supplier
	Organization E	Electricity provider

The exclusion of end-users from the system boundaries of the original system is based on the fact that the WM system is still at a pilot scale. Although main groups of consumers of the recovered materials have been identified (metal factories, vineyards, wineries, La Llagosta city, and public utility, among others), these are not defined. If no specific consumers can be identified, assessing their social performances would be significantly difficult and even more time-consuming. Additionally, the uncertainty that including end-users will introduce to the study will have major effects on the final results. Nevertheless, similar to the indirect inclusion of upstream suppliers explained above, the end-users of these product systems are indirectly included by evaluating the effect of the CS operator on its customers in general. Thus, the end-users are only included as affected stakeholders, part of the Sociosphere (Figure 7).

The same issue applies to the identification of the chemical suppliers of the original system. However, a proxy is selected since the CS operator has experience procuring chemicals and can identify potential chemical suppliers in the Spanish market (Table 5). From the list of potential chemical suppliers, one organization is used as a proxy based on the availability and accessibility of its site-specific data. In addition, the construction of the facilities, maintenance, transportation, and machinery used are excluded from this study.

The product systems of the current WWTP and the WM system, thus, include two main operations: procurement and waste treatment. From the lenses of S-LCA, the first concerns the social performance of suppliers (Organizations A-F); how their business operations affect different stakeholder groups. The second regards how the business activities of the focal organization (CS operator) affect its stakeholders.

The product systems specific to the reference system and the original system can be inferred from the general depictions presented above (Figure 7 and Figure 8) and Table 5 that presents the organizations within the system boundaries of each product system.

4.2.1.6. Scope definition: activity variable

The output of a process may be linked to an activity related to that process, and what measures process activity is an activity variable (UNEP, 2020). Activity variables represent the relative significance of each process in the product system (UNEP, 2020). This means that those processes that require relatively more worker hours or generate more added value will become more critical in the product system, indicating that the social issues associated with them will increase in relevance. Accordingly, the more hours a worker spends at a unit process, the longer s/he is exposed to the social risks related to that process. Furthermore, since activity variables can be scaled to the functional unit, the results can also be calculated according to the functional unit (UNEP, 2020).

The most typically used activity variable is worker-hours, which consists of the number of hours necessary to deliver a certain number of products (UNEP, 2020) or treat a certain amount of waste. Value-added is the other activity variable used in S-LCA, and it is related to how much value (or "economic enhancement", profit) a process creates.

Activity variables will be used in this study. Furthermore, activity variables are encouraged when multiple actors are involved in a product system as they can be given different relative importance (Tsalidis & Korevaar, 2019). On the other hand, the worker hour activity variable is a fundamental part of the calculation of social risks in the PSILCA database. In the database, activity variables reflect how much of a social flow is linked to the product system. Thus, they are like inventory indicators in E-LCA (UNEP, 2020), so they can be interpreted as the quantity of the risk-assessed social flow associated with the process.

As can be expected, obtaining data about how many hours are necessary for each unit process and how much economic value a process creates is a pretty complicated task. Therefore, the importance of each unit process (organization) in each product system will be represented by its share of the total costs. Although this does not meet the definition of an activity variable (because it does not measure any process activity), it will still be referred to as one because it meets the same purpose and will be used in the same way.

4.2.1.7. Scope definition: stakeholders included and affected

Stakeholders are at the heart of an S-LCA; hence, from an organizational perspective, the stakeholders potentially affected by the conduct of the organizations within the system boundaries must be included. The choice of stakeholder categories will play an essential role in selecting impact subcategories.

Since the S-LCA methodology proposed in the Guidelines is applied in this assessment, all the stakeholder categories suggested, except Children, are considered. This stakeholder category concerns themes (impact subcategories) about the education of children, impacts of products on the health of children as consumers, and the effects of marketing campaigns on children. The operation of the organizations included is mainly developed in a business-to-business context, and these organizations' activities (WWTP, chemical and electricity providers) do not affect children directly. A water utility may be open to educational site visits from schools, but activities like this can be captured in the stakeholder category Local Community. Therefore, it is considered that the Children stakeholder category is only affected indirectly as part of the bigger society (Society) and the neighboring local community (Local Community).

The five stakeholder categories considered almost entirely align with the stakeholder groups included in the PSILCA database (v. 3) since the latter excludes Consumers. Furthermore, the stakeholder categories most commonly included in the reviewed S-LCAs (section 3.5) are Workers, Society, and Consumers (included in nine studies out of eleven). Local community and Value chain actors were included in eight and seven studies, respectively.

A description of the stakeholder categories included in this study is provided in Table 6. These definitions apply to the stakeholders of all the organizations included in the product systems and are closely linked to the geographical location of their operations. For example, big corporations with manufacturing facilities in different countries may affect the well-being of the local communities in each country.

Table 6: Definition of stakeholder categories

Stakeholder category	**Description**
Workers	People who are employed by an organization to deliver a service in exchange for remuneration. These individuals are often exposed to accidents, hazardous chemicals, and other elements (e.g., constant exposure to bad odor or noise) (García-Sánchez & Güereca, 2019; Padilla-Rivera et al., 2016).
Consumers	Given the business-to-business characteristic of the operations of the organizations included in the product system, "consumers" are considered to be other organizations rather than individuals.
Local Communities	Groups of people in close proximity to the organization's physical operations. These neighboring communities are considered to be directly affected by the organization's activities (Mark J. Goedkoop et al., 2018). Regarding the urban WWTP, its purpose is to provide a public service that affects the members of the community by protecting (or worsening) the quality of the surrounding environment.
Society	People and other organizations (e.g., NGOs, government agencies, universities) beyond the local communities, who may be directly or indirectly affected by the organizations' activities. These organizations may be at the micro (local agencies) or macro level (national institutions, associations) (Arcese et al., 2017).
Value Chain Actors	Suppliers of the inputs required for the organization's proper operation in the product systems.

4.2.1.8. Scope definition: selection of impact subcategories

The first selection of impact subcategories is made in the identification of the affected stakeholder categories; however, further refinement is needed. Although considering all the impact subcategories suggested in the Methodological Sheets ensures complete coverage of relevant social issues, doing so demands substantial time and effort from the practitioner and the organizations that must provide this information. Thus, a strategy should support the selection of impact subcategories. In this study, the strategy consists of the following tasks:

- Performing a literature review: a literature review helps identify the topics of interest and areas of concern in the studied sector. Concerning the water sector in general, the literature review presented in section 3.5 revealed that the impact subcategories often assessed are “Fair salary” (73%), “Working hours” (73%), “Health and safety” (Workers) (73%), “Safe and healthy living conditions” (64%), “Local employment” (55%).
- Performing desk research: the primary purpose of this task is to identify issues that are of interest in the area where the case study takes place. In this research, this step concerns issues that are relevant to the water sector in Spain.
- Social hotspot screening using the PSILCA database: the Guidelines recommend performing a screening assessment of the product system using an S-LCA database. By doing this, hotspots in the product’s life cycle can be identified, and limited resources can be directed to collect more refined data about them. However, it may happen that social hotspots occur in a country but not in the organizations involved.
  For the social hotspot screening, first, the economic sectors closest to the economic activity of the organizations involved must be identified. Specifically, the organizations that make up the product systems operate in the manufacture of chemicals, production of electricity, and treatment of wastes in Spain. Additionally, since the WWTP and the WM case study are located in Spain, it is crucial to understand the social issues or risks of this country and these CSS. Therefore, the CSS that best match the business activities of the organizations included in the system boundaries are “Manufacture of chemicals and chemical products”, “Production and distribution of electricity”, and “Market sewage and refuse disposal, sanitation and similar activities”. Second, the impact assessment is carried out for each of those sectors individually, for one unit of output in monetary terms (i.e., 1 USD). This provides an even better picture of each sector's social issues. Third, a contribution analysis is performed to distinguish how many social risks occur specifically in Spain from those in other sectors further upstream in the value chain.
- Experts’ judgement: one of the tasks included in the WM project was to perform a survey among experts in the water sector in order to determine the practicality, uncertainty, importance, and simplicity of social issues in urban and industrial wastewater treatment. Participants included experts from academia, WWT facilities, and governmental bodies.

Finally, some of the common impact subcategories included in the S-LCAs of WM case studies were also considered. As a result, eleven subcategories were selected. Table 7 provides a summary, including a description of each subcategory and the reasons for its inclusion. While most of these descriptions are based on the Methodological Sheets (UNEP, 2021), adaptations are made based on the industries included in this study.

Table 7: Description of impact subcategories included and reasons for their inclusion

Impact subcategory	Description
Freedom of association and collective bargaining	Workers have the right to freely associate to promote and defend their economic and social interests (MITES, 2021b). Workers also have the right to collectively negotiate fair working conditions with industry and business representatives (ILO, 2017). These are fundamental rights proclaimed in the Universal Declaration of Human Rights and the ILO Declaration on Fundamental Principles and Rights at Work (ILO, 2022; United Nations, 1948). The social hotspot analysis results show that Spain's "Market sewage and refuse disposal, sanitation and similar activities" sector is responsible for 53% of the total social risks in this subcategory. Additionally, from the reviewed literature, the following studies included this subcategory: Padilla-Rivera et al. (2016), Serreli et al. (2021), Shemfe et al. (2018), Tsalidis et al. (2020) and Tsalidis and Korevaar, (2019).
Equal opportunities/discrimination	Regardless of gender, race, religion, disability, age, and sexual orientation, everybody has the right to be treated equally and to access equal opportunities regarding employment (Publications Office of the European Union, 2021). Furthermore, one of the themes of the 20 key principles and rights of the European Pillar of Social Rights is equal opportunities and access to the labor market (European Commission, 2017; Publications Office of the European Union, 2021). Concerning the workforce in Spain, the sectors with the lowest participation of women are "Electricity, gas, steam and air conditioning supply" and "Water supply; sewerage; waste management and remediation activities" (following NACE classification 2009), each with only 0.3% of total employed women (INE, 2021). Subsequently, the contribution of the "Market sewage and refuse disposal, sanitation and similar activities" sector in Spain to the total risks in this subcategory was 56%. Some of the reviewed articles included this subcategory (Padilla-Rivera et al., 2016; Serreli et al., 2021; Shemfe et al., 2018; Tsalidis et al., 2020; Tsalidis & Korevaar, 2019).
Occupational health and safety	Organizations should protect their workers' physical, mental and social well-being by ensuring safe working conditions and identifying and preventing risks. Organizations should have management practices and preventative measures in place for the protection of the health and safety of their workers. The preliminary results of the survey on social impacts in the water sector show that experts consider that the health and safety of workers is one of the most important social issues in the sector. In addition, the number of non-fatal occupational accidents in the "Water supply; sewerage; waste management and remediation activities" sector in Spain is twice as large as the total average of sectors in that country (MITES, 2021). Furthermore, this subcategory was also included in most of the reviewed S-LCA articles (Do Amaral et al., 2019; García-Sánchez & Güereca, 2019; Padilla-Rivera et al., 2016; Padilla-Rivera & Güereca, 2019; Serreli et al., 2021; Shemfe et al., 2018; Tsalidis et al., 2020; Tsalidis & Korevaar, 2019). A national study about the clean water supply and sanitation sector revealed that most occupational incidents with leave

	are due to poor posture and overexertion, entrapment, and road traffic accidents (AEAS/AGA, 2020). Workers' health and safety is also a common impact subcategory of WM case studies.
Fair salary	Organizations must pay fair wages to their workers, which should comply with national regulations and standards. Several reviewed S-LCAs have included this subcategory in their studies (Do Amaral et al., 2019; García-Sánchez & Güereca, 2019; Padilla-Rivera et al., 2016; Padilla-Rivera & Güereca, 2019; Serreli et al., 2021; Shemfe et al., 2018; Tsalidis et al., 2020; Tsalidis & Korevaar, 2019). Moreover, this is one of the common subcategories included in the S-LCAs of other WM case studies. Additionally, the social hotspot screening analysis revealed that Spain's "Market sewage and refuse disposal, sanitation and similar activities" sector contributes 50% to the total social risks in this subcategory.
Working hours	The hours worked by employees should comply with national laws and international standards. Overtime should be voluntary and paid at a premium rate. It is known that workers are expected to work in shifts in utility facilities. In fact, that is why many researchers included this subcategory in their studies (Foglia et al., 2021; García-Sánchez & Güereca, 2019; Padilla-Rivera et al., 2016; Padilla-Rivera & Güereca, 2019; Serreli et al., 2021; Shemfe et al., 2018; Tsalidis et al., 2020; Tsalidis & Korevaar, 2019). It is essential to monitor and evaluate the compliance of the organizations in the product systems.
End-of-life responsibility	In an LCA, end-of-life refers to the last stage of a product's life cycle. It consists of the management of waste, i.e., final product disposal, reuse, or recycling. The disposal of a product can lead to environmental and/or human health consequences. This subcategory is mainly about the producer's responsibility to provide consumers with accurate information about their products' end-of-life options. This is one of the common subcategories included in S-LCAs of WM case studies.
Access to material resources	The operations of organizations may harm the environment, affecting the quantity and quality of local material resources. Organizations should have risk management plans to prevent environmental damage and not limit the communities' access to those local material resources. The manufacturing industry is responsible for 11% of the total waste produced in Spain, of which almost 10% was toxic waste (MITECO, n.d.). Therefore, the following goals for 2030 related to resource use efficiency and waste are stipulated in the Spanish Circular Economy Strategy: increase water use efficiency by 10%, increase reuse and reuse-enabling activities of municipal waste by 10%, reduce waste generation by 15% concerning 2010 quantities, and reduce materials consumption by 30% in relation to the GDP of 2010 (MITECO, n.d.). In addition to being a subcategory of interest in the Spanish context, this subcategory is one of the common subcategories of the WM case studies.

Safe and healthy living conditions	Organizations' activities could also affect the local community's safety and health by emitting toxic materials into the air and water and producing hazardous waste. In April of this year, it was decided that Spain should be referred to the Court of Justice of the European Union for failing to comply with the Urban Waste Water Directive in 133 large agglomerations (European Commission, 2022b). This Directive establishes that in agglomerations larger than 2,000-population equivalent and 10,000-population equivalent, Member States must provide secondary and advanced treatment, respectively (*Council Directive 91/271/EEC*, 1991; European Commission, 2022). Furthermore, Spain was already sanctioned in 2018 for not collecting and treating urban wastewater discharged in 17 agglomerations. The fine has accumulated over time, reaching almost EUR 63 million (Asiaín, 2022; Court of Justice of the European Union, 2018; Planelles, 2022). Therefore, this subcategory is deemed relevant for this S-LCA. This subcategory has also been included in previous S-LCAs in the water sector (Muhammad Anwar et al., 2021; Padilla-Rivera et al., 2016; Padilla-Rivera & Güereca, 2019; Serreli et al., 2021; Tsalidis & Korevaar, 2019).
Local employment	The promotion of local employment and the preference for locally-based suppliers that organizations may have bring benefits to local communities, as income, jobs, and training opportunities are made available to them. In the hotspot screening assessment, the Spanish "Market sewage and refuse disposal, sanitation and similar activities" sector contributed to 55% of the total impacts on this subcategory. Moreover, this subcategory was considered a very important social issue in the water sector, according to the preliminary results of the WM survey on social issues. Subsequently, this impact subcategory is also one of the common subcategories across the S-LCAs of WM case studies. Finally, the literature review also revealed that this subcategory is relevant in the water sector (Opher et al., 2018; Padilla-Rivera et al., 2016; Padilla-Rivera & Güereca, 2019; Serreli et al., 2021; Tsalidis et al., 2020; Tsalidis & Korevaar, 2019).
Public commitment to sustainability issues	Organizations should direct efforts to reduce their impacts on the environment and society. They may set targets, publish their progress and actions in sustainability reports, and join international initiatives. This is a common subcategory included in the social assessments of the WM case study.
Promoting social responsibility	Organizations should pay more and more close attention to the environmental and social performance of their suppliers. In addition to being considered a very relevant issue in the water sector according to the preliminary results of the WM survey, this subcategory is a common subcategory in the social assessments of WM case studies. Furthermore, it has been included in a few of the reviewed articles (Foglia et al., 2021; Padilla-Rivera et al., 2016; Padilla-Rivera & Güereca, 2019; Serreli et al., 2021; Tsalidis & Korevaar, 2019).

4.2.1.9. Scope definition: indicators selection

Since the S-LCA methodology suggested in the Guidelines is applied, the indicators to be included for each impact subcategory are mainly based on those suggested in the Methodological Sheets. Furthermore, based on the selected RS method, the indicators must represent organizations' engagement with social issues through policies and management systems and actions. The latter aims to prove that proper measures are implemented to reduce adverse social effects on stakeholders and ensure compliance with regulations. Given that the suggested indicators for some subcategories in the Methodological Sheets are limited, new indicators are added based on previous studies which applied the same RS method. Furthermore, in aiming to measure proactive behavior, social indicators from other works are considered (M. J. Goedkoop et al., 2020; M.J. Goedkoop, de Beer, Harmens, Saling, Morris, Florea, Hettinger, Indrane, Visser, Morao, Musoke-Flores, Alvarado, Schenker, et al., 2020; Mark J. Goedkoop et al., 2018; Life Cycle Initiative & Social Life Cycle Alliance, 2022).

Regarding the indicators for the generic assessment, all the indicators from the PSILCA database are included, except those related to "Environmental footprints" and "GHG footprints", which better represent environmental aspects, and, thus, are not relevant for this study.

4.2.1.10. Scope definition: impact assessment approach

This section addresses the type of IA approach selected for this study and its subsequent method. Furthermore, adaptations to the selected RS method are discussed.

Selection of S-LCIA approach: reference scale or impact pathway?

An impact assessment that follows the IP approach may be seen as an objective and robust method for calculating (*de facto*) social impacts since it relies on established impact pathways. However, some pathways are case-specific, which requires practitioners to develop characterization models appropriate to their case studies. As this is a rather complex task, studies focusing on the IP approach mainly belong to the research field (Pollok et al., 2021; UNEP, 2020). Contrarily, RS methods are more operational (UNEP, 2020), as illustrated by the many case studies available in the literature. Assessing the social performance of organizations may be very useful to their decision-makers, who will learn about how their organizations perform in specific social sustainability themes and be able to design and implement strategies to improve their performances.

Bearing in mind all the characteristics of each IA approach described, the Guidelines suggest selecting one based on the study's goal (UNEP, 2020). The RS approach should be used if the goal is to describe a product system's social performance or social risk. If the goal is to evaluate the consequences of a product system by characterizing its potential social impacts, the IP approach should be used. As noted in section 4.2.1.1, this study focuses on the social performance and the social risks of the product systems under consideration. Therefore, the RS approach is the most appropriate impact assessment approach.

Selection of Reference Scale method

Next, a specific RS method should be selected before the life cycle inventory so that the reference scales can be established and the data needs can be identified. It was described previously that there is no consensus on a specific RS method, and thus, a wide variety of methods exist. In a literature review including 190 articles in S-LCA, Ramos Huarachi et al.

(2020) identified the most used S-LCIA method currently: the Subcategory Assessment Method (SAM) proposed by Ramirez et al. (2014).

SAM can be described as a referencing method characteristic of the RS approach. The method is based on the subcategories defined in the Guidelines and their definitions, as provided in the Methodological Sheets. It allows for the evaluation of the social performance of organizations in different subcategories in a uniform and consistent manner by referencing it to normative information. Thus, a reference scale for each subcategory is elaborated following the same approach: each scale is divided into four different levels (A, B, C, and D) based on a so-called "basic requirement" (BR). A BR for an impact subcategory is constructed from the indicators suggested in the Methodological Sheets, which define what is assessed under each subcategory and what actions organizations may undertake to demonstrate compliance. For all the subcategories that do not provide practical examples of information that can be collected, SAM uses the presence of a management system or policy as the BR.

Regarding the assessment step, an organization reaches level B if it fulfils the BR or level A if it demonstrates proactive behavior by encouraging the fulfilment of the BR along the value chain. If the organization, on the other hand, does not fulfil the BR, it reaches level C or D, depending on the context. More specifically, if the organization operates in a positive context (i.e., peers meet the BR or the country promotes the BR, which stimulates compliance), it reaches level D. In contrast, if it operates in a negative context, it reaches level C. Therefore, the reference scale proposed in this method uses two types of PRPs; normative PRPs (the compliance level B) and the socio-economic context of the organization's activities (levels C and D).

SAM is considered appropriate for this S-LCA for a few reasons. The first regards the inclusion of the context in the assessment, an essential social dimension that will not be lost in the aggregation of results (Chhipi-Shrestha et al., 2015). However, it is important to note that this is only the case when organizations do not meet the BR since the fulfillment of the BR automatically leads to level B without considering the social conditions of the organizations' activities. Another advantage of this method is that it has a semi-quantitative character. It allows for converting qualitative data into quantitative information (Ramirez et al., 2014); thus, there is no restriction on the collected data type. Subsequently, SAM facilitates getting to the subcategory assessment (IA step) directly from the inventory information (Ramirez et al., 2014). Lastly, this referencing method will be applied in all the S-LCAs of the WM project to ensure consistency and comparability of the results.

Adaptations to the Subcategories Assessment Method (SAM)

The authors of SAM have noted that defining the BRs for each impact subcategory was the most challenging step of the method (Ramirez et al., 2014). Most of the subcategories (about 77%) had BRs based on organizational management indicators (Ramirez et al., 2014). Indeed, some authors noted that the BRs proposed by Ramirez et al. (2014) are inconsistent since the BRs for some subcategories are based on organizational management indicators while others relate to organizations' performance (de Santo, 2019; Hannouf & Assefa, 2018). In reality, this may be problematic since an organization may have policies to address issues related to an impact subcategory, but it may not implement specific actions to promote or prevent those issues. For example, an organization may have equal opportunities and diversity policies, but workers complain that they are not given equal opportunities for specific job positions.

To overcome that limitation, the modified SAM proposed by Hannouf & Assefa (2018) suggests implementing two levels of assessment, thus, differentiating between the commitment to the subcategory in company policies (first level of assessment) from the evidence of good or bad practices relating to the subcategory (second level of assessment). While doing this has the advantage of assessing companies objectively and more encompassingly, the method has some questionable aspects. Firstly, it does not provide examples of good and bad performance. Assuming that these can be derived from the indicators proposed in the Methodological Sheets, most of these indicators measure good or positive performance. Not meeting those positive performance indicators might be interpreted as a negative performance and vice versa. However, that is not always true. Consider that an organization does not have publicly available documents as promises or agreements on sustainability issues (a social indicator of "Public commitment to sustainability issues") and that this indicator measures positive performance; should the absence of this indicator then be interpreted as a negative performance? This is not clear. Likewise, should the absence of a negative performance indicator (e.g., the presence of suspicious deductions in wages) be interpreted as positive performance? The absence of negative indicators does not directly translate into a positive performance.

Secondly, in this method, an organization can achieve different levels (very good, satisfactory, inadequate, and bad performance) depending on how many good (positive performance indicator) and bad practices (negative performance indicator) it undertakes. Specifically, if an organization meets the BR but one or two negative performance indicators are found, it is assessed as "satisfactory performance". However, if more than two negative performance indicators are found, it is considered "inadequate performance".

Consider that for the subcategory "End-of-life responsibility", only one indicator is assessed (excluding the indicator that is used as BR), and it is a negative performance indicator ("incidents of non-compliance with regulatory labelling requirements"). If there is evidence of this for a given company, it will directly be assessed as "bad performance". In contrast, the absence of evidence probably will lead to the "very good performance" level. This change in performance levels is abrupt and may affect a company's social performance result. Thus, the number of positive and negative performance indicators seemingly affects the performance levels that organizations can achieve in practice. Furthermore, the possibility of taking actions to tackle this type of negative performance by a company is not considered in such an assessment. Although the assessment proposed by Hannouf & Assefa (2018) has valuable characteristics, because of the lack of clarity and the methodological shortcomings described above, it is not considered helpful for this study.

The approach considered in this study aims to address the inconsistency of SAM by separating the BRs from the social indicators per se, and by assessing compliance with the normative BRs via indicators that regard commitments in the form of policies or management systems, and indicators that relate to actions that organizations may take. To achieve the first, the BRs are established somewhat differently in this study compared to SAM. Instead of using a social indicator as the BR or formulating a BR based on the indicators from the Methodological Sheets, the BR for each subcategory is directly drawn from international standards or norms of conduct for organizations. These should reflect the subcategory definitions and aims provided in the Methodological Sheets; hence, this document remains the foundation for the BR establishment. This will then allow evaluating the fulfilment of the BR by considering a combination of indicators that measure both management efforts and actual performance in the considered social aspect.

This approach also makes it possible to evaluate slightly different aspects of the same impact subcategory, measured by different social indicators. In other words, an impact subcategory may include the consideration of different social issues that may deserve different BRs, and, thus, different reference scales (an example regarding "Local employment" will be provided in the following section). Furthermore, it may also happen that compliance with one BR can be evaluated via indicators that measure performance in different aspects (an example regarding "Equal opportunities/discrimination" will be provided in the following section).

Another aspect of SAM that needs some adaptation is the "proactive behavior" level of the reference scale, which considers the promotion of the BR to value chain actors. For instance, for a company to achieve this level in the subcategory "Access to material resources", it needs to have an environmental management system in place *and* encourage its suppliers to do the same. However, actions similar to the latter are already accounted for in the subcategory "Promoting social responsibility"; therefore, it will contribute to double counting. Instead, actions undertaken by companies that go beyond the compliance level (Level B) are considered for "proactive behavior" assignment. However, this usually entails more data collection efforts.

Having explained the primary adaptations to SAM, how the reference scales are constructed for each impact subcategory is described in more detail in the following section (4.3.1).

4.3. Social life cycle inventory (S-LCI)

4.3.1. Establishment of reference scales

As mentioned in the LCI section of the previous chapter (3.2), one of the data types required in S-LCA concerns the PRPs (or, in this case, BRs). Thus, the preparation of the RSs starts in the LCI phase, when data for the BRs must be collected (UNEP, 2020).

The reference scales adopted in this study have four levels. These levels are associated with numbers so that the presentation and aggregation of results are facilitated. A general representation of the reference scales is provided in Table 8.

Table 8: Reference scale for this study (adapted from Ramirez et al., 2014)

1	Proactive behavior
2	Compliance with the BR
3	Non-compliant situation and negative context OR No data and positive context
4	Non-compliant situation and positive context OR No data and negative context

In establishing reference scales for each subcategory, the first step is the identification of BRs that align with the subcategory description. The BRs are based on international organizational standards or norms of conduct for all the subcategories. Second, the social indicators proposed in the Methodological Sheets are included, and it is ensured that indicators related to commitments in the form of policies and action-oriented indicators are included. One particular instance is the subcategory “Access to material resources” because it only includes one indicator, which is related to a commitment (Presence of an environmental management system). In order to address this, whether organizations are ISO 14000 certified is evaluated, which includes actions taken by organizations to address environmental impacts.

Third, all the social indicators must be covered by the BR. Suppose there is more than one indicator measuring the same BR, and these indicators cover the same aspect (e.g., “freedom of association and collective bargaining are included in policies” and “percentage of employees covered by a collective bargaining agreement”). In that case, they are all included in one reference scale (see the reference scale FACB1 in Appendix V).

Furthermore, it may also happen that social indicators measure alignment with the same BR in different ways. For example, regarding the subcategory “Equal opportunities/discrimination”, the BR establishes that organizations shall not engage in or support discrimination in hiring, remuneration, access to training, etc., based on race, religion, disability, gender, or sexual orientation (SAI, 2014, p. 11). This can be measured by the “presence of policies on equal opportunities and established procedures to address discrimination issues” and “announcements of job positions through channels open to the general public”. Given that these indicators are different but, at the same time, measure compliance with the same BR, two different scales are needed (see the reference scales for “Equal opportunities/discrimination” in the Appendix V).

In some cases, more than one BR is considered relevant for an impact category. For example, the Methodological Sheets consider that an organization can contribute to the subcategory “Local employment” by having a preference for hiring locally and working with local suppliers. Accordingly, two BRs, each covering one of these aspects, are identified. The first stipulates that organizations should aim to hire local workers (OECD, 2011, p. 36), whereas the second establishes that organizations should give preference to local suppliers (ISO, 2010). Thus, more than one reference scale is established to measure conformance properly.

Fourth, the context is considered if there is no data and compliance with the BR cannot be assessed. If the organization operates in a context where the performance of the sector or similar organizations is considered positive, it attains level 3. Contrarily, if it operates in a negative context, it reaches level 4. In a recent report including S-LCAs of pilot projects aiming to demonstrate the applicability of the new version of the Guidelines, “no data” is given the worst score (-2) on the reference scale (Life Cycle Initiative & Social Life Cycle Alliance, 2022, p. 34). However, this may be unreasonable if the organization operates in a country with no indications or a very low risk of a social issue (e.g., child labor in Sweden) (M.J. Goedkoop, de Beer, Harmens, Saling, Morris, Florea, Hettinger, Indrane, Visser, Morao, Musoke-Flores, Alvarado, Schenker, et al., 2020). Hence, considering the regional or sectoral context of the organization provides a clearer indication of what the behavior of an organization might be.

Fifth, the reference scales include examples of actions that organizations may undertake (in addition to meeting the compliance level) that may qualify them to achieve level 1. Examples are given for at least one reference scale of each subcategory. For three subcategories, namely, “End-of-life responsibility”, “Public commitment to sustainability issues”, and “Promoting social responsibility", no examples in the literature were found. In general, these examples aim to increase this assessment's transparency by showcasing ways organizations can achieve the best score.

Furthermore, since social indicators per se do not make up the BRs, some social indicators can be combined. Following the above example, a policy regarding local hiring preferences and data on the percentage of the workforce hired locally are both assessed to verify compliance (level 2). Despite this, when there is not enough information to assess the action-oriented indicator (e.g., % of local workforce), the presence of a policy is deemed sufficient for meeting the BR. The above is thus an attempt to combine management efforts with actual performance to meet the BR.

4.3.2. Data requirements

The data needed for the site-specific as well as generic assessments can be summarized as follows:

Data needs for the site-specific analysis:

- Data on the physical flows of the product systems (quantities, costs, suppliers)
- Data on the BRs
- Data on the social flows of each organization in the product systems
- Additional data for the assignment of a score if there is no site-specific data or if the BR is not met
- Additional data for sensitivity analyses

Data needs for the generic analysis:

- Data on the physical flows of the product systems (quantities, costs, country of origin)
- Data on social flows of the reference system and the original system
- Data for the calculation of the activity variable (worker hours). This includes data on the number of hours worked by employees in the reference and original systems, the total output of the systems in monetary terms, and the average wage of employees.

Regarding the site-specific analysis, knowing the physical flows in amounts and costs is necessary for calculating the activity variable. Obtaining information on the costs of inputs is a rather challenging task. As expected for the original system, when a project is being tested at a pilot scale and a chemical supplier(s) cannot be identified with certainty, neither can the costs. Additionally, the costs of inputs in the current WWTP (reference system) are also troublesome to obtain because they may be company-sensitive information and/or difficult to obtain, even if it is within the same organization.

BRs must be defined first in order to construct each reference scale. The international standards and/or industry best practices, which are the base of the BRs, should be defined for each impact subcategory. Once the reference scales are prepared, the social performance of organizations can start to be evaluated. For this, organization-specific data on each indicator must be collected. When this is not possible, the assessment can still take place by considering the situation in the sector and/or peers' behavior. That is, assessing the behavior of other companies in the sector that are not included in the assessment might be necessary, especially if the organization under study does not meet the BR or lacks site-specific data.

As for the generic analysis, information about inputs' quantities, costs, and country of origin are needed. Accordingly, to select the correct CSS, it is crucial to know where those inputs are produced; thus, this data needs to be collected. Having identified the inputs and their CSSs, it is necessary to collect information on the social flows originating in the product systems under study and the worker hours. The first can be replicated from the "Market sewage and refuse disposal, sanitation and similar activities" process (processes in PSILCA are input-output CSS). The second can be calculated based on the worker hour equation used in PSILCA (see section 3.2.1).

4.3.3. Main sources of data

There are two main sources of data. Primary data is data that has been collected by the researcher directly through interviews, surveys, and focus groups (UNEP, 2020). On the other hand, data initially collected by an institution or a person different from the researcher, with a purpose different from the one of the study, is considered secondary data (UNEP, 2020). Some sources of secondary data are scientific articles, company reports, and databases.

4.3.3.1. Primary data sources

Data regarding the physical flows (costs, suppliers, country of origin) and data needed for calculating the activity variables can be obtained directly from the CS operator. Additionally, data on the indicators should be obtained directly from the organizations in the product system. For this, a semi-structured interview can be performed and/or questionnaires can be filled out by employees from the organizations under study.

Sampling is a statistical process comprising the selection of a subgroup ("sample") of the population under study to make observations and perform analyses (Bhattacherjee, 2012). This process is carried out in three steps: identifying the target population, choosing a sampling frame, and choosing a sample from the latter (Bhattacherjee, 2012). The units of analysis of this thesis are the organizations included in the product systems; hence, the employees working for these organizations, their end-consumers, suppliers, and individuals of the local communities where the organization operates are the population of interest. Each represents the stakeholder group on which the organization's activity (behavior) may have effects. However, given this study's very limited time and resources and the uncertainty about the end-users and suppliers of some organizations, it is impossible to assess all the populations from the different organizations. Thus, the people who most likely can provide data regarding the social indicators of each impact subcategory affecting different stakeholder groups are the organizations' employees.

Next, a sample can be obtained from a sampling frame, which is a list that contains information about a fraction of the population of interest (Bhattacherjee, 2012). For this study, the CS operator facilitated a list of contact persons for each organization. Additionally, an online platform (LinkedIn) was used to access the list of employees from each organization.

Then, a sample was selected using a non-probability sampling approach: purposive or judgment sampling. This method implies that individuals are selected according to a set of non-random criteria (e.g., expertise in the areas under study). This approach is helpful when the researcher aims to gather detailed information about a phenomenon in order to describe it (not make statistical inferences) (Kumar, 2011; McCombes, 2019). Therefore, it is deemed appropriate for this study since employees in certain positions may have more information and knowledge about the performance of their organizations. In view of the indicators selected, employees from the Human Resources and Corporate Social Responsibility (or the like) departments, as well as Area or Country Managers and Managers, are considered suitable for participation.

4.3.3.2. Secondary data sources

In most cases, the CS operator could not provide information regarding the country of origin of the chemicals used, especially for the original system. As mentioned above, the system is operating at a pilot scale, and not even a chemical supplier could be identified with certainty. Therefore, two approaches to determine the country of origin of chemicals are identified. The most straightforward approach is consulting this data directly with the chemical supplier; in this case, the data is from a primary source. The second approach is using online databases to collect this information, such as the Observatory of Economic Complexity (Simoes & Hidalgo, 2011) and BACI (Gaulier & Zignago, 2010).

Furthermore, as expected, the BRs are drawn from standards and conventions from international organizations such as the International Labor Organization, Organization for Economic Co-operation and Development, Social Accountability International, International Finance Corporation, and the International Organization for Standardization (IFC, 2012; ILO, 2015; ISO, 2010; OECD, 2011; SAI, 2014).

The social performance of organizations was also based on information collected from companies' sustainability reports and websites, online news articles, online articles from NGOs, and online databases such as Spain's National Statistics Agency (INE) and ILOSTAT.

4.3.4. Data collection strategy

Since most of the data for the generic analysis can be obtained from the CS operator, this section mainly concerns the strategy for collecting data for the site-specific analysis. The main approach for data collection is based on (1) desk research and (2) performing interviews with employees from each considered organization or asking them to fill in a questionnaire.

The desk research is a crucial step for collecting all the relevant information regarding the social indicators of each organization prior to the interviews. This step has mainly two purposes; the first is to collect information that can be further elaborated on or explained by the participants, and the second is to accelerate data collection by gathering all the data already available on the companies' annual reports or websites. Additionally, this step helps participants save time in completing the questionnaire (if preferred) and shows initiative from the researcher. As one participant put it, "this report is our most comprehensive public data" (participant from Organization B, personal communication, April 14, 2022), referring to their company's ESG report. Additionally, this step is crucial for identifying organizations' negative performance, such as non-compliance with regulations, since these are usually not provided voluntarily (UNEP, 2020).

Survey interviews and survey questionnaires are the two main categories of survey research. Survey research uses standardized interviews or questionnaires for data collection (Bhattacherjee, 2012). Although data collection through interviews is resource-intensive and may take a great deal of time, it is more personalized, and questions can be clarified by the interviewer if needed (Bhattacherjee, 2012; Kumar, 2011). Contrarily, questionnaires are less time-intensive and are completed by the respondents, allowing them to respond at their convenience (Bhattacherjee, 2012; Kumar, 2011). For this reason, receiving the filled-out questionnaires may take weeks or months, prompting the researcher to send several reminders.

Before the interviews are performed, questionnaires that include open-ended questions are prepared, serving as interview protocols. The questionnaires start with a description of the WM project, the WM case study, and the research goals. In addition, the S-LCA methodology is briefly introduced. Then, the questions, organized into impact subcategories and stakeholder categories, are presented. The open-ended questions are based on the social indicators and provide opportunities for interviewees/participants to elaborate on their answers freely. The questionnaire is provided in Appendix II.

The researcher can perform follow-up questions in interviews. For example, during the desk research, it was noted that Organization C is working on a diversity and inclusion roadmap. Then, during the interview, following the question on whether the organization has policies that promote equal opportunities and non-discrimination, the researcher could ask in more detail what the diversity and inclusion program is about. Collecting more information about this aspect is relevant for identifying proactive behavior, allowing organizations to achieve a better score in the impact assessment step.

Given the social indicators, the interview or questionnaire may resemble auditing processes, making the interviewee feel uncomfortable and, worst case, unwilling to share information. Therefore, to avoid this, special attention was paid to the questions' wording.

When the participants were approached for data collection, they were asked whether they would like to complete the questionnaire in an (online) interview or individually in an offline setting. Somewhat surprisingly, most of the participants preferred the second. This type of response might be due to their own time constraints, the potential need to check with other colleagues for information, or to avoid providing too much information. In fact, when in-depth information is required, interviews might be better than questionnaires (Kumar, 2011). Consequently, some participants gave very short yes/no answers, which affected their organizations' results since the information was insufficient to either meet a BR or be qualified as a proactive behavior.

Finally, collecting data from various individuals and using different data collection methods are both crucial for triangulation, increasing the results' validity and credibility (Bhattacherjee, 2012).

4.3.5. Data quality assessment

Because of all the different data sources mentioned above, it becomes substantially necessary to assess the data quality as this is pivotal to ensuring the reliability and validity of the results (UNEP, 2020). However, the Guidelines point out that even though there is currently no general guidance on how to address the data quality requirements for social data in S-LCA, a data quality option is available (UNEP, 2020).

The quality of the collected data can be assessed according to relevant indicators of data quality which an ordinal scale can rate, e.g., from 1 (indicating very good performance) to 5 (indicating very bad performance) (Maister et al., 2020; UNEP, 2020). This can be done with the use of a pedigree matrix. The pedigree matrix was first introduced by Funtowicz and Ravetz (1990 as cited in Ciroth & Franze, 2013; Ciroth et al., 2016) for uncertainty analyses. This pedigree matrix was then introduced to LCA by Weidema & Wesnæs (1996) and later modified by Weidema (1998). From then on, it was widely adopted in the LCA community and adapted for specific uses by many authors (e.g., it is applied in the ecoinvent database, PSILCA database) (Ciroth et al., 2016; Maister et al., 2020; UNEP, 2020).

The pedigree matrix combines aspects related to the reliability of the data sources, completeness, temporal, geographical and technical conformance. Given that the proposed pedigree matrix in the Guidelines is based on that used in the PSILCA database, a slight modification is made to be adopted in this study. Accordingly, data points are assessed based on the source's reliability, completeness, and temporal and geographical conformance.

The reliability of the source is related to how the data was acquired and whether it was verified. Verification relates to whether the data obtained is comparable to other data sources or if a third person reviewed it. The scores do not assess the origin or sources of data per se but whether those sources are reliable (Bo P. Weidema, 1998). Data is complete if it has enough breadth and depth for the study and no parts are missing (Pipino et al., 2002). The temporal conformance relates the year of the obtained data with the year of the study; it aims to assess whether the data obtained is up-to-date for the task at hand (Pipino et al., 2002; Bo P. Weidema, 1998). Lastly, the geographical conformance indicates whether the data is from the specific site under study or other areas with similar or different social conditions (Ciroth & Franze, 2013; Mark J. Goedkoop et al., 2018). The pedigree matrix used in this study was adapted from PSILCA (Maister et al., 2020), Ciroth and Franze (2013) and the PSIA Handbook (Mark J. Goedkoop et al., 2018) (Table 9).

Table 9: Data quality matrix adapted from PSILCA (Maister et al., 2020), Ciroth and Franze (2013) and the PSIA Handbook (Mark J. Goedkoop et al., 2018)

Indicator	Scores				
	1	2	3	4	5
Reliability of the source(s)	Statistical study, or verified data from primary data collection from several sources.	Verified data from primary data collection from one single source or non- verified data from primary sources, or data from recognized secondary sources.	Non-verified data partly based on assumptions or data from non-recognized sources.	Qualified estimate (e.g. by an expert).	Non-qualified estimate or unknown origin.
Completeness conformance	Complete data for country-specific sector/ country.	Representative selection of country-specific sector/ country.	Non-representative selection, low bias.	Non-representative selection, unknown bias.	Single data point/ completeness unknown.
Temporal conformance	Less than 1 year of difference to the time period of the dataset.	Less than 2 years of difference to the time period of the dataset.	Less than 3 years of difference to the time period of the dataset.	Less than 5 years of difference to the time period of the dataset.	Age of data unknown or data with more than 5 years of difference to the time period of the dataset.
Geographical conformance	Data from specific site under study.	Data from other sites of the company in the same region.	Data from relevant sites of the company in other regions.	Data from other companies in same region with similar production conditions.	Average sector or country data from public or third-party database provider.

4.3.6. Multifunctionality and allocation

For any process with more than one function, its economic and social flows need to be allocated to each functional flow. A functional flow is any economic flow that fulfills the process' goal, i.e., the waste inflows of a waste treatment process and the product outflows of a production process (Guinée et al., 2021).

However, multifunctional processes need to be identified before solving the multifunctionality problem. Accordingly, Guinée et al. (2021) propose three steps for that identification. The first step is determining whether a flow between two processes is a good or a waste. In order to make such a differentiation, the flow's economic value can be considered, as Guinée et al. (2004) suggested. Hence, a good is a flow between two processes whose economic value is equal to or larger than zero, whereas a waste is a flow with an economic value smaller than zero. Second, the functional flow(s) of a process can be identified by pinpointing the product(s) produced and/or the waste(s) treated. Third, multifunctional processes, which are those processes with more than one functional flow, can be identified. By following these steps, the WWT process in each product system was identified as multifunctional. Table 10 provides a summary.

Table 10: Assessment of multifunctionality of the WWT processes of the reference and original systems

Reference system	
1. Identification of goods and wastes	• The incoming municipal wastewater has a negative economic value (the user pays for its treatment); hence, it is a waste. • Biogas is produced in the WWT process. Biogas has an economic value larger than zero; thus, it is a good. The biogas produced is entirely reused in the same facility. • Sludge is produced in the process. Since the sludge is sold for agricultural uses, it is a good. • Another type of sludge produced is waste since it has a negative economic value and is sent to other facilities for treatment.
2. Identification of functional flows	Municipal wastewater, biogas, and sludge for agriculture (3)
3. Determination of multifunctionality	The process is multifunctional.
Original system	
1. Identification of goods and wastes	• Municipal wastewater enters the system, and it is a waste since its value is <0. • Water is recovered with two types of quality. One is suitable for agricultural uses, and since it will be sold to irrigators, it has a positive economic value (good). The other one is high-quality water for industries. Since this water will also be sold, it is a good. • Vivianite is produced, and it will be sold to end-users (good). • Sludge for agricultural uses is produced, and it will be sold to farmers (good). • Biogas is produced, but it will not be sold; instead, it will (potentially) be treated as waste by incineration.
2. Identification of functional flows	Municipal wastewater, water for agriculture, water for industries, vivianite, and sludge (5)
3. Determination of multifunctionality	The process is multifunctional.

Next, the multifunctionality problem must be solved. According to ISO 14044 (ISO, 2006b), solutions for multifunctionality are defined in three steps. First, allocation should be avoided by dividing the multifunctional processes into sub-processes and collecting input and output data for each (i.e., performing a more refined data collection). Alternately, allocation can be avoided by including the additional functions delivered by the process in the system boundaries (i.e., system expansion). Second, if allocation cannot be avoided, the inputs and outputs should be allocated to the different functional flows based on their underlying physical relationships (i.e., physical allocation). Third, if physical relationships cannot be established or used for allocation, partitioning of the inputs and outputs between the functional flows should be based on other types of relationships between them.

A fourth approach not included in ISO 14044 is that regarding the avoided burdens method or substitution (Guinée et al., 2021). The method is very similar to system expansion. Suppose that the impacts of a multifunctional process need to be allocated to products A and B. The impacts allocated to product A can be calculated by subtracting the impacts from an alternative process producing a product similar to product B from the total impacts. Thus, the avoided burdens are those generated in the production of a similar product by another stand-alone process.

In this study, both WWT systems represented in each product system include multiple unit processes. However, since an organizational perspective is taken and social flows are not directly linked to unit processes, each WWT system is considered as one including all those unit processes. Thus, the inputs and outputs of each product system represent the total sum of all the inputs required and products produced in their single unit processes.

Allocation cannot be avoided since data collection is specific enough for each product system. Suppose the WWT process is divided into sub-systems. In that case, it is not possible to collect more data regarding the social indicators since most of them are related to the behavior of the organization that operates all these processes (CS operator). Furthermore, expanding the system boundaries will not yield the results expected in terms of treating 1 m^3 of wastewater. Instead, the analysis will regard treating 1 m^3 and producing other materials, and it will require adding other processes that are not part of the current WWTP in La Llagosta (reference system).

As for the allocation approach to be implemented, economic allocation is considered the most suitable since some social flows may have a stronger connection to the economic value created rather than the physical quantity of products produced or wastes treated. Furthermore, the co-products generated in the original system (e.g., vivianite) are valuable resources. Given that a relatively small quantity of vivianite is recovered in the original system using allocation factors based on physical allocation will not give proper account to the importance of this material. However, it is crucial to note that there are no obvious causal links between the social and functional flows, or these are not strong. Therefore, solving for multifunctionality in S-LCA seems even more artificial than in E-LCA, which should be acknowledged.

Economic allocation consists of allocating the non-functional flows of a multifunctional process to its functional flows based on their shares in the total proceeds (Guinée et al., 2004). Accordingly, the allocation factors are determined by the share of each product in the total sales of a process (Guinée et al., 2004). Although prices fluctuate, the share of each product in the total proceeds is what is needed, and these can be assumed to remain constant (Guinée et al., 2004). The calculation of the allocation factors for the reference and original systems are presented in Table 11 and Table 12. As mentioned in Table 10, the recovered biogas in the reference system is reused in the same facility. Therefore, it is a closed-loop recycling (virtual) process[2]. Allocation of a closed-loop recycling process is irrelevant as long as the supply and demand of the recycled flow balance (Guinée et al., 2021).

Table 11: Economic allocation factors for the WWT process of the reference system

Functional flow	**Quantity**	**Price (EUR/unit)**	**Proceeds (EUR)**	**Allocation factor**
Municipal wastewater (inflow; m^3)	-1.000	-0.139	0.139	0.856
Biogas (outflow; Nm^3)	0.137	0.109	0.015	0.092
Sludge for agriculture (outflow; kg)	0.468	0.018	0.008	0.052
Total			0.163	1

Table 12: Economic allocation factors for the WWT process of the original system

Functional flow	**Quantity**	**Price (EUR/unit)**	**Proceeds (EUR)**	**Allocation factor**
Municipal wastewater (inflow; m^3)	-1.000	-0.997	0.997	0.661
Vivianite (outflow; kg)	0.040	10.000	0.400	0.265
Sludge for agriculture (outflow; kg)	0.088	0.018	0.002	0.001
Water for agriculture (outflow; m^3)	0.720	0.074	0.053	0.035
Water for industries (outflow; m^3)	0.280	0.200	0.056	0.037
Total			1.508	1

Data regarding the quantity of the functional flows for each system were obtained from the CS operator. The price of treating 1 m^3 of wastewater was calculated based on the price of all the inputs used (see Table 13 and Table 14). In turn, the unit prices of each input were obtained from the CS operator. Regarding the reference system, the unit price of biogas was obtained from the ecoinvent database (v. 3.8) (ecoinvent, 2016), while the unit price of sludge for agriculture was obtained from the CS operator.

As for the original system, the unit price of vivianite was obtained from Y. Wu et al. (2019), who performed a literature review on the recovery of P as vivianite from wastewater. The unit price of water for agriculture was obtained from Villar-García (2016), who analysed the costs of reclaimed water production in Spain. Finally, the unit price of high-quality water for industries was estimated based on the unit cost of deionised water produced in one case study of the Zero Brine project in Spain.

Table 13: Data used for the calculation of the cost of treating 1 m^3 of wastewater in the reference system

Inputs	**Quantity**	**Unit price (EUR)**	**Total (EUR)**	**Note/reference**
Sodium hypochlorite (kg)	1.40E-04	1.00E-01	1.40E-05	CS Operator
Polymer for sludge conditioning (kg)	2.00E-03	1.50E+00	3.00E-03	CS Operator

[2] Guinée et al. (2021) note that through partitioning or allocation, a multi-functional process is split up into different mono-functional processes. They refer to these mono-functional processes as virtual processes.

Polyaluminum chloride (kg)	4.50E-02	2.00E+00	9.00E-02	CS Operator
Antifoaming (kg)	8.80E-04	5.00E+00	4.40E-03	CS Operator
Electricity (kWh)	3.80E-01	1.10E-01	4.18E-02	CS Operator
Total (cost of treating 1 m^3 wastewater)			1.39E-01	

Table 14: Data used for the calculation of the cost of treating 1 m^3 of wastewater in the original system

Inputs	Quantity	Unit price (EUR)	Total (EUR)	Note/reference
Sodium bicarbonate (kg)	1.50E+00	3.00E-01	4.50E-01	CS Operator
Ferrous chloride tetrahydrate (kg)	8.00E-02	2.00E+00	1.60E-01	CS Operator
Hydrochloric acid (kg)	1.27E-02	8.00E-01	1.02E-02	CS Operator
Sodium hydroxide (kg)	1.70E-02	5.00E-01	8.50E-03	CS Operator
Electricity (kWh)	3.35E+00*	1.10E-01	3.69E-01	CS Operator
Total (cost of treating 1 m^3 wastewater)			9.97E-01	

*The electricity amount used in the reverse osmosis process was obtained from Salinas-Rodríguez et al. (2021), which corresponds to the electricity requirement for the treatment of brackish water by reverse osmosis. The reverse osmosis used in the original system is assumed to operate under the same conditions.

4.3.7. Activity variables to be used

4.3.7.1. Site-specific analysis activity variable

It was discussed in section 4.2.1.6 that each organization's weight in a product system would be determined by the share of the cost of its product in the total costs incurred by the system. This is associated with the total costs of treating 1 m^3 of wastewater (functional unit) in each product system. Given that the total costs are calculated based on the material and energy inputs needed to deliver the functional unit (see Table 13 and Table 14), the CS operator's weight cannot be determined. In order to address this, the costs of personnel in relation to the functional unit were estimated per each product system (see equation below) and then added to the costs of the materials and energy inputs. The share of each organization in the reference and original systems is shown in Table 15.

$$Personnel\ costs\ per\ FU = \frac{annual\ average\ wage\ (EUR) \times number\ of\ employees}{total\ wastewater\ treated\ in\ previous\ year\ (m3)}$$

Table 15: Activity variable results of each product system

	Site-specific activity variable
Reference system	
CS operator	0.1053
Organization A	0.0001
Organization B	0.0193
Organization C	0.5784
Organization D	0.0283
Organization E	0.2686
Original system	

CS operator	0.0179
Organization F	0.6191
Organization E	0.3629

The organization with the largest share in the reference system is Organization C (ca. 60%), followed by Organization E (27%). Organization C's large share is because of all the chemicals used, the one provided by them is used in the largest amount, and it is also the second most expensive. Organization A's contribution is the smallest one (almost null) because the chemical they supply is used in minimal quantities, and its price is extremely low. The share of the CS operator went from 10.5% in the reference system to only 1.8% in the original system. The reason is that more chemicals and electricity are used in this system than in the reference system; hence, the chemical and electricity suppliers carry more weight (62% and 36%, respectively). Notably, the activity variable for the original system was calculated from data estimations regarding its pilot scale operation.

However, this approach to calculating the site-specific activity variable carries some limitations. Firstly, like value-added, the (relative) good social performance of an organization whose product is used in higher quantities or has a high price is given more importance and determines most parts of the results. On the other side, an organization whose social performance is (relatively) poor and whose share in the product system is small (e.g., its product is too cheap or not used in large quantities) plays a less determining role in the calculation of the total results. Secondly, multiplying the share of each organization by the social performance scores may introduce more uncertainty in the results as some indicators are qualitative and were converted to semi-quantitative values (scores) (UNEP, 2020).

4.3.7.2. Generic analysis activity variable

For each product system, worker hours need to be calculated. As mentioned, this is done using the same equation in PSILCA (see section 3.2.1). The number of worker hours per unit of output equals the unit labor costs divided by the mean hourly wage. The unit labor costs are calculated from the average wage paid at the CS operator, the cost of treating 1 m^3 of wastewater (Table 13 and Table 14), and the total amount of wastewater treated in 2021. The mean hourly wage is derived from the annual wage average paid at the CS operator, considering that a year has 52 work weeks, and employees work 40 hours per week. All the current prices and wages are adjusted for inflation and converted to USD, the exchange rate of 2015. Table 16 shows the worker hour results for both systems.

Table 16: Worker hour results of the reference and original systems, based on the Equation from PSILCA

Calculation of worker hours	Reference system	Original system
Unit labor costs (USD/USD)	0.1177	0.0183
Mean hourly wage (USD/h)	10.8585	10.8585
Worker hours (h/USD)	**0.0108**	**0.0017**

4.4. Social life cycle impact assessment (S-LCIA)

4.4.1. Classification

Given the IA approach adopted in this study, the classification of impact subcategories into stakeholder categories is deemed adequate and necessary for calculating and presenting results. Additionally, the social inventory indicators are also classified into impact subcategories, following the classification approach in E-LCA, where the inventory results (all the elementary flows) are classified into impact categories. The classification of social indicators into impact subcategories, and impact subcategories into stakeholder categories follows the same classification presented in the Guidelines and the Methodological Sheets. For clarity purposes, this classification is also provided in Appendix III.

4.4.2. RS approach: organizations' social performance evaluation steps

This section aims to show how the performance of an organization is assessed for each impact subcategory. Firstly, compliance with the BR is evaluated by considering the relevant social indicators. If compliance is met, two alternatives exist: additional information indicates that the organization is best in class or demonstrates a proactive behavior, so the organization gets a score of 1, or there is no further information that proves proactive behavior, so it aligns with level 2. If the organization does *not* meet the BR, its context is assessed; it gets a score of 3 if it operates in a negative context and 4 if it operates in a positive one.

For example, take the subcategory "Safe and healthy living conditions", which has two reference scales. The BR of one of the reference scales concerns the organization's efforts to avoid or reduce the use of hazardous materials. Organization E only reports the number of hazardous wastes generated throughout the year and their end-of-life treatment. Since this does not precisely meet the BR, the performance of peers in the energy sector in Spain was evaluated. Like Organization E, peers only report quantities of hazardous wastes; hence, the context is negative (score of 3). Figure 10 visually summarizes how each level is differentiated and how scores are assigned.

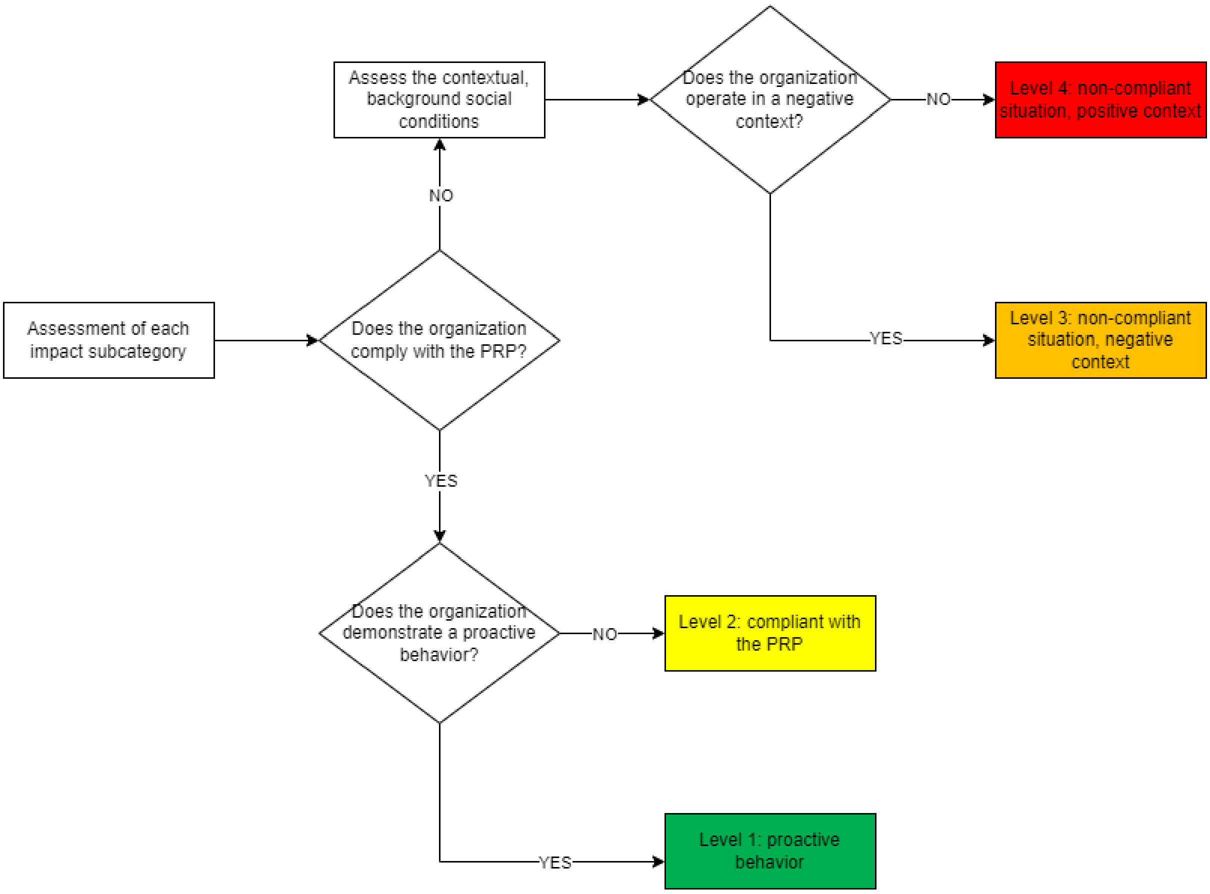

Figure 10: Step-by-step assessment of each subcategory (adapted from Ramirez et al. (2014))

4.4.2.1. Aggregation and weighting

Aggregation and weighting are common steps in the IA phase that can occur at many different points. Mainly, (1) indicators may be aggregated into subcategories; (2) subcategories may be aggregated into stakeholder groups; and (3) subcategories or stakeholder categories may be aggregated to a single final score (Harmens et al., 2022; UNEP, 2020) (Figure 11). Aggregation helps synthesize rich and complex information so that it can be better understood and the results can be communicated more straightforwardly (UNEP, 2020). However, this step should be done with caution to prevent losing context and misinterpreting the results. For example, when the results of a complex product system are aggregated by stakeholder category (e.g., Workers), the results from operations in one country are aggregated with results from another country. As results are location-dependent, much important information is lost, hampering an insightful analysis and interpretation. Thankfully, the SAM already includes the social context in the assessment when evaluating organizations' social performances.

Furthermore, when aggregation is performed, weights are implicitly or explicitly applied to the inventory data, subcategories, or stakeholder categories. These weights represent the relative importance of each social indicator to the impact subcategory or the impact subcategory to the overall score (UNEP, 2020).

In this study, aggregation occurs first at the reference scale level, given that in most subcategories, more than one reference scale exists (see Appendix V). After an organization has been given scores on each reference scale, the average of these forms the *subcategory* score for that given organization. Thus, equal weights are applied to each reference scale. Next, aggregation is performed at the subcategory level by aggregating the subcategory score of each organization into a single score. In order to reflect the relative importance or contribution of each organization to the given subcategory, weights are assigned based on the activity variable. Additionally, a scenario where each organization has the same importance is also considered by assigning equal weights to each.

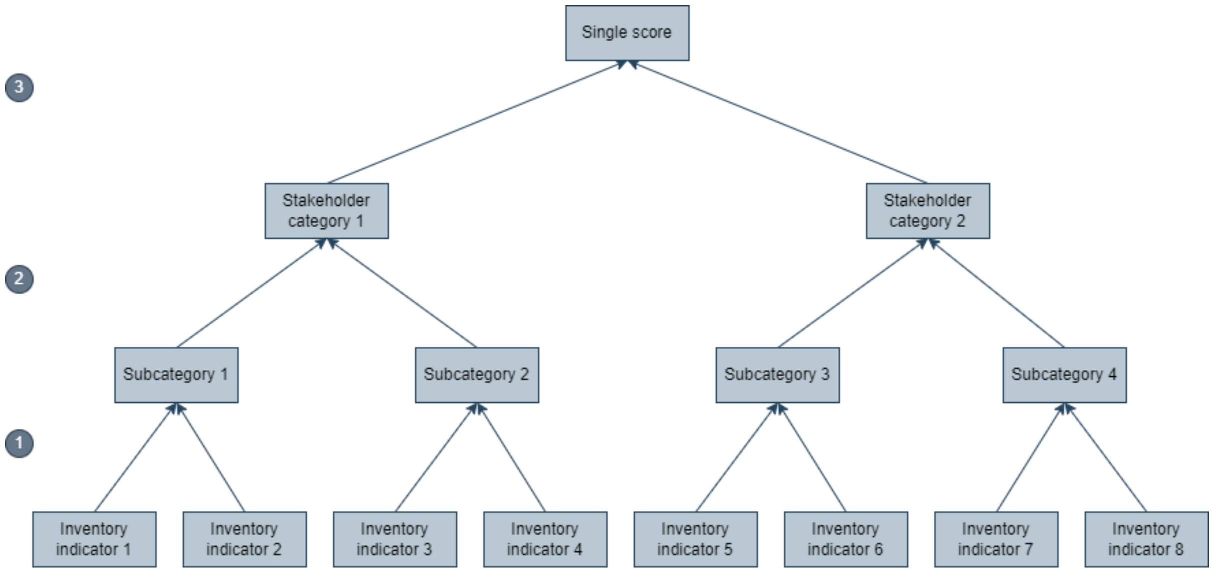

Figure 11: Illustration of aggregations at different points of impact assessment (adapted from Harmens et al., 2022)

4.4.3. Generic S-LCIA: steps for the calculation of social risks in PSILCA

The PSILCA database is first imported to openLCA for the generic assessment. The following steps are described below:

1. Prepare the inputs

After identifying the quantities, unit costs, and the country of origin of the chemicals and electricity used in each product system, these are adjusted for inflation and then converted to USD, using the currency exchange rate of the year 2015. The exchange rate of 2015 is used because the database uses the 2019 release of EORA, which is based on 2015 data (Maister et al., 2020). Data from online tools are used for inflation adjustment and exchange rate calculation (Inflation Tool, 2022; XE.com Inc., 2022). Then, the inputs must be matched to appropriate CSSs. For instance, to represent the input of chemicals produced in Spain, the best suitable sector is “Manufacture of chemicals and chemical products - ES”. The inputs for the reference and original systems, their country of origin and their corresponding CSS are listed in Appendix IV.

2. Create a new process for each product system

The new processes created in openLCA must represent waste treatment processes, with wastewater (functional flow) as an input. Next, all the material and energy inputs from the corresponding CSS should be added in USD. The inputs should be related to what is needed to treat wastewater for the amount of 1 USD. Creating a process for 1 USD of the functional flow is essential for consistency with the worker hours. However, to match this study’s functional unit, the functional flow unit must be in m^3 instead of USD. Thus, the amount of the wastewater inflow must be equivalent to 1 USD. For the reference and original systems, treating wastewater for 1 USD is equivalent to treating 7.7 and 1.1 m^3 of wastewater, respectively.

3. Add social flows and co-products as outputs

For this step, risk-assessed social flows can be copied from an equivalent process or CSS. “Market sewage and refuse disposal, sanitation and similar activities – ES” is similar to the WWT process. Thus, the same social flows as in that CSS are expected in the processes representing the product systems. All the social flows included, as well as their risk levels, are shown in Table 17. PSILCA database (version 3) includes a total of 74 social indicators. However, only 68 are considered in this study for the reasons mentioned in section 4.2.1.9.

Once the worker hours is obtained (Table 16), it is added manually as the quantity of each risk-assessed social flow in the “outputs” window. Furthermore, the co-products produced in each system must be added as outputs. Apart from being an outflow, biogas was added as an input in the reference system because it is used in the same facility. Additionally, for the software to implement economic allocation, each functional flow’s unit price must be added to each (functional) flow’s property. Then, the software automatically calculates the allocation factors, which can be seen in the “Allocation” tab.

Table 17: Stakeholder categories, subcategories, and social indicators with their corresponding risk level of the CSS “Market sewage and refuse disposal, sanitation and similar activities – ES” in PSILCA

Stakeholder category	**Impact subcategory**	**Social flow (indicator)**	**Risk level**
Worker	Child labor	Children in employment, female	Low risk
		Children in employment, male	Medium risk
		Children in employment, total	Low risk
	Discrimination	Gender wage gap	High risk
		Men in the sectoral labor force	Very low risk
		Women in the sectoral labor force	High risk
	Fair salary	Living wage lower bound	Very high risk
		Living wage upper bound	Very low risk
		Living wage, per month (AV)	High risk
		Minimum wage, per month	Medium risk
		Sector average wage, per month	Very low risk
	Forced labor	Frequency of forced labor	Very low risk
		Goods produced by forced labor	No data
		Trafficking in persons	Low risk
	Freedom of association and collective bargaining	Right of association	No risk
		Right of collective bargaining	No risk
		Right to strike	No risk
		Trade union density	Very high risk
	Health and safety	DALYs due to indoor and outdoor air and water pollution	Very low risk
		Presence of sufficient safety measures	No data
		Rate of fatal accidents at workplace	Very low risk
		Rate of non-fatal accidents at workplace	Low risk

		Violations of mandatory health and safety standards	High risk
		Workers affected by natural disasters	Very low risk
	Social benefits, legal issues	Evidence of violations of laws and employment regulations	Medium risk
		Social security expenditures	Low risk
	Working time	Weekly hours of work per employee	Low risk
Local community	Access to material resources	Certified environmental management systems	Low risk
		Extraction of biomass (related to area)	Very high risk
		Extraction of biomass (related to population)	Very low risk
		Extraction of fossil fuels	Very low risk
		Extraction of industrial and construction minerals	Low risk
		Extraction of ores	Low risk
		Level of industrial water use (related to renewable water resources)	Medium risk
		Level of industrial water use (related to total withdrawal)	Low risk
	Local employment	Unemployment rate in the country	High risk
	Migration	Emigration rate	Medium risk
		Immigration rate	Low risk
		International Migrant Stock	High risk
		International migrant workers in the sector	No data
		Net migration rate	Medium risk
		Number of asylum seekers in relation to total population	Medium risk
	Respect of indigenous rights	Indigenous People Rights Protection Index	Low risk
		Presence of indigenous population	Medium risk
	Safe and healthy living conditions	Drinking water coverage	Very low risk
		Pollution level of the country	Low risk
		Sanitation coverage	Very low risk
Society	Contribution to economic development	Contribution of the sector to economic development	High opportunity
		Embodied value added total	Very low risk
		Illiteracy rate, female	Low risk
		Illiteracy rate, male	Low risk
		Illiteracy rate, total	Low risk
		Public expenditure on education	Low risk
		Youth illiteracy rate, female	Very low risk
		Youth illiteracy rate, male	Very low risk
		Youth illiteracy rate, total	Very low risk
	Health and safety	Domestic and external health expenditure (% of current health expenditure)	Low risk
		Domestic and general government health expenditure (% of current health expenditure)	Low risk
		Global Peace Index	Low risk
		Health expenditure, external resources	Very low risk

		Health expenditure, out-of-pocket	Very low risk
		Health expenditure, public	Low risk
		Health expenditure, total	Medium risk
		Life expectancy at birth	No risk
Value chain actors	Corruption	Active involvement of enterprises in corruption and bribery	Very low risk
		Public sector corruption	High risk
	Fair competition	Presence of anti-competitive behavior or violation of anti-trust and monopoly legislation	No data
	Promoting social responsibility	Membership in an initiative that promotes social responsibility along the supply chain	Medium risk

4. Create a product system

Before calculating results, the newly created process needs to be converted to a product system. In this step, a cut-off of 1.00E-6 is selected due to computational power limitations; i.e., processing an extensive database like PSILCA requires a lot of memory usage. Thus, all the upstream processes contributing less than 1.00E-6 medium risk hours are excluded. Additionally, the allocation approach must be selected in this step.

5. Calculate the impact assessment results

In this step, the functional flow should be adjusted to match the functional unit or reference flow of the product system in order to calculate the results based on the functional unit. This is done by filling “1” m^3 in the “target amount” field of the “General information” tab. The process is then scaled automatically, and the results are calculated. The calculation is based on the Social Impacts Weighting Method described in section 3.2.1. Moreover, these results can be exported to Excel so that graphs, tables, and further analysis can be performed.

5. Results and analysis of results

5.1. S-LCIA

5.1.1. Site-specific RS results

5.1.1.1. Assessment scores of each organization

Following the Guidelines' recommendation, organizations' (unaggregated) social performance evaluations can be observed in Table 18, which shows the scores of individual organizations in each of the different reference scales. In addition, for ease of comparison, Figure 12 and Figure 13 show the social performance of all the organizations in the reference and original systems, respectively. Both figures show the results of aggregated reference scales in each subcategory.

All the organizations meet the BRs of "*Freedom of association and collective bargaining*". This might be because freedom of association and collective bargaining are protected by national legislation in Spain. Furthermore, the CS operator and Organization B achieved the highest score in FACB1[3], as they reported that employee representatives are relevant parties usually included in decision-making processes.

In "*Equal opportunities/discrimination*", Organization A and D's performances are poor. In both cases, whether they meet the BRs regarding the composition of employees and the ratio of basic salary of women to men could not be assessed due to the lack of data. Therefore, since the sector's performance was negative, they achieved a score of 4 on these two reference scales (EODI2 and EODI3). Additionally, Organization D received the worst performance in EODI1 because it did not meet the BR, and the context was positive. The good performance of the CS operator is mainly because it has management systems that promote equal opportunities and non-discrimination and employs more women than the sector average. In addition to having management systems in place, Organizations C and E's good performance is due to the higher ratio of basic salary of women to men than the sector. However, it is worth highlighting that this indicator must be taken with caution, especially in these sectors. The chemical and energy sectors are both characterized by a strong male presence, especially in management and technical positions. This means that the average salary of men might have been calculated from a data set with many data points. In contrast, the average salary of women might have been calculated only on a few entries, which depending on their job positions, may make the average higher or lower. Furthermore, Organization C's data for this indicator included only white-collar workers, which might give an erroneous impression of a narrow gender wage gap.

As for the "*Health and safety*" of workers, Organizations A, C, and E received the highest scores due to diverse health and safety practices in their organizations, in addition to meeting the BR.

All the organizations assessed met the BRs of the "*Fair salary*" subcategory. This is mainly because these organizations follow national regulations regarding this aspect, and in most cases, the salaries are based on collective bargaining agreements. However, Organizations B and C were considered to have proactive behavior (FSAL1), as the average salary of their employees is higher than the sector in Spain. It needs to be noted that the average salary in Organization B is higher than in the sector because their activities in Spain only regard the

[3] This is the name of a reference scale. All reference scales are detailed in Appendix V.

distribution of chemicals. Thus, they employ fewer workers who may have relatively better-paid administrative positions. Concerning Organization C, it is not clear which workers and from which locations were included in the average salary calculation. Thus, that reported average salary might be misleading.

The “*Working hours*” subcategory also includes indicators regulated by national legislation; thus, all the organizations meet the BRs. Only Organization E goes beyond the BR by establishing flexible working hours and promoting work-life balance among its employees. This information, however, could not be corroborated by or asked about in more detail to their employees since they were not available to participate in this study.

The subcategory “*End-of-life responsibility*” required special attention since the CS operator and Organization E could not be assessed due to the nature of their business operations. Given that the business activities of the CS operator can be described as construction work, infrastructure maintenance work, or utility operation, there is little that they can inform the end-user about the end-of-life options of their products/services. Likewise, Organization E provides electricity, and while they provide information to their customers about the source of energy and its environmental impacts, there is no additional information that they can provide on the end-of-life options. They may have other business operations where they provide products with an actual end-of-life phase, but this information could not be found. As for the rest of the organizations, they all operate in the European chemical sector, where strict labelling regulations establish what should be disclosed to the consumer (e.g., safety information and instructions on how to dispose of the product and its packaging). Thus, based on the collected data, all the organizations met the BRs.

Organizations B, C and E performed best in “*Access to material resources*”. Organizations B and C’s actions are considered “proactive” because they are both engineering ways to reduce raw material use, increase their products’ biodegradability, and replace fossil-based materials with renewable ones. Organization E also has management systems to promote a circular economy, efficiently use resources, and reduce their environmental impacts. The BR was not met by organization D, and given that other companies in the chemical sector (peers) met this requirement, the context is positive, assigning them a score of 4.

The BRs of “*Safe and healthy living conditions*” were met by only two organizations (B and C). The CS operator met the BR for SHLC1 but not the one regarding the reduction of hazardous substances. Since neither of the other organizations in its sector (peers) specifically addressed this topic, the context was deemed negative, and it received a score of 3. Regarding the same reference scale (SHLC2), Organization E did not meet the BR, and its context was negative, causing it to receive a score of 3. On the other hand, no data and a negative context caused Organization A to receive a 4. Since Organization D only distributes chemicals (including hazardous chemicals), it was decided to exclude them from the assessment in this reference scale. Similarly, part of Organization F’s business is to handle and store hazardous chemical substances for their clients; thus, it was deemed appropriate to exclude them from this part of the assessment (SHLC2). It can be noted that most organizations (including peers) only address hazardous *wastes* by (sometimes) establishing reduction goals, reporting the amounts generated and their end-of-life treatment. Very few organizations have policies and actions to reduce the use of hazardous substances.

Concerning organizations' contributions to the health of local communities (SHLC1), there was no data for Organization A, and the BR was not met by Organization D. As for Organization F, although there was no data, some evidence was found that the organization interacts with the local community. However, since this was not clear enough to account for meeting the BR, a score of 3 was given. Furthermore, despite the company statements on constantly communicating with local community actors on the impacts of their operations, evidence was found that Organization E ignored a community's concern about the installation of a new power plant in Mexico. Therefore, they also obtained a score of 3.

As for "*Local employment*", there was no data for Organizations A, C, E, and F, and the context was negative, so these organizations received the lowest score. Furthermore, Organization D did not meet the BR regarding policies that stipulate local hiring preferences, whereas the CS operator and Organization B did. This result is in line with those from Tsalidis et al. (2020), as they found that the companies in their site-specific analysis prefer to hire locally. However, only one company implemented specific policies on this. Nevertheless, it may be a rule of thumb for organizations to hire locally, especially for positions that require work in shifts, while they do not have specific policies on this aspect. One employee from the CS Operator pointed this out: "There is no explicit policy on hiring locally, but this is normally used as a criterion for operative personnel" (participant from the CS operator, personal communication, April 5, 2022).

When organizations' preference toward local suppliers was evaluated, there was no data for Organizations A and F; thus, they received a score of 3. Organization C scored four since it did not meet this BR. Organization D scored three because only 30% of its suppliers were local, although an employee indicated they had preferences for local suppliers.

Organizations A, D, and F did not meet the BR for "*Public commitment to sustainability issues*". The context is positive in the chemical sector, but instead of receiving a score of 4 like Organization D, Organizations A and F were scored 3. This is because these organizations were awarded a Silver medal in their most recent EcoVadis assessment, and Organization A received external recognition for its efforts in CSR.

All organizations, except Organization D, met the BR of "*Promoting social responsibility*" regarding the promotion of the protection of human rights across value chain actors. On the other hand, Organizations A, D and F did not meet the BR concerning inspections or audits to value chain actors on social responsibility topics. Regarding Organization F, although it is stated in their Code of Conduct that suppliers must allow this organization or third-party persons to verify their compliance, no evidence that controls are carried out was found; hence, it received a score of 3.

Table 18: Social performance scores and data quality scores per organization for each reference scale

Stakeholder category	Subcategory	Reference scale	Assessment score (data quality score)						
			CS operator	Org. A	Org. B	Org. C	Org. D	Org. E	Org. F
Worker	Freedom of association and collective bargaining	FACB1	1 (1.2)	2 (1.4)	1 (1.3)	2 (1.3)	2 (1.4)	2 (1.3)	2 (1.4)
		FACB2	2 (1.3)	2 (1.4)	2 (1.3)	2 (1.3)	2 (1.3)	2 (1.3)	2 (1.4)
	Equal opportunities/ discrimination	EODI1	1 (1.0)	2 (1.3)	1 (1.3)	1 (1.3)	**4 (1.6)**	1 (1.3)	2 (1.3)
		EODI2	1 (1.0)	**4 (2.3)***	2 (1.3)	2 (1.8)	**4 (2.3)***	2 (1.3)	**4 (2.3)***
		EODI3	2 (1.5)	**4 (2.8)***	2 (2.8)	1 (1.3)	**4 (2.8)***	1 (1.8)	**4 (2.8)***
		EODI4	2 (1.3)	**3 (2.0)***	2 (1.3)	2 (1.3)	2 (1.3)	2 (1.3)	2 (1.3)
	Health and safety	OHSA1	1 (1.0)	2 (1.1)	2 (1.3)	1 (1.2)	2 (1.3)	1 (1.2)	2 (1.3)
		OHSA2	2 (1.0)	**3 (2.1)***	2 (1.3)	2 (1.8)	2 (1.3)	2 (1.3)	**3 (2.8)***
	Fair salary	FSAL1	2 (1.3)	2 (1.3)	1 (1.3)	1 (1.5)	2 (1.3)	2 (1.4)	2 (1.5)
		FSAL2	2 (1.1)	2 (1.5)	2 (1.3)	2 (1.5)	2 (1.3)	2 (1.5)	2 (1.5)
	Working hours	WHOU1	2 (1.1)	2 (1.5)	2 (1.3)	2 (1.4)	2 (1.3)	1 (1.4)	2 (1.3)
		WHOU2	2 (1.3)	2 (1.5)	2 (1.3)	2 (1.5)	2 (1.4)	2 (1.5)	2 (1.4)
Consumers	End-of-life responsibility	EOLR1	NA	2 (1.4)	2 (1.4)	2 (1.3)	2 (1.3)	NA	2 (1.8)
		EOLR2	NA	2 (1.3)	2 (1.3)	2 (1.3)	2 (1.3)	NA	2 (2.0)
Local community	Access to material resources	AMRE1	2 (1.0)	2 (1.0)	1 (1.4)	1 (1.2)	**4 (2.0)**	1 (1.4)	2 (1.0)
	Safe and healthy living conditions	SHLC1	2 (1.4)	**3 (2.0)***	2 (1.3)	2 (1.5)	**4 (1.6)**	**3 (1.5)**	**3 (1.3)**
		SHLC2	**3 (1.0)**	**4 (2.0)***	2 (1.3)	2 (1.2)	NA	**3 (1.3)**	NA
	Local employment	LEMP1	2 (1.3)	**4 (2.0)***	2 (1.3)	**4 (2.0)***	**3 (1.3)**	**4 (1.3)***	**4 (2.0)***
		LEMP2	2 (1.3)	**3 (2.0)***	2 (1.3)	**4 (2.0)**	**3 (1.3)**	2 (1.3)	**3 (2.0)***
Society	Public commitment to sustainability issues	PCSI1	2 (1.1)	**3 (1.5)**	2 (1.3)	2 (1.3)	**4 (2.0)**	2 (1.3)	**3 (1.6)**
Value chain actors	Promoting social responsibility	PSRE1	2 (1.0)	2 (1.3)	2 (1.3)	2 (1.3)	**4 (2.0)**	2 (1.3)	2 (1.3)
		PSRE2	2 (1.0)	**4 (2.0)**	2 (1.3)	2 (1.3)	**4 (2.0)**	2 (1.3)	**3 (1.3)**

* denotes “no data” situations. Higher values are in bold. The values within parenthesis indicate the data quality scores.

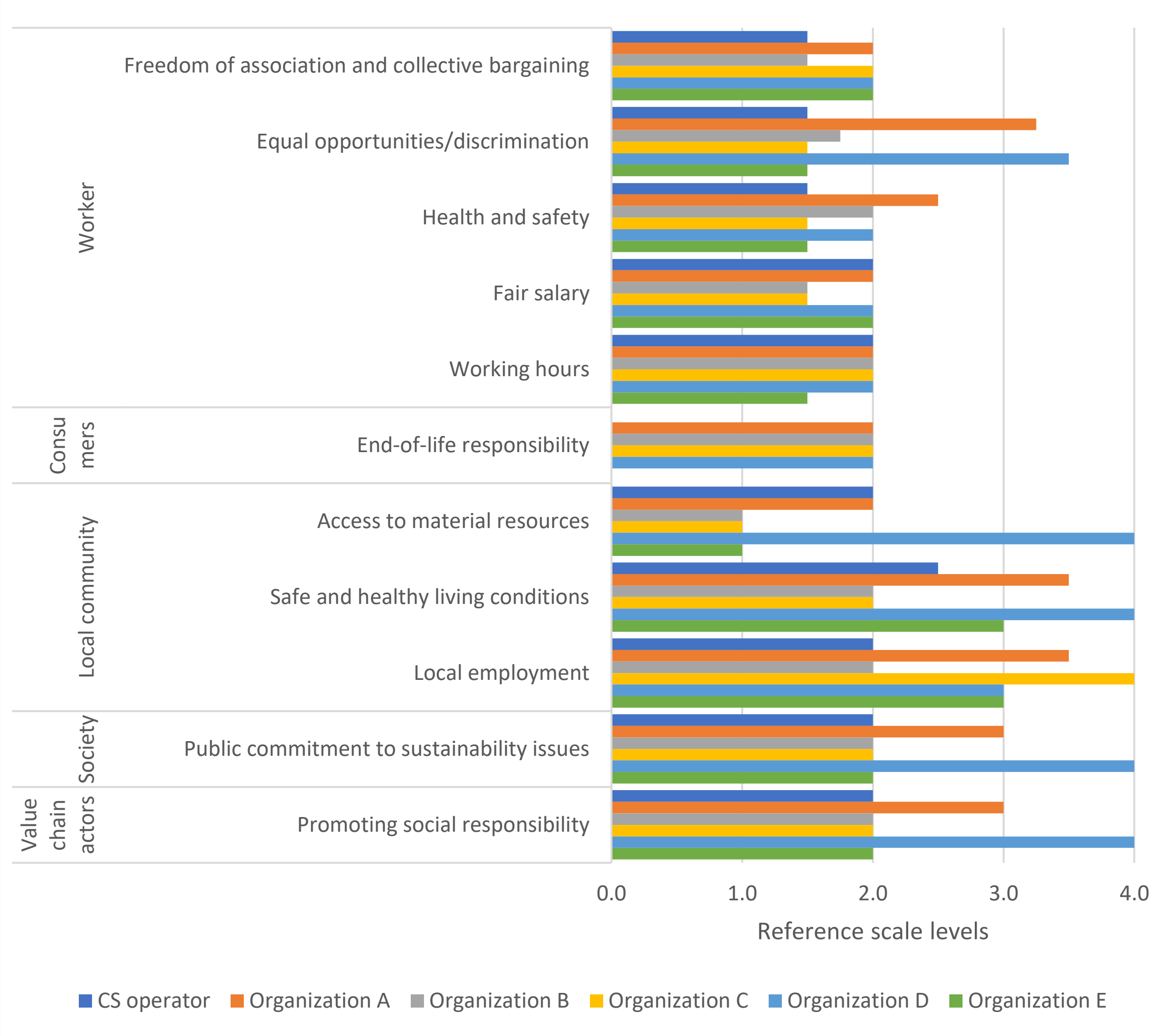

Figure 12: Site-specific results for the reference system, per organization, per subcategory

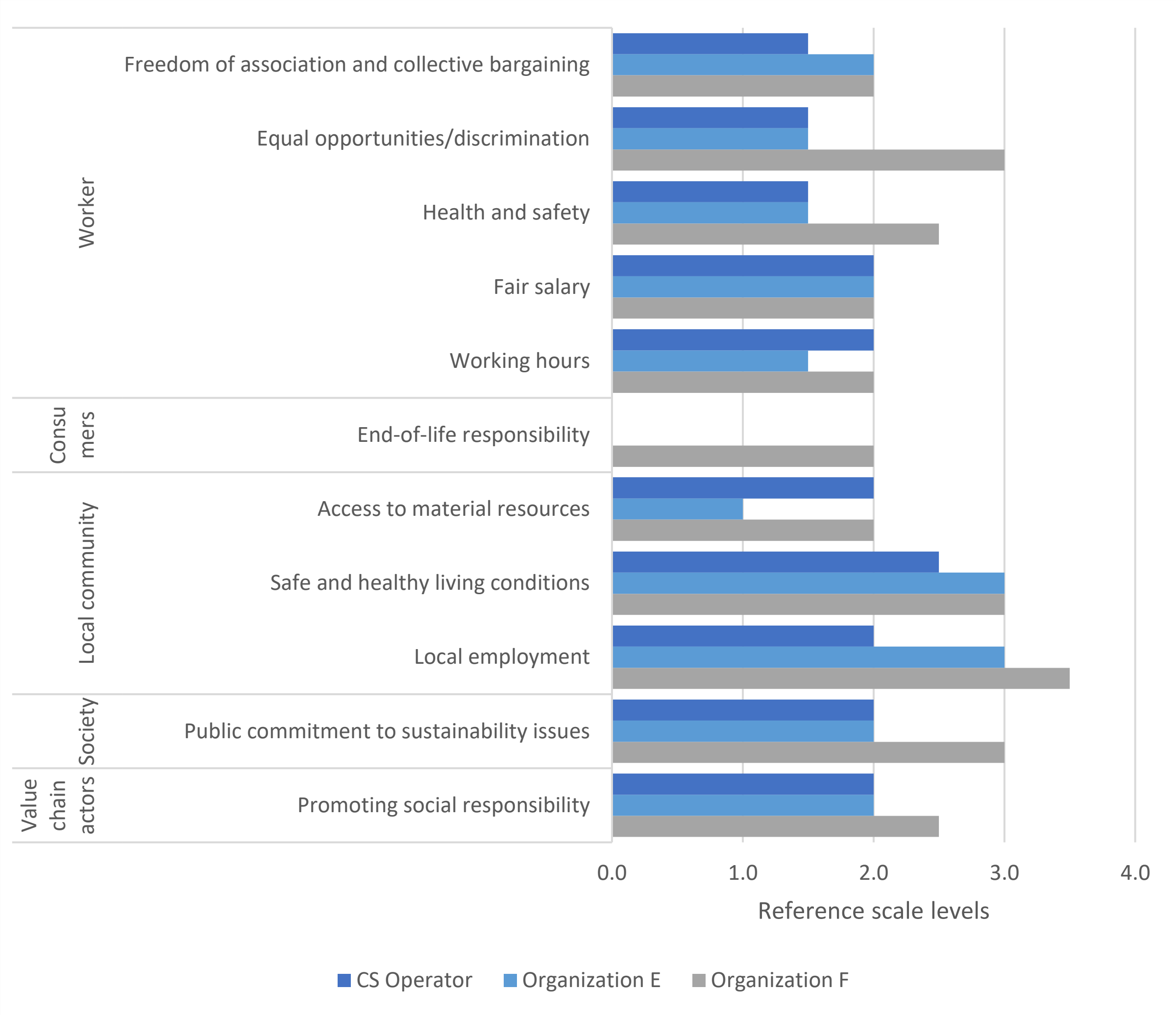

Figure 13: Site-specific results for the original system, per organization, per subcategory

Looking at the two product systems (Figure 12 and Figure 13), the organizations whose social performance is better or worse than the BR level can be identified. In the reference system, the organizations that met or went beyond the BR for most subcategories were the CS operator, Organizations B, C and E. On the other hand, Organizations A and D did not meet the BRs of six[4] impact subcategories. The lack of data affected the evaluation of Organization A's performance in the following subcategories: "Equal opportunities/discrimination", "Health and safety", "Safe and healthy living conditions", and "Local employment" (see Table 18 and Figure 12).

In the original system, the CS operator and Organization E met the BR in most subcategories. However, none of the three organizations met the BRs of the subcategory "Safe and healthy living conditions". Regarding poor social performance, Organization F did not meet the BRs of six subcategories. Similar to Organization A, the lack of data was detrimental to Organization F's performance in the subcategories "Equal opportunities/discrimination", "Health and safety", and "Local employment" (see Table 18 and Figure 13).

[4] Note that in Figure 12, the score of Organization D in the subcategory "Safe and healthy living conditions" represents one reference scale instead of two. Also note that the CS operator and Organization E were not assessed in "End-of-life responsibility"; thus, they are not included in the Figures.

In some instances, differentiating a “no data” from a non-compliant situation was not straightforward. In the subcategory “Safe and healthy living conditions”, whether organizations had systems in place to reduce their use of hazardous substances (SHLC2) was difficult to assess because most organizations only addressed hazardous wastes. Therefore, no information on their policies or actions to minimize the use of hazardous substances could be found, which could be interpreted as “no data”. Since the CS operator and Organization E only mentioned hazardous wastes, the *lack* of information on hazardous substances was assessed as non-compliant.

Likewise, regarding whether organizations had policies that promote hiring locally, the interviewee from Organization C preferred not to answer the question. Although it is more likely for this organization to have this information, it cannot be considered a non-compliant situation because this information is not disclosed. Therefore, in this case, and in the case of Organization D, whose representative did not provide data on the composition of the workforce and the ratio of basic salary of women to men (EODI2 and EODI3), the situation was assessed as “no data”. The distinction between “no data” and a non-compliant situation would result in different results. For instance, assuming that the context is positive and there is no data, an organization would score 3; however, if it is a non-compliant situation, it will receive a 4.

In the “Public commitment to sustainability issues” subcategory, the respondent from Organization D did not provide answers regarding whether the organization’s policies and goals address sustainability issues (PCSI1). Similar to the above, this could qualify as a no data or non-compliant situation. However, considering that the organization does not publish sustainability reports and the like, it was assessed as a non-compliant situation.

5.1.1.2. Size of companies/characteristics of the organizations

While collecting data and evaluating organizations’ performances, it was evident that certain organizational characteristics play a role in how an organization performs socially. Regarding the social indicators considered and the nature of the small organizations’ businesses, the question about whether it is fair to assess them with the same “rule” used to assess larger organizations arises. For example, in “Access to material resources”, environmental management systems’ presence was evaluated. However, organizations like Organization D may have activities that are not significantly harmful to the environment. As the participant put it, “we are distributors, we generate few wastes which are processed by an external facility” (participant from Organization B, personal communication, May 26, 2022).

Another subcategory that might have been challenging for smaller organizations is “Safe and healthy living conditions”. Active interactions with local communities regarding activities that may affect or contribute to their health (SHLC1) may not be a material issue for smaller organizations. Thus, they may not be prioritizing resources for activities like this. Similarly, from the experience of this thesis, it seems that committing to sustainability issues is not a priority for smaller organizations; hence, if addressed, this is rather superficial in their codes of conduct. Consequently, they do not report on sustainability matters (PCSI1) nor control their suppliers’ sustainability performances (PSRE2). This may change in Europe in the coming years when the Corporate Sustainability Reporting Directive (CSRD) is adopted, which may happen later this year (European Commission, 2021b). The CSRD stipulates the implementation of EU sustainability reporting standards, which require reporting based on a double materiality approach (i.e., risks associated with climate change faced by companies and the social and environmental impacts of companies' activities) (European Commission, 2021a; KPMG, 2021). Listed Small and Medium-Sized Enterprises (SMEs) might also need to abide by the Directive (European Commission, 2021a; European Parliament, 2022).

Regarding whether SMEs may be required to report on sustainability issues, they are receiving increasing demands for sustainability information from banks, investors, and large customer companies. Therefore, they must keep up with the expectations of these stakeholders and regulations and build resilience, which will be facilitated if they commit to minimizing their social and environmental impacts and sustainability reporting.

5.1.1.3. Comparison of the reference and original systems by subcategory

This section aims to look at each product system as a whole and determine its global social performance and the subcategories where the performance is poor. The entire system's performance in each subcategory can be presented in two ways: one regards organizations as having the same weight or contribution to the results, and the other takes into account the activity variables. The reference system meets the BRs in more than half of the subcategories. If all organizations are assumed to contribute equally to the social performance of the system, the system achieves a global social performance score of 2.20. The subcategories in which the social performance is poor are "Equal opportunities/discrimination", "Safe and healthy living conditions", "Local employment", "Public commitment to sustainability issues", and "Promoting social responsibility" (Figure 14). These subcategories can be considered hotspots. The hotspots are mainly caused by the poor performance of Organizations A and D, except for "Safe and healthy living conditions" and "Local employment", where four organizations in total did not meet the BRs.

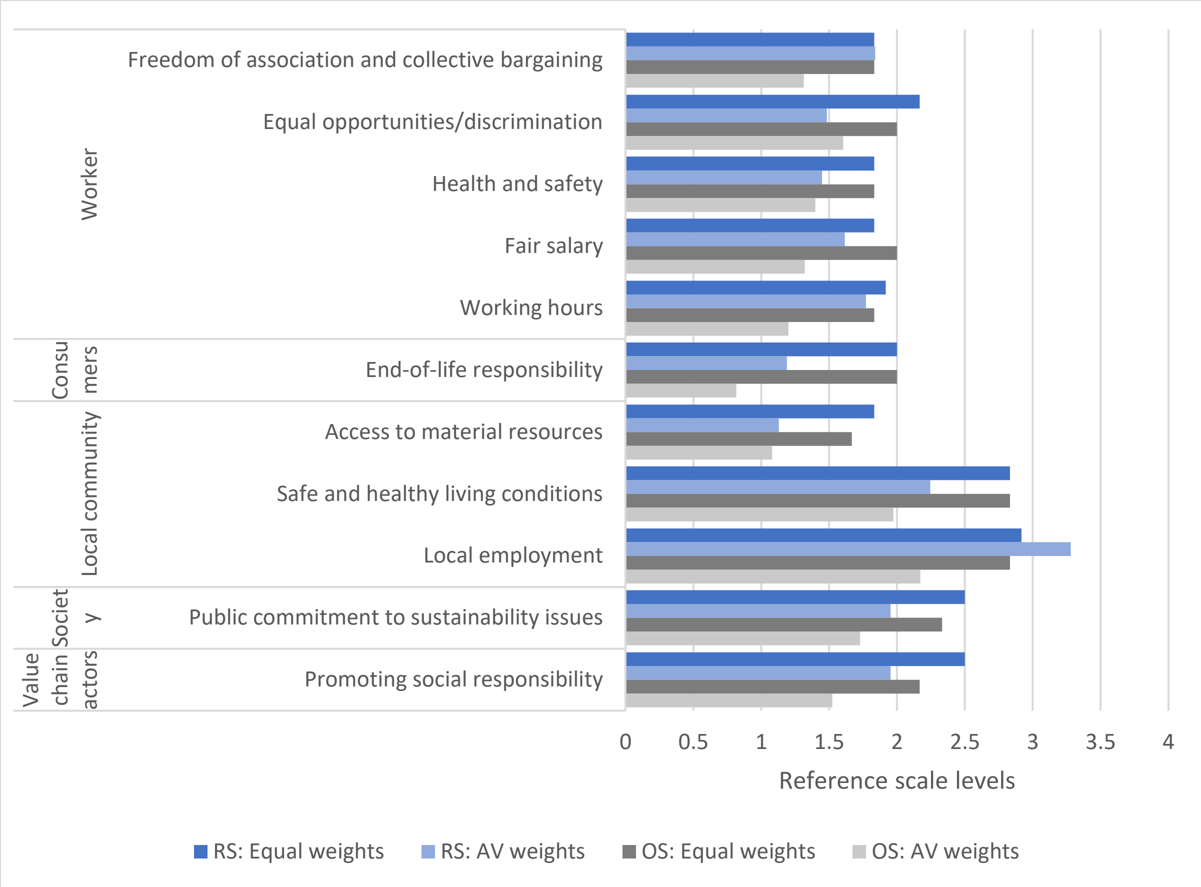

Figure 14: Reference and original systems' scores per impact subcategory, calculated based on equal weights and activity variable-based (allocated) weights

However, if the share of each organization represents the extent to which it is responsible for the social performance of the whole system, a link between the product system and the conduct of organizations is made. Thus, multifunctionality can be solved by considering the allocation factor (0.95) (in addition to organizations' weights) in calculating results. Consequently, the global social performance score improves to a score of 1.81, and it is related to the treatment of 1 m^3 of wastewater in the reference system.

Under this condition, the system needs to improve in the "Safe and healthy living conditions" and "Local employment" subcategories. As shown in Figure 14, an improvement in most of the subcategories can be observed compared with the results obtained if organizations are given equal weights. Just as the performance improves in "Equal opportunity/discrimination" due to Organization C's good performance and share (58%), "Local employment" is negatively affected by its poor performance.

Regarding the original system, considering all the organizations as having equal weights, the global social performance is 2.12. Performance in the subcategories "Safe and healthy living conditions", "Local employment", "Public commitment to sustainability issues", and "Promoting social responsibility" can be improved (Figure 14).

On the other hand, multifunctionality can be solved when the organizations' shares are considered and a link is established between their behavior and the product system. Thus, factoring in organizations' weights and the allocation factor (0.66) results in a global social performance score of 1.47, indicating a considerable improvement. This result indicates the social performance associated with treating 1 m^3 of wastewater in the original system. The activity variable-based allocated global social performance score is mainly attributed to Organizations F and E's performances, whose shares are equivalent to 62% and 36%, respectively. Despite Organization F's performance being (relatively) the poorest in the original system, allocation to the wastewater functional flow favors the system's score. Nevertheless, improvements are still necessary for the subcategory "Local employment" (Figure 14). Therefore, using organizations' shares in the product system combined with an allocation factor provides relative better results as level 2 is achieved in almost all subcategories.

It is worth mentioning that global scores involved aggregations of reference scales, organizations, subcategories, and stakeholder categories, which, as mentioned earlier, introduced uncertainty. Considering that 66% of the original system is formed by the same organizations in the reference system, it is expected that no big differences in the overall social performances can be seen. Consequently, improvements are needed in the same subcategories for the reference and the original systems. Nevertheless, if a different proxy for the chemical supplier in the original system is selected, different results may be produced, which will be tested in the sensitivity analysis.

It should be noted that the subcategory "End-of-life responsibility" needs special consideration. Recall that the CS operator and Organization E were not evaluated in this subcategory. Since both organizations form two-thirds of the original system, the scores (equal weights-based and activity variables-based) represent only Organization F.

5.1.1.4. Social hotspots for each organization and recommendations

Social hotspots are unit processes, activities, or locations in the life cycle of a product where a social issue (problem or risk) or an opportunity is likely to occur (UNEP, 2020). Since an organizational perspective is taken in this S-LCA, unit processes in the life cycle of products are represented by the activities of organizations. Subsequently, the focus lies on hotspots associated with the negative performance of each one of them. Thus, this section aims to suggest measures that could help improve each organization's social performance, enhancing the social sustainability performance of both product systems.

In the previous sections, the organizations that negatively contribute to the performance of the reference system and the original system were identified (Organizations A and D, and Organization F, respectively). However, these organizations are by no means the only ones that need to implement strategies to improve their social performances. Given that organizations were evaluated on more than one reference scale for each subcategory, the single scores per organization in Figure 12 and Figure 13 do not tell the whole story. Therefore, it is necessary to look at each organization individually to identify the areas where their scores were above 2.

In the reference system, the performances of Organizations A, C, D, E and the CS operator are identified as hotspots. Regarding the original system, apart from the CS operator and Organization E, the performance of Organization F is identified as a hotspot. The following section provides recommendations specific to each organization so that, if implemented, these organizations will achieve better scores.

Organization A

It was mentioned earlier that the lack of data severely affected Organization A's performance in four subcategories (Table 18). In those situations, the evaluation was made based on the performance in the sector (context). Negative contexts in the chemical sector in Spain were found in the following social aspects: less participation of women in the workforce (EODI2), a relatively wide ratio of basic salary of women to men (EODI3), lack of measures to reduce the use of hazardous substances (SHLC2), and lack of local hiring policies (LEMP1). In turn, Organization A scored 4 in these subcategories, and no specific recommendations for this organization can be drawn.

However, Organization A did not meet the BRs in two subcategories:

1. **Recommendations related to "Public commitment to sustainability issues"**: to improve in this subcategory, Organization A needs to first commit to sustainability matters, recognizing that this will have positive impacts on its relations with its employees, customers, local community and the public in general. Additionally, it could take a new perspective on how it carries out its business operations and define specific targets related to reducing the impacts of its activities. Progress towards these targets could then be made public by reporting about these on the company website and newsletter. Considering that EcoVadis and other third-party organizations have assessed Organization A, information related to sustainability has already been collected and is available to the organization. Organization A could make better use of these types of resources that they already have to improve its performance in this aspect.
2. **Recommendations related to "Promoting social responsibility":** Organization A could work closer with its suppliers on aspects related to social responsibility. This can be done by implementing an evaluation system to assess its value chain actors on environmental and social topics. Such a system requires that the organization monitors its suppliers constantly. This evaluation would help identify potential problems in the supply chain and raise the bar for suppliers. For example, if suppliers achieve low scores, the organization could work with them on how to improve. A strategy like this will benefit the organization to improve its performance in this assessment and the sustainability assessments mandated by the organizations they supply.

Organization C

1. **Recommendations for "Local employment":** Organization C does not meet the BR related to having a preference for locally based suppliers. Whereas many different aspects are relevant when choosing a supplier (e.g., costs, quality, ability to deliver on time, ability to deliver the required amount, etc.), Organization C could consider the contribution that they make to the local economy if they were to choose locally based providers, especially if they have operations in developing countries. Therefore, purchasing from local suppliers could become another criterion in Organization's C procurement process.

Organization D

1. **Recommendations related to "Equal opportunities/discrimination":** even though Organization D is small and does not have many employees, it could strengthen its commitment to non-discrimination and equal opportunities by stating this aspect in, for example, its Code of Conduct and hiring policies. Furthermore, it could implement certain practices that promote these principles across the organization. For example, by

providing training to employees and promoting measures to raise awareness. Human Resources and Management employees could also be trained on unconscious biases and inclusive leadership.

2. **Recommendations related to "Access to material resources":** it is important to note that this subcategory concerns organizations' strategies for preventing and mitigating their operations' adverse effects on the environment, which may put the quality of the material resources available to the local community at risk. Such strategies include pollution prevention, sustainable use of resources, and waste recycling (UNEP, 2021). Thus, Organization D could implement specific measures to reduce the impacts of its distribution activities. Organization D could consider low-emission transportation modes (e.g., shifting from roads to rail, low-emission or electric trucks), implement strategies to optimize vehicle loads, reduce packaging and opt for recyclable materials. Adopting more sustainable strategies will increase Organization D's competitive advantage as initiatives like these are important for its customers who may be aiming to reduce their Scope 3 emissions.
3. **Recommendations related to "Safe and healthy living conditions":** one of the aspects measured in this subcategory is an organization's initiatives to contribute to or strengthen a community's health and safety (UNEP, 2021). The actions recommended above will benefit the health of the communities where Organization D operates as emissions will be reduced. Furthermore, Organization D could also organize activities together with local community actors regarding public health issues of concern to the community, share health services with local community members, or support local initiatives that promote public health and safety.
4. **Recommendations related to "Local employment":** Organization D could implement policies that contribute to the development of the local economy. This could be achieved by adopting hiring preferences for people living in the neighboring communities and by opting to procure goods and services from local suppliers. Although Organization D has preferences for local suppliers, it could implement specific targets on this matter and increase its current network of local suppliers.
5. **Recommendations related to "Public commitment to sustainability issues":** similar to Organization A, Organization D could reconsider how its activities may be impacted by sustainability issues like climate change, at the same time that they may contribute to climate change. Thus, Organization D could make commitments regarding sustainability aspects, implement measurable targets, and communicate its progress regarding those targets. Initiatives like these will increase Organization's D visibility and attractiveness to potential new customers. Apart from the above, it will also make the business more resilient and forward-looking to potential changes in European legislation regarding sustainability reporting.
6. **Recommendations related to "Promoting social responsibility":** Organization D needs to step up on its commitment to protecting human rights. Human rights protection must be addressed in Organization D's Code of Conduct for Suppliers. Also, similar to the recommendations given to Organization A, Organization D could work closer to its suppliers and monitor their behavior related to environmental and social impacts.

Organization E

1. **Recommendations related to "Safe and healthy living conditions":** it seems that due diligence in Environmental Impact Assessment processes in some countries does not fully address the concerns of local communities or that more oversight is needed from the organization. To improve in this area, Organization E could reconsider their current stakeholder involvement strategies by reflecting on what went wrong in previous activities with local community members and what improvements can be made.
   In addition, Organization E could implement management strategies to reduce its use of hazardous substances. In fact, the development of sustainable and safe chemicals and materials for application in the energy sector is an increasingly relevant aspect in the region (European Commission, 2020).

Organization F

1. **Recommendations related to "Safe and healthy living conditions":** there are some indications that Organization F might have been implementing actions to maintain communication and interaction with the local community regarding health and safety issues. However, Organization F could benefit from communicating about these actions more actively. Furthermore, Organization F could jointly organize activities with local community members to address health and safety issues of concern.
2. **Recommendations related to "Public commitment to sustainability issues":** the recommendations given to Organizations A and D in this aspect could also be applied to Organization F.
3. **Recommendations related to "Promoting social responsibility":** like the above, recommendations given to Organization A could also be applied to Organization F.

CS operator

1. **Recommendations related to "Safe and healthy living conditions":** last April, the European Commission announced the "Restrictions Roadmap" plan to ban toxic substances (European Commission, 2022a). The plan, under the European Commission's Chemical Strategy for Sustainability, could affect the chemicals and materials used in the construction sector. In view of the EU moving toward more sustainable and safe chemicals and materials (European Commission, 2020), the CS operator could implement a hierarchy of chemicals in its procurement operations to avoid toxic substances. Strategies like these are particularly relevant since the construction sector is considered a sector with a high potential for circularity, and requirements to minimize the use of toxic substances will be prioritized (European Commission, 2020).

Apart from social performances regarding impact subcategories, there are some recommendations for the CS operator that could enhance the overall social performance of the product systems. Considering that most impacts likely occur upstream in the value chain, it is indispensable to pay close attention to the sustainability aspects of suppliers. For example, based on this S-LCA, the CS operator could choose suppliers with solid takes on sustainability based on their Codes of Conduct and organization-wide targets.

Finally, it should be highlighted that the social hotspots identified in this study might not be issues of relevance for these organizations. For example, contributing to better health and safety conditions in a community might not be directly linked to Organization D's activities (i.e., distribution of chemicals); hence, it may not be a material issue for them. Similarly, contributing to local employment by purchasing from local suppliers might not be relevant to Organization C if it needs large quantities or specific raw materials for manufacturing its products that local suppliers cannot provide. Subsequently, the hotspots identified and the recommendations drawn here might not be significant to all the organizations.

If the organizations are involved at the beginning of the S-LCA, the selection of subcategories and indicators could be based on what is relevant to them, making the results more valuable. However, what is important to each organization is based on their activities and their contexts. Therefore, involving organizations in the definition of significant issues has two effects; first, the issues relevant to an organization might not align with the social issues of concern in the life cycle of a product. Second, the material issues of an organization might not be the same as those of other organizations in the life cycle. Therefore, balancing different organizations' interests and producing results that are relevant to all of them remains a challenge.

5.1.2. Generic results

This section regards the results obtained from the use of the PSILCA database for the calculation of social risks along the value chains of the reference system and the original system.

5.1.2.1. Comparison between the reference and original systems

The total social risks along the entire value chains in medium risk hours (mrh) are 2.7 and 13.8 for the reference and original systems, respectively. As these results indicate, the risks for social impacts along the value chain of the original system are about five times larger than the reference system. The indicator results from PSILCA were aggregated per impact subcategory and stakeholder category. These results can be seen in Figure 15 for both systems. Additionally, following the recommendations from the Guidelines, and for reasons of transparency, Figure 16 shows the results per each social indicator for both systems. These results correspond to the treatment of 1 m^3 wastewater in each product system.

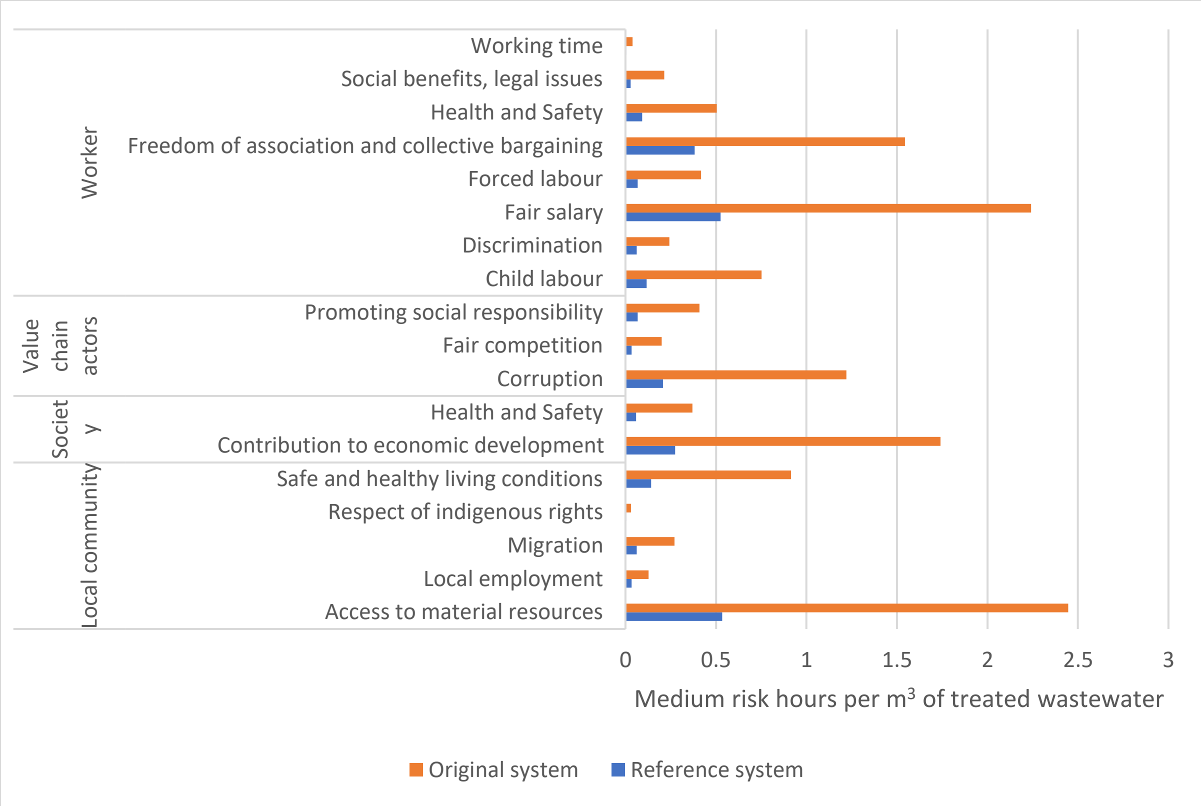

Figure 15: Generic analysis results: social risks aggregated per impact subcategory and grouped by stakeholder categories

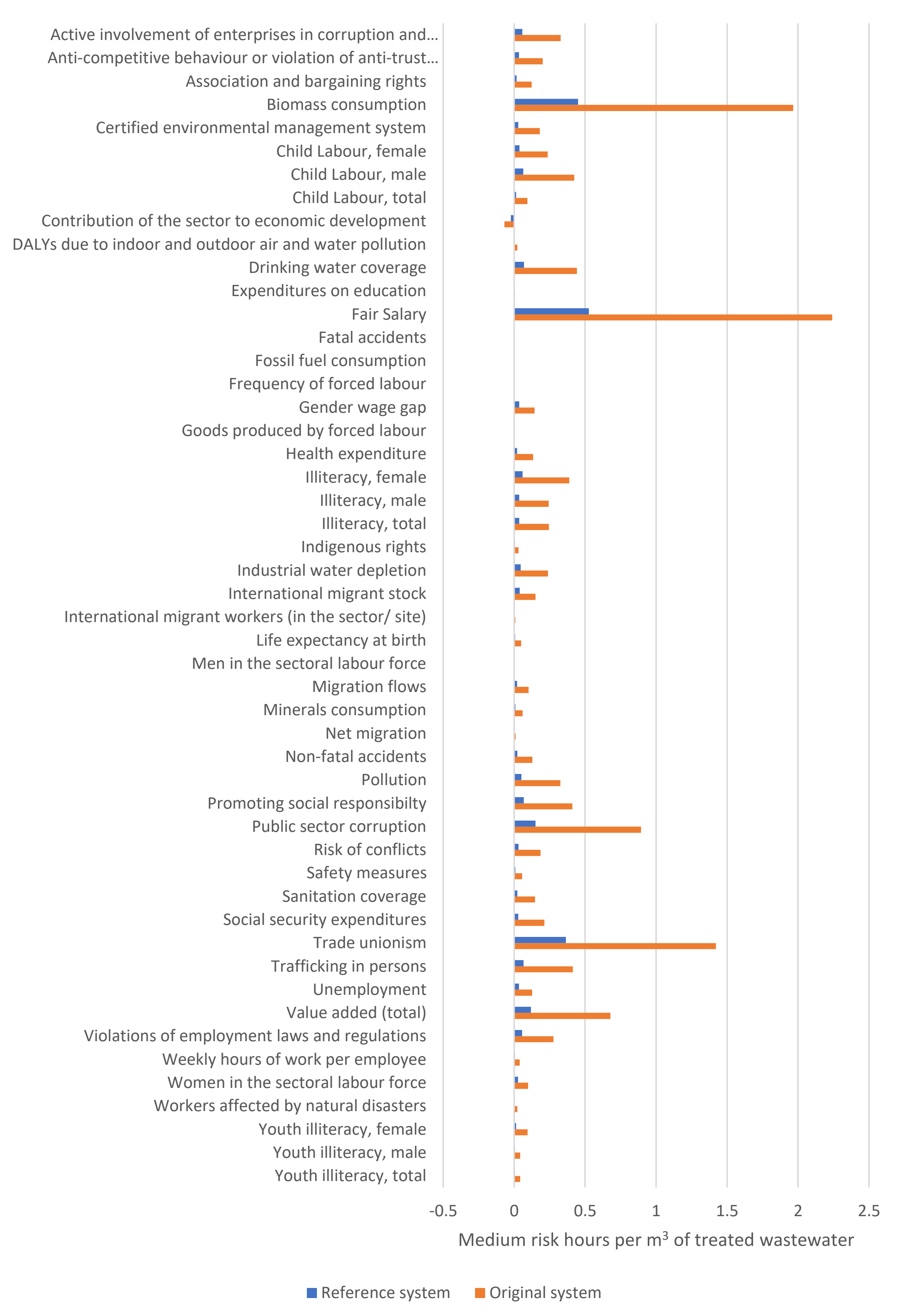

Figure 16: Generic analysis results: social risks per social indicator

Looking at the aggregated results, the subcategories with the greatest contributions to the final results in both product systems are: “Access to material resources”, “Fair salary”, “Freedom of association and collective bargaining”, “Corruption”, and “Contribution to economic development”. Together, these subcategories represent 71% and 67% of the total results for the reference and original systems, respectively. The social risks from the reference system are about 14-26% of those of the original system.

The subcategory “*Access to material resources*” is formed by the indicators regarding the level of industrial water use, extraction of material resources (biomass, minerals, and fossil fuels), and certified environmental management systems. This subcategory aims to assess whether commercial or industrial operations have restricting effects on the access of local communities to material resources (Maister et al., 2020). The indicator “Biomass consumption” makes up 84% and 80% of the total social risks for this subcategory in the reference and original systems, respectively. Biomass consumption measures the total biomass extraction in tons per capita and tons per km^2, and the values are at the country (not CSS) level. The foreground processes representing the reference and original systems make up 29% and 5% of the social risks for this social indicator. This occurs because biomass extraction in Spain equals 225.13 t/km^2, which is assessed as a “very high risk”. However, biomass extraction per capita is assessed as “very low risk”, which suggests that local communities might not be highly affected by biomass extraction. It is not straightforward to assess how local communities are affected by high extraction rates; on the one hand, they may be affected by environmental degradation, and on the other, resource extraction may be due to the construction of infrastructure that benefits those communities (i.e., roads, hospitals) (Maister et al., 2020). Spain’s contributions to this indicator results are 65% and 49% for the reference and the original system, respectively.

Next, the social risks related to the subcategory “*Fair salary*” are mainly due to “Living wage (lower bound/upper bound/per month)”, “Minimum wage, per month”, and “Sector average wage, per month”. Because these indicators were aggregated automatically by PSILCA, it is not clear which of these contributed to the results the most. As for process contributions to the total social risks in the “Fair salary” subcategory, the reference system process contributes 28%, while the original system process contributes 5%. These process contributions can be traced back to the (sub-)indicators “Living wage, lower bound” and “Living wage, per month”, both assessed at the country level, and whose risk levels are “very high risk” and “high risk”, respectively. The “Living wage” indicator (group) aims to measure how much a person needs to cover the costs that are necessary for living (Maister et al., 2020). Data for “Living wage” related indicators were obtained from a survey about living costs in different countries. The lower and upper bound intervals of a living wage are considered to take into account the different ranges given by respondents. In Spain, the lower bound living wage and the living wage per month equal USD 1,015 (very high risk) and USD 610 (high risk), respectively. These indicators alone will not determine whether workers are paid fair wages in a given sector, but they give a good indication as to whether sector average or minimum wages are fair. Spain’s contributions to this indicator results are 61% and 48% for the reference and the original system, respectively.

The subcategory “*Freedom of association and collective bargaining*” in PSILCA is formed by the indicators “Right to strike”, “Right of association”, “Right of collective bargaining”, and “Trade union density”. Of all these indicators, most social risks for this subcategory can be attributed to “Trade union density” since it makes up 95% and 92% in the reference and original systems, respectively. “Trade union density” aims to assess the level of organization of workers in a country. The reference and original system processes account for 36% and 7% of the total social risks regarding this indicator. According to the database, “Trade union density” in Spain is 13.9%, which is “very high risk”. It is important to note that this indicator only measures the level of unionization of workers, without considering the bargaining power of worker associations (Hayter & Stoevska, 2011, p. 2). Therefore, even though the trade unionism level in Spain is low, collective bargaining plays a significant role in establishing the terms and conditions of work. Furthermore, the workers from most economic sectors in Spain are covered by collective bargaining agreements, and this right is protected by law (MITES, 2021a). Spain’s contributions to this indicator results are 80% and 68% for the reference and the original system, respectively.

Two indicators are included within the subcategory “*Corruption*”, “Active involvement of enterprises in corruption and bribery”, and “Public sector corruption”. Most social risks (73% for both systems) in this subcategory are due to the latter. “Public sector corruption” regards the level of corruption in a country, and it is measured by the Corruption Perception Index, which includes values from 0 (highly corrupt) to 100. The reference and original system processes’ contributions to this indicator are 9% and 1%, respectively. However, most of the contributions to this indicator in the original system are not from the foreground process, but from the “Mining and quarrying (energy)” process in Russia, with a contribution of 6%. In Spain, the Corruption Perception Index score is 43, considered “high risk”, whereas Russia’s score is assessed as “very high risk”. Spain’s contributions to this indicator results are 19% and 7% for the reference and the original system, respectively. In the original system, the country that contributes the most is Iran, with 17%. Most of the impacts from this country are from “Collection, purification and distribution of water”.

“*Contribution to economic development*” is formed by the following indicators: “Embodied value-added total”, “Public expenditure on education”, “Contribution of the sector to economic development”, and illiteracy rates disaggregated by sex and age. It is worth noting that this subcategory includes one indicator that represents opportunities for positive social impacts: “Contribution of the sector to economic development”. This indicator aims to measure the extent of a sector’s contribution to a country’s Gross Domestic Product (GDP). Thus, instead of being risk assessed, the indicator is “opportunity assessed”. If a sector’s share in the country’s GDP is high (high opportunity), its contribution to the economic development of that country is considered significant, leading to potential positive social impacts. Since negative social impacts cannot be offset by positive impacts and to avoid the misinterpretation of the results, the opportunity for positive social impacts measured by this indicator (in mrh) was separated from this subcategory in Figure 15. The opportunities for positive social impacts from the this indicator in the reference and original systems equal 0.02 and 0.07 mrh, respectively. The large differences between the two systems is explained below. Furthermore, to indicate the positive contribution of this indicator in contrast to the rest, its results are shown with the opposite sign in Figure 16.

After separating the positive contribution of the “Contribution of the sector to economic development” indicator from the subcategory results, the subcategory still had a significant share in the total results. The reason is the results from the indicator “Embodied value-added total”, whose share in the subcategory results is 39% in the reference system and 38% in the original system. “Embodied value-added total” indicates the difference between the selling price and the production costs of a sector per 1 USD of outputs (Maister et al., 2020). This indicator is measured for each CSS, and the smaller the value, the higher the risk level in a given sector. The process contributions of the reference and original system processes are less than 1%, meaning that other processes upstream of the value chain are responsible for this indicator (i.e., “Chemicals, chemical products and man-made fibres” in France, for both systems). Small embodied value-added from sectors indicate low contributions to a country’s economy. Spain’s contributions to this indicator results are 50% and 48% for the reference and the original system, respectively. In both product systems, the risks from the country Spain are due to the low contribution (“very high risk”) of the sector “Anthracite, coal, lignite and peat”.

All the most contributing indicators mentioned above were measured at the country level (except for “Embodied value-added total”). This explains why the subcategories that contribute the most to the total results are the same for both systems. Moreover, the foreground processes representing the reference and original systems were the major individual contributors to those indicators, except for “Public sector corruption” of the original system and “Embodied value-added total” of both systems. However, all the upstream processes combined contribute the most to the social risks of most subcategories in both systems.

In addition, as seen in the summary table below (Table 19), the original system process contributions were smaller than those from the reference system. The main reason behind this is that the worker hours of the original system are much smaller than in the reference system (Table 16). A smaller worker hour resulted from the high costs of treating 1 m^3 of wastewater in the original system compared to the reference system (see “unit labor costs” in Table 16). Furthermore, as more inputs are required in the original system than in the reference system to treat 1 m^3 of wastewater, the total social risks (and opportunities) are larger in the original system and they are distributed further upstream in the supply chain than in the reference system. Specifically, the original system requires 6.5 and 9 times more chemical and electricity inputs than the reference system, which implies that even with the use of allocation factors, more inputs are used in the original system.

Table 19: Generic analysis results: social hotspot subcategories and indicators and process contributions

Subcategory	**Most contributing indicator (% RS, % OS)**	**Reference system process contribution to indicator (%)**	**Original system process contribution to indicator (%)**
Access to material resources	Biomass consumption (84, 80)	29	5
Fair salary	Fair salary	28	5
Freedom of association and collective bargaining	Trade union density (95, 92)	36	7
Corruption	Public sector corruption (73, 73)	9	1
Safe and healthy living conditions	Drinking water coverage (49, 48)	<1	<1

5.1.2.2. Relevant findings from the generic results

The results presented above regarding the most contributing indicators align with the study from Serreli et al. (2021). Their three wastewater treatment lines produced high social risks in “Public sector corruption” and “Trade union density”. Although their case study was from Italy, the socio-economic conditions in Spain do not differ greatly from Italy’s. Furthermore, Andrade et al. (2022), who assessed the social impacts of agricultural activities in Spain, Belgium, and Germany using PSILCA, also found that the highest social risks of the agricultural practices in Spain were related to the indicators “Fair salary”, “Biomass consumption”, “Embodied value-added total”, “Public sector corruption”, and “Trade union density”. Although Andrade et al.'s (2022) study was about agricultural activities, the results are comparable to the results of the present study, given that most of those indicators are measured at the country level.

From the generic analysis results, organizations can learn about the main social hotspots in the product’s value chain in terms of social indicators, processes, and countries that contribute the most to the overall social risks. The organizations from the product systems in this study, especially the CS operator, could pay special attention to the social indicators described above to avoid those risks and contribute to enhancing the socio-economic conditions in the country(ies) where they operate. More specifically, by learning that the living wage in Spain is relatively high, organizations could ensure that the minimum wage they pay is at least the same as the living wage. It is relevant to note that all the organizations assessed pay minimum legal wages, which are above the Spanish living wage amount reported in the database. Nevertheless, ensuring that minimum wages align with living wages in the lowest paid or informal sectors in Spain and other countries guarantees that workers can cover their basic needs. Additionally, organizations should promote this principle along their supply chains to avoid this risk.

As for the rate of biomass extraction in Spain, organizations could evaluate whether their businesses contribute to biomass extraction, and if they do, they could adopt measures to ensure that the biomass is extracted at a sustainable rate or that it comes from legal and sustainable sources.

Although all the organizations assessed follow local legislation and their workers are free to associate and join unions, they could ensure that trade unionism does not represent a risk for negative social impacts by providing a grievance mechanism for employees to report violations against this right and other support mechanisms that workers could use to get better informed about this topic. Given the index score in public sector corruption in Spain and its high risks, organizations could ensure they have appropriate measures to prevent corruption and bribery.

Finally, the social hotspot screening results that assisted in the selection of relevant impact subcategories to be evaluated in this study (“Freedom of association and collective bargaining”, “Equal opportunities/discrimination”, “Fair salary”, and “Local employment”; section 4.2.1.8), proved right in identifying two of the subcategories that resulted in actual hotspots in the generic assessment. Interestingly, the screening results also identified two of the hotspot subcategories in the site-specific assessment (“Equal opportunities/discrimination” and “Local employment”). Using databases to identify areas of concern and prioritize data collection is, thus, useful in S-LCA.

5.2. Interpretation

5.2.1. Materiality principle

In the site-specific analysis, the significant or material subcategories that affect the global social performance of each product system have been identified in sections 5.1.1.1 and 5.1.1.3. Furthermore, the significant or material processes in the life cycle—represented by organizations—were identified in section 5.1.1.1. The calculation of the site-specific activity variable links organizations to the product systems.

Regarding the generic analysis, the contribution of social indicators to the significant impact subcategories was performed in section 5.1.2.1.

5.2.2. Completeness check

This step of the Interpretation phase is performed narratively, as suggested in the Guidelines, by answering the suggested guiding questions (UNEP, 2020, p. 110). Whether the results answer the research questions of this study will be evaluated in section 7.1.

The Goal and Scope of the study were clearly defined in section 4.2.1. Additionally, all the relevant stakeholders were considered, except for Children. As provided in section 4.2.1.7, the reason for its exclusion is that all the organizations included operate in a business-to-business context, and they may only influence children indirectly. Thus, it was considered that the consideration of children was included in the "Society" and "Local community" stakeholder categories. Moreover, all the processes relevant to the product systems have been included, following the study's goals. The cut-offs of the product systems (products) were justified based on the availability of data.

The data collected in the Inventory phase was deemed sufficient to evaluate the subcategories of interest. The reference scales were prepared in such a way that if data about a specific organization was unavailable, the evaluation was still doable.

As for impact assessment, the social indicators and subcategories were sufficient for calculating the social performances of different organizations. The social indicators were mainly sourced from the Methodological Sheets, and when more were needed, they were added from different S-LCA studies. As for the generic assessment, all the social indicators from PSILCA were used, except for those related to environmental impacts (environmental footprints and GHG footprints).

5.2.3. Consistency check

Like the completeness check, this step is carried out in a narrative way by answering the guiding questions proposed in the Guidelines (UNEP, 2020, p. 111).

In this study, special attention was paid to the consistent use of the terminology. Furthermore, the impact assessment approach applied was coherent with the study's goals. Moreover, the functional unit has captured the relevant properties of the systems under study. In addition, the double layer of the product system and system boundaries ensured that all the technical processes and stakeholders were included.

The types of data are coherent with the Goal and Scope of the study. Similar to other S-LCAs, qualitative and quantitative, primary and secondary, site-specific and generic data have been used. Allocation rules and system boundaries have been applied consistently in both product systems.

The impact assessment method, aggregation, and weighting are also consistent with the study's goals. In the reference scales, the BRs were consistently defined for each impact subcategory based on international standards. All the reference scales are presented in Appendix V. Furthermore, the impact assessment method selected facilitated considering the geographic and sector-specific social context, and the results have been aggregated in a way that allows interpretation in line with the goals of the study.

5.2.4. Sensitivity and data quality check

In this study, the uncertainty of the data was assessed through a data quality pedigree matrix. The data were assessed on four criteria, and a score from 1 to 5 was assigned to each criterion. A higher score represents larger uncertainty of the data. The data quality results are presented in Table 18. The best data quality corresponds to that of the CS operator since more primary data could be collected, and more than one employee provided information on certain indicators, increasing the source's reliability. Data regarding the performance of Organizations A, D, and F had the lowest data quality. Recall that for these organizations, no site-specific data were available for many social indicators, and no employees from Organizations A and F participated in the study. The above prompted the researcher to use generic information to assess the performances of those organizations, which had implications for the source's reliability, and temporal and geographical conformance criteria.

5.2.4.1. Sensitivity analysis 1

In the first sensitivity analysis, a different organization was selected as the chemical supplier for the original system. Recall that the original system is operating at a pilot scale and that the chemical supplier(s) for a fully operational plant are still unknown. Therefore, based on a list of potential chemical suppliers provided by the CS operator, Organization F was selected as a proxy (see 4.2.1.5). As indicated in the results above, gathering site-specific data from Organization F was burdensome and the lack of data affected Organization F's performance in three subcategories: "Equal opportunities/discrimination", "Health and safety", and "Local employment". Furthermore, Organization F did not meet the BRs of "Safe and healthy living conditions", "Public commitment to sustainability issues", and "Promoting social responsibility".

Consequently, to see the effects on the results, Organization F was substituted with Organization G. Organization G was selected for the sensitivity analysis based on its market share in the Spanish chemical industry (Arufe et al., 2022; El Economista, 2022). This organization is one of the top 5 in the chemicals and plastics sector; hence, it was assumed that enough data was available. Furthermore, it is relevant to note that the selection of Organization G was not based on its ability to provide the chemicals needed in the original system.

Organization G's social performance was evaluated via the 22 reference scales corresponding to the 11 impact subcategories selected for this study. Table 20 shows the social performance scores of all the organizations in the original system, including Organization G's. Furthermore, each data point was evaluated under the same data quality criteria defined in section 4.3.5. In some reference scales, the data quality related to Organization G is worse than Organization F's due to more data sources considered and more assumptions made based on statements that the organization abides by local legislation. For example, it was assumed that the number of hours worked per week does not exceed the maximum amount allowed by law.

Unlike Organization F, there was data for all the indicators included in the reference scales for Organization G. Organization G met the BRs of almost all the subcategories and received a score of 1 in five reference scales. Nevertheless, it did not meet all the BRs of “Health and safety”, “Safe and healthy living conditions”, and “Local employment”. In the first, the data available regarding the evidence of occupational accidents was provided in only a couple of indicators whose units differed from other organizations and the sector, hampering comparison. Although it disclosed some information, this information was not deemed enough to meet the BR. In the subcategory “Safe and healthy living conditions”, the organization did not meet the BR regarding the reduction of hazardous substances use. The organization has initiatives in place that seek to increase the share of recycled and renewable-based raw materials, but no explicit indication that the organization aims to reduce its use of hazardous substances was found. Finally, since the organization aims to attract highly qualified professionals, no policy regarding local hiring preferences was found; thus, it did not meet this BR.

A visual comparison of Organizations F and G’s social performances in the subcategories under study is shown in Figure 17. Except for “Fair salary” and “End-of-life responsibility”, where both organizations received the same scores and met the BRs (see Figure 18, OS and SA equal weights), Organization G achieved a better performance than Organization F in all the impact subcategories. Thus, an improvement in the social performance of the original system is observed after the substitution. Furthermore, the system’s “End-of-life responsibility” score is only determined by the chemical provider as neither the CS operator nor Organization E was evaluated in this subcategory.

Table 20: Sensitivity analysis 1: social performance scores and data quality scores per organization for each reference scale

Stakeholder category	Subcategory	Reference scale	Assessment score (data quality score)			
			CS operator	Electric. provider	Chemical supplier	Chemical supplier
			CS operator	Org. E	Org. F	Org. G
Worker	Freedom of association and collective bargaining	FACB1	1 (1.2)	2 (1.3)	2 (1.4)	1 (1.5)
		FACB2	2 (1.3)	2 (1.3)	2 (1.4)	2 (1.5)
	Equal opportunities/ discrimination	EODI1	1 (1.0)	1 (1.3)	2 (1.3)	1 (1.3)
		EODI2	1 (1.0)	2 (1.3)	**4 (2.3)***	2 (1.5)
		EODI3	2 (1.5)	1 (1.8)	**4 (2.8)***	2 (1.4)
		EODI4	2 (1.3)	2 (1.3)	2 (1.3)	2 (1.3)
	Health and safety	OHSA1	1 (1.0)	1 (1.2)	2 (1.3)	1 (1.3)
		OHSA2	2 (1.0)	2 (1.3)	**3 (2.8)***	**3 (1.8)**
	Fair salary	FSAL1	2 (1.3)	2 (1.4)	2 (1.5)	2 (1.5)
		FSAL2	2 (1.1)	2 (1.5)	2 (1.5)	2 (1.5)
	Working hours	WHOU1	2 (1.1)	1 (1.4)	2 (1.3)	1 (1.5)
		WHOU2	2 (1.3)	2 (1.5)	2 (1.4)	2 (1.5)
Consumers	End-of-life responsibility	EOLR1	NA	NA	2 (1.8)	2 (1.3)
		EOLR2	NA	NA	2 (2.0)	2 (1.3)
Local community	Access to material resources	AMRE1	2 (1.0)	1 (1.4)	2 (1.0)	1 (1.1)
	Safe and healthy living conditions	SHLC1	2 (1.4)	**3 (1.5)**	**3 (1.3)**	2 (1.5)
		SHLC2	**3 (1.0)**	**3 (1.3)**	NA	**3 (1.3)**
	Local employment	LEMP1	2 (1.3)	**4 (1.3)***	**4 (2.0)***	**3 (1.3)**
		LEMP2	2 (1.3)	2 (1.3)	**3 (2.0)***	2 (1.8)
Society	Public commitment to sustainability issues	PCSI1	2 (1.1)	2 (1.3)	**3 (1.6)**	2 (1.3)
Value chain actors	Promoting social responsibility	PSRE1	2 (1.0)	2 (1.3)	2 (1.3)	2 (1.3)
		PSRE2	2 (1.0)	2 (1.3)	**3 (1.3)**	2 (1.3)

* denotes "no data" situations. Higher scores are in bold. The values within parenthesis indicate the data quality scores.

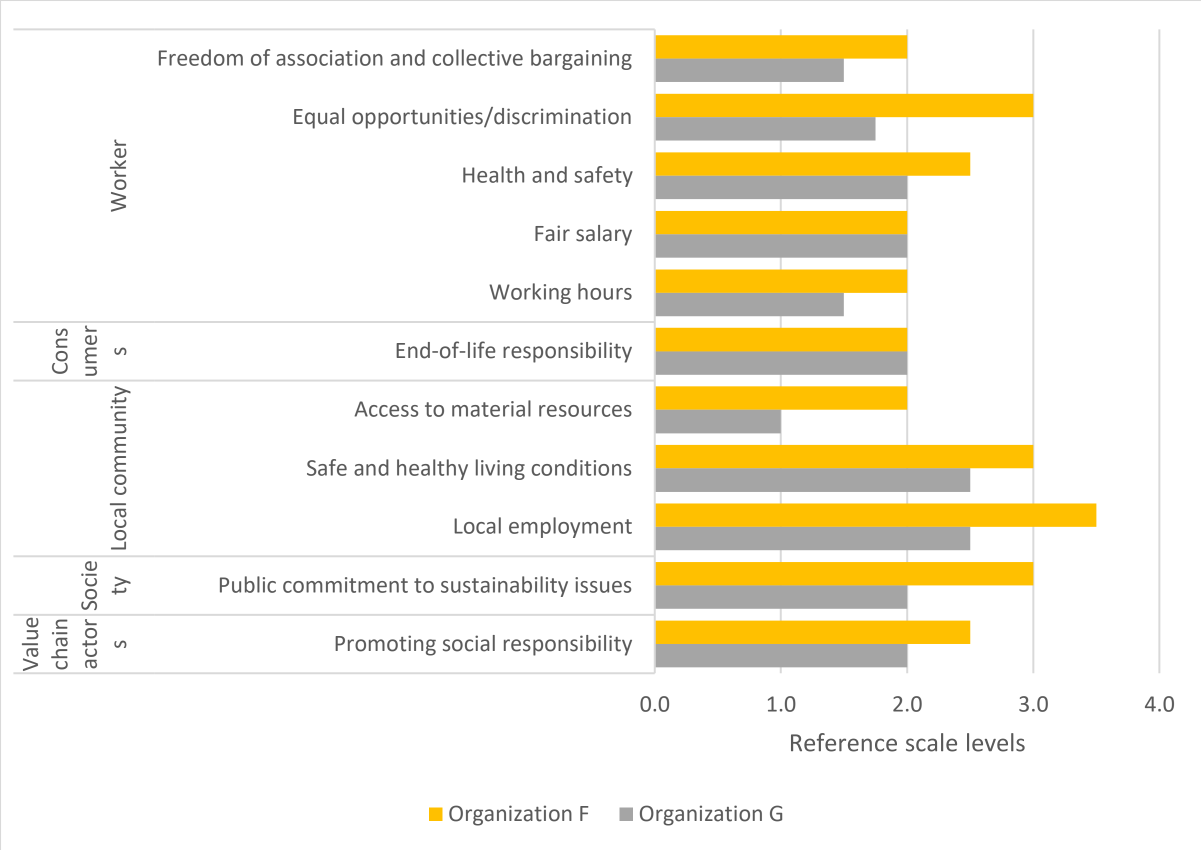

Figure 17: Sensitivity analysis 1: Organizations F and G's social performance by impact subcategory

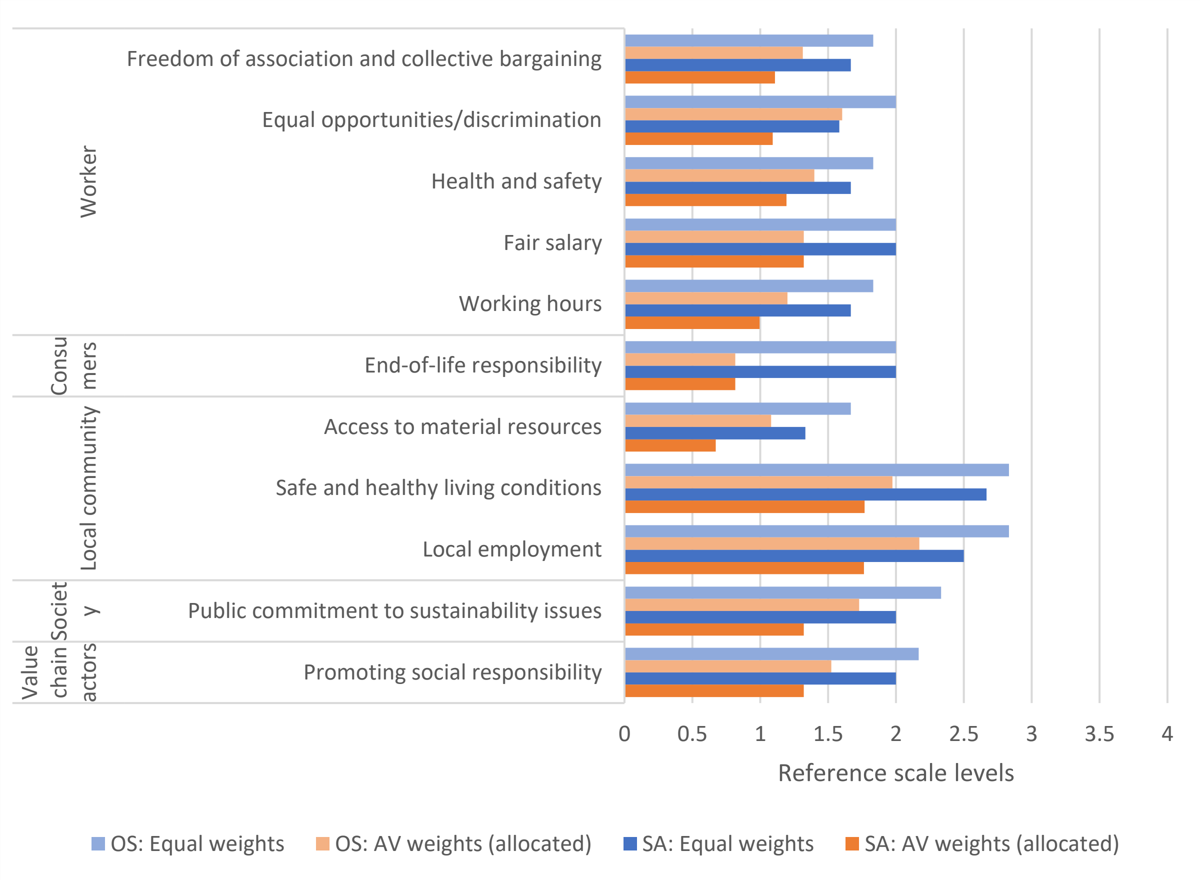

Figure 18: Sensitivity analysis 1: social performance of the original system prior to and after the sensitivity analysis based on equal weights and activity variable-based (allocated) weights.

"OS" refers to the original system prior to the sensitivity analysis, and "SA" refers to the original system posterior to the sensitivity analysis.

It is important to highlight that the substitution of Organization F with Organization G resulted in meeting the BRs of "Public commitment to sustainability issues" and "Promoting social responsibility". The former occurs because Organization G integrates sustainability issues in its policies and company goals and produces publicly available documents (sustainability reports). The latter is due to the evidence found that Organization G performs audits regarding social responsibility issues. In fact, Organization G is a member of an industry-led initiative ("Together for sustainability") aiming to improve sustainability along the value chain. Contrarily, Organization F did not meet these requirements. Thus, when Organization F was included, the social performance of the system in these two subcategories was not in line with the BRs (see Figure 18, OS and SA equal weights).

The global social performance score of the original system (based on equal weights and site-specific activity variables) improved (Table 21). Overall, whether organizations are aggregated using equal weights or activity variable-based weights, improvements in all the impact subcategories can be seen when a chemical supplier with better performance or for which there is more data available is included. However, this was not enough for two subcategories, namely, "Safe and healthy conditions" and "Local employment", indicating that improvements in the performance of Organization E and the CS operator are also required (see "SA: Equal weights" series in Figure 18).

Table 21: Sensitivity analysis 1: comparison of global social performance scores prior and posterior to the sensitivity analysis (original system)

Equal weights		Activity variable-based weights	
Before sensitivity analysis	After sensitivity analysis	Before sensitivity analysis	After sensitivity analysis
2.12	1.92	1.47	1.22

5.2.4.2. Sensitivity analysis 2

In the second sensitivity analysis, sector-wide changes regarding reductions in the use of hazardous materials were assumed. Given that a new plan to ban thousands of hazardous chemicals in the EU was announced earlier this year (European Commission, 2022a; Neslen, 2022) and that most of the organizations included in both product systems do not have any policies or practices in place to reduce their use of toxic substances, it was deemed appropriate to evaluate how such restrictions would alter organizations' social performances. The EU's Restrictions Roadmap aims to facilitate the prioritization of toxic substances for group restrictions under REACH (European Commission, 2022a). These substances pose considerable risks to human health and the environment.

Under this assumption, organizations can choose to continue business-as-usual or to implement new measures to abide by the new restrictions and thus, meet the BR. The latter was considered for this sensitivity analysis, and new scores were assumed for each organization regarding the reference scale SHLC2. Table 22 shows two reference scales of "Safe and healthy living conditions" before the sensitivity analysis and the reference scale (SHLC2) posterior to the sensitivity analysis. Regarding Organization A, "no data" remains unchanged. However, a different score is achieved because it is assumed that organizations in the sector will abide by the new regulations, i.e. the context will change from negative to positive, which will cause a change in the score (from 4 to 3). The social performance of the CS operator and Organizations E improved in SHLC2.

Table 22: Sensitivity analysis 2: social performance scores per organization for each reference scale

Stakeholder category	Subcategory	Reference scale	Assessment score						
			CS operator	Org. A	Org. B	Org. C	Org. D	Org. E	Org. F
Local community	Safe and healthy living conditions	SHLC1	2	3*	2	2	4	3	3
		SHLC2 (before SA)	3	4*	2	2	NA	3	NA

		SHLC2 (after SA)	**2**	**3***	**2**	**2**	**NA**	**2**	**NA**

* denotes "no data" situations. "SA" stands for sensitivity analysis.

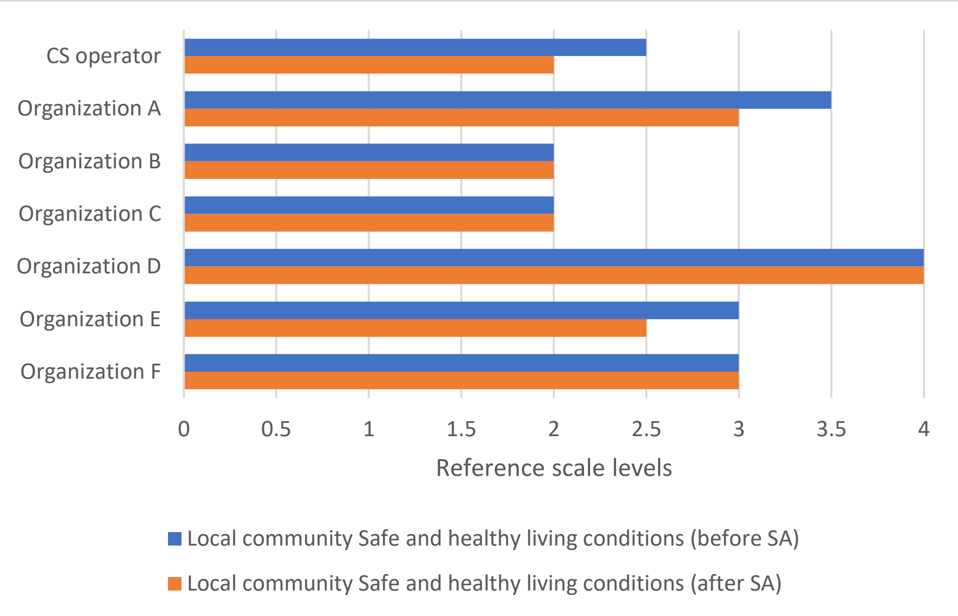

Figure 19: Sensitivity analysis 2: social performance of each organization in the "Safe and healthy living conditions" subcategory

Considering that "Safe and healthy living conditions" includes two reference scales, the final scores for this subcategory for each organization were calculated by aggregating the reference scales. This is presented in Figure 19. Despite the improvement in most organizations' performances, Organizations D, E and F need to implement further improvements to meet the BRs of this subcategory, specifically, in the reference scale SHLC1. Organization A's performance may be better evaluated if data availability improves.

Finally, the social performance of the reference system and the original system before and after the sensitivity analysis can be calculated by aggregating the organizations (based on equal weights). The results are presented in Figure 20. The social performance of the reference and original systems do not level 2 even after the change. As noted previously, the performance of Organizations D, E and F in SHLC1 needs to be improved in order for both systems to reach level 2 in this subcategory.

In general, the social performance of both systems improves after the sensitivity analysis, which indicates that changes in the context, especially in regulations, have an essential role in the performance of organizations. Depending on the number of social indicators or reference scales, this type of change could affect the overall social performance of product systems, as indicated above.

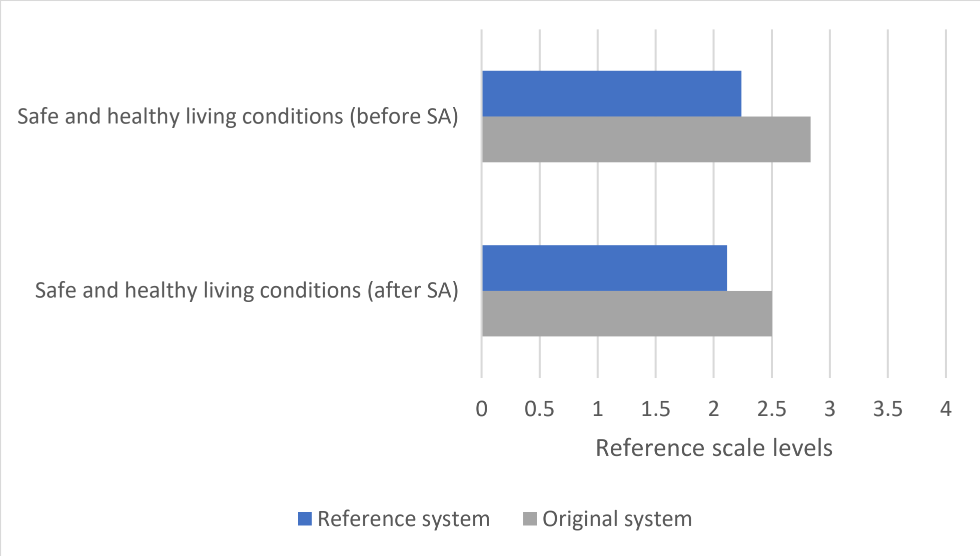

Figure 20: Sensitivity analysis 2: social performance of reference system and original system in “Safe and healthy living conditions”, before and after the sensitivity analysis

6. Discussion

This section discusses the main issues found during the site-specific and generic assessments. The last section provides a summary of the main general learnings from the application of S-LCA in this study.

6.1. Site-specific assessment

6.1.1. Selection of social impact subcategories and indicators

As this thesis concerned the application of the S-LCA methodology, the social indicators included in the site-specific analysis were mainly those suggested in the Methodological Sheets. Nevertheless, some other indicators were adopted from other studies (section 4.2.1.9) to be able to assess not only organizations' commitment but also their performance in related social issues. Thus, the indicators added were mainly in line with the descriptions of the impact subcategories detailed in the Methodological Sheets. However, the indicators suggested in the Methodological Sheets are not exhaustive, and indicators specific to the case study or the sector under consideration may be included in the S-LCA. Notably, more than half of the reviewed S-LCAs in the water sector included subcategories and indicators different from those proposed in the Guidelines. For example, Padilla-Rivera et al. (2016) included indicators like availability of wastewater management documentation, performance monitoring program, and effluent quality. Nevertheless, it is worth mentioning that the geographic location of processes may present special topics to pay attention to, which may not apply in other locations.

The selection or the definition of new social indicators is challenging due to the subjective nature of certain social issues. Like in the subcategory selection, stakeholder or expert consultation might be necessary to arrive at a specific list of indicators relevant for a case study (e.g., through a focus group or Delphi method). It is essential to consider that choosing social indicators especially relevant to wastewater treatment facilities is only helpful for assessing the wastewater treatment stage. As such, inventory data regarding WWT indicators will be collected from the organization in charge of operating the WWTP. However, these indicators will not apply to other organizations that might be included in the product system, whose activities are different from treating wastewater. Additionally, including social indicators related to wastewater treatment may not considerably benefit this S-LCA since the same organization is responsible for operating both the reference and the original systems. Thus, the social performance will remain the same. An exception would be the inclusion of WWT-related indicators that are particular to each product system, e.g., more training might be needed with newer technologies in the original system or workers might be more or less exposed to entrapment risks.

The selection of indicators could also benefit from existing resources. For example, if the main sources of data are sustainability or corporate reports or third-party assessment reports (e.g., EcoVadis, CDP assessments), indicators can be derived from these. The limitation of this is that not all the organizations included in an assessment might have been assessed by the same third-party and that each organization prepares their sustainability reports differently by choosing what and how to disclose information. The latter affects inventory data collection, mainly when many organizations are included in the assessment. Thus, harmonization of social indicators from information already available still presents challenges. The introduction of new European sustainability reporting standards might, to some degree, facilitate harmonization, but only for organizations operating in this region. Furthermore, additional data collection might be required as not all organizations report thoroughly and transparently.

6.1.2. Inventory data collection

As with any LCA, life cycle inventory comprised one of the most time-consuming phases of this study. One of the main limitations of data collection was that too few employees were willing to participate and had time availability. While the goal was to include one or two employees from each organization, for three organizations (Organizations A, E, and F), this was not the case either because they were not interested or did not have the availability. Nevertheless, in some cases, it is necessary to collect information from more employees. For example, organizations with facilities in different parts of the world may have different management systems in place following different regulations, and thus, data might need to be collected from different persons. Even if organizations operate in the same country, one employee may not have detailed information on each social indicator. Therefore, identifying which persons in the company are appropriate to participate is crucial, particularly for larger organizations.

Another aspect regards the inclusion of different members of each stakeholder category. If the goal is to measure the effects of an organization's behavior on different stakeholders, data collection should undoubtedly include those stakeholders as sources of data. The use of survey questionnaires and interviews with site-specific workers (e.g., operators, technicians), local community members, and members of the wider society is helpful for such a data collection endeavor. However, interviewing value chain actors may pose a rather challenging task as an organization may have hundreds of suppliers from different locations. Another point to consider, particularly for business-to-business operations, is that although consumers are part of the value chain, they are treated as a separate stakeholder category in the Guidelines.

In this study, this would require performing interviews or collecting data via questionnaires from the stakeholder groups of interest of the CS operator and its suppliers. Such a process requires substantial resources and possibly needs to occur in different geographical locations. One alternative would be narrowing the scope to include only certain stakeholder groups (e.g., workers) or not including suppliers. However, this will result in limited results and the loss of a life cycle perspective. Another alternative would be applying expert or judgmental sampling to select a sample of each stakeholder group. The resources available for this thesis are not enough for applying the latter.

The size of organizations also played a role in data collection. For larger, multinational organizations, organization-specific data was more accessible than for smaller organizations. Likewise, there was more data from external sources for larger organizations. This makes sense since, in some instances, large organizations must abide by more regulations; hence, they track their operations in different countries and collect more data. Furthermore, large organizations have more resources to focus on other areas than just the economic aspect; they need to manage shareholders' expectations and are under considerable public scrutiny. Consequently, some employees were easier to reach and helpful in providing information, while others were not.

On the contrary, smaller organizations might be tighter in resources (time, capital, and human) and focus most of their efforts exclusively on economic business activities. This was the impression gained from the data collection experience in this thesis since the employees were harder to reach and less willing to collaborate. Moreover, given that they do not publish sustainability-related or annual reports in general, accessing data was quite complicated. Reluctance to share social data information may also be related to the relative lack of awareness about the S-LCA method since it is relatively new. Additionally, the social indicators often regard data that might be sensitive for businesses to share. In fact, one participant pointed out that maybe with a non-disclosure agreement, the company would be more willing to share information (participant from Organization C, personal communication, May 2, 2022).

Therefore, the researcher was limited in her ability to access company data compared to an auditor or a client company employee. In this regard, the data collection phase could have benefitted more should the CS operator have exerted some more of its influence by formally introducing the study and the researcher to its suppliers so that these would be more willing to participate.

6.1.3. Impact assessment method

The reference scales were established based on the PRPs that fulfilled the subcategory descriptions and the social indicators proposed in the Methodological Sheets. Ensuring that the BRs indeed covered the subcategories and social indicators and that the latter actually measured the BRs was dependent on the researcher’s judgment. The method adopted in the construction of the reference scales used the BRs as an intermediary between the subcategory descriptions and the social indicators. Other reference scales used the social indicators directly and referenced them to international agreements so that they can be understood as BRs (García-Sánchez & Güereca, 2019; Hannouf & Assefa, 2018; Padilla-Rivera et al., 2016; Ramirez et al., 2014). The latter’s advantage is that it makes establishing reference scales more straightforward and reduces subjectivity. Some disadvantages are that (i) not all indicators can be used because they cannot be referenced to national legislation or international agreements, and (ii) there is almost one reference scale per social indicator. On the other hand, while combining social indicators into a single reference scale allows for one single reference scale per subcategory, building reference scales is more complex and time-consuming.

One advantage of finding BRs for each subcategory and matching them with indicators is establishing a more explicit link between the social indicator and the subcategory. Another advantage is that the social indicators do not define the subcategories. Accordingly, it is easier to identify gaps between the subcategory definition and the social indicators, and if gaps are found, more social indicators can be added. Since the availability of social indicators and subcategory-specific PRPs are the base for establishing a reference scale, there is no shortcut or standard reference scale for all subcategories; each reference scale must be built separately.

Another aspect deserving consideration is the importance of different social indicators and impact subcategories. The method applied in this thesis considered all the indicators as having equal weights. For instance, the announcement of job positions through different channels was considered as important as the evidence of serious occupational accidents in the organization. However, it is clear that not all indicators and impact subcategories have equal importance. Determining a universal weighting system is not plausible due to the subjective and complicated nature of social issues and because the relevance of each subcategory may be related to the goal of the study. On the other side, applying weights was necessary for calculating and interpreting the results due to the many reference scales and organizations considered.

It is worth noting that the non-compliance levels (levels 3 and 4) concerned assessing the context. Assessing the context, in some cases, was related to assessing the situation in the sector, and in other cases, it was related to assessing other organizations in the sector. Assessing the sector was mainly applied to quantitative indicators such as occupational accidents, number of female workers, average wages, and gender wage gaps, which correspond to the "Worker" stakeholder category. For qualitative indicators or indicators for which there was no sectoral data (e.g., the share of local suppliers, human rights protection along the supply chain, the inclusion of sustainability principles in the organization's policy), the performance of peers was evaluated. Peers were selected based on their market share in their corresponding sectors in Spain, which were all large corporations. As expected, this process added extra data collection needs and efforts to the assessment.

Although valuable, taking the geographical context into account in the assessment is limited because it only applied to levels 3 and 4. Not considering the context in levels 1 and 2 can arguably be understood as a normalization step, mainly when the organizations in the product system operate in very different social contexts (e.g., different geographical locations with different levels of social risks). It may be more difficult for an organization embedded in a negative context to achieve the BR or exhibit a proactive behavior than for an organization that operates in a positive context since it may require implementing more policies and procedures. An improvement can be made by including the same consideration in the assessment of levels 1 and 2. However, this will require even more data collection.

Lastly, since most of the indicators are at the organizational level and data is not exclusively site-specific, it is somewhat misleading to refer to this assessment as "site-specific". Though there are limits to the achievable degree of specificity, this can be improved by collecting as much data about a specific site as possible.

6.1.4. Use of activity variables

In chapter 3, it was discussed that unlike E-LCA, where a product's impacts are directly linked to the inputs and outputs of the processes necessary to deliver its function, the social impacts of a product are difficult to account for. In S-LCA, the impacts are mainly attributed to the behavior of the organizations included in the product life cycle. However, linking the behavior of companies to a specific product system is troublesome because, in most cases, the organization's activities cannot be quantitatively linked to a specific product. Therefore, the question of how to improve the social aspects of a specific product system remains.

There are two approaches in S-LCA that connect the social impacts and the product system. The first is implementing the IP approach in S-LCIA, where impact pathways are used. The second approach regards using activity variables to give relative weights to the different unit processes which organizations represent. Since the activity variables reflect the contribution of each organization in the life cycle of a product, the impact assessment results will be linked to the product system.

However, in most cases, the social inventory data regarding an organization's activities cannot be exclusively linked to one of the organization's products because the performance of organizations does not have a quantitative link to their products. If an organization is involved in corruption and bribery, it will continue to be corrupt regardless of how many types or units of products they produce. In other cases, the link is direct, e.g., producing more of a particular product may imply more accidents, more hours of work, or more child labor.

Furthermore, the fact that an organization has a supplier in a high-risk area of human rights violations and that this supplier might be linked to such violations is of enormous importance. In comparison, which of the supplier's products is linked to forced labor or how many products are purchased from this supplier become irrelevant issues. Take the garment industry facing Xinjiang cotton issues linked to forced labor of Uyghur people as an example. Under the consideration that their supply chains may be affected, many clothing brands decided to change their sourcing of cotton to other countries. Even brands not manufacturing garments or getting fabric from the region had to ensure that Xinjiang cotton was removed from their supply chains (Stevenson & Maheshwari, 2022). Otherwise, continuing business-as-usual for these businesses would come at a high reputational and capital cost.

Therefore, considering that inventory data cannot be linked to one specific product and that the social performance of an organization's behavior is not proportional to a product (its function), using activity variables to link the results to the product system is artificial and comes with limitations. Similar to choosing an allocation method in E-LCA, using activity variables introduces bias in S-LCA, which must be acknowledged. Essentially, allocation and activity variables serve methodological purposes. However, in reality, environmental impacts cannot be split among co-products as if they exist in isolation, and social impacts are not entirely specific to a defined product. Thus, what Guinée et al. (2004) concluded on the allocation problem can be applied to the S-LCA issues discussed here: wishing to link the social performances of organizations to a specific product system results in the use of artifacts such as activity variables. Since the problem can only be solved artificially, there might not be a "correct" way of doing it, and there is room for more advancements in this regard in the S-LCA field.

6.1.5. Multifunctionality and social impacts

Following the discussion above, this section focuses on the issues of multifunctionality, which is a characteristic of circular economy systems, and social impacts. In the site-specific analysis, activity variables were used to account only for the social impacts of treating wastewater. First, and as discussed above, activity variables were used to link the organizations' social performance with the product system. Second, because a link could be established, the multifunctionality problem in each product system could be solved. Given that each input (including the personnel costs from the CS operator) represents a non-functional flow, it could be allocated to the different functional flows of the process. More specifically, the share of each organization (represented by the share of its inputs in the total costs) was multiplied by the appropriate allocation factor. Consequently, the results exclusively represent the social performance associated with the treatment of 1 m^3 of wastewater. However, it is essential to note that how the activity variables are calculated directly affects the final (allocated) results. For instance, if the shares of the organizations are calculated differently than how it was done in this study, the social performance results per 1 m^3 will be altered. This adds another level of uncertainty to multifunctionality solutions in S-LCA studies applying the RS approach.

The same approach to solving multifunctionality was taken in the generic analysis, with the difference that the allocation factors and calculation of results were automatically performed by the LCA software. Like in the site-specific analysis, the worker hours in PSILCA were also allocated to the functional flow of interest. Allocating the worker hours in the generic analysis was particularly important because the social flows were calculated based on them. If the worker hours had not been allocated, neither would have been the social flows, causing the results of the foreground process not to represent the social risks of the functional unit.

Solving multifunctionality processes is particularly relevant in resource recovery systems or circular economy systems that produce more than one valuable product. In turn, comparing the social impacts of a business-as-usual process with those of a more resource-efficient process will not yield very different results if the recovered resources (i.e., co-products) are not taken into account.

Nevertheless, in reality, it does not matter how the allocation is performed because the social impacts are not entirely specific to a determined product, and, as in E-LCA, they are not inherent to each co-product independent of another. As Guinée and colleagues put it: “The multi-functionality problem is an artefact of wishing to isolate one function out of many. As artefacts can only be cured in an artificial way, there is no ‘correct’ way of solving the multi-functionality problem, even not in theory” (Guinée et al., 2004, p. 33).

Having acknowledged the limits of allocation and multifunctionality solutions in general, the question that still remains is: do circular economy systems (multifunctional systems) produce more or less social impacts than conventional, linear systems? One could argue that they produce less negative impacts on stakeholders because they may replace products that come from socially deficient systems (e.g., replacement of magnesium imported from Russia, where the impacts on workers were mainly negative (Tsalidis et al., 2020)). However, circular economy systems may also result in more social impacts. Following the previous example, the reduction of imports could translate into fewer hours of work, less access to training, fewer contributions to the economic development of that region, and stakeholders there might be negatively affected. Therefore, special attention must be paid to issues like the ones above, particularly when comparing linear and circular systems.

6.1.6. Nature of reference scales in S-LCA

One of the issues concerning the reference scale approach is that the reference scales are ordinal in nature. Whereas quantitative data might be ratios or intervals, categorical data can be nominal or ordinal. The emphasis of ordinal scales lies on the order of the categories or levels, and the actual distances between one level and the next are unknown. Consequently, arithmetic operations cannot be applied to ordinal values, and descriptive statistics are limited to the median, mode, and ranges. Furthermore, not even the median can be calculated in all cases; for instance, when the total number of data points is even, calculating the media requires adding and dividing two numbers, which cannot be done. Therefore, strictly adhering to these rules would limit the calculation and presentation of impact assessment results.

However, while some approaches exist to address this issue (e.g., social impact valuation, BASF Seebalance® method, SHDB, PSILCA database) (Ciroth, 2012; M.J. Goedkoop, de Beer, Harmens, Saling, Morris, Florea, Hettinger, Indrane, Visser, Morao, Musoke-Flores, Alvarado, Rawat, et al., 2020), most of them rely on quantitative data. As discussed previously, relying on quantitative data might limit the analysis since most indicators are associated with qualitative information. Furthermore, as exemplified by different studies and the Guidelines, aggregation of reference scales appears to be a common practice in S-LCA (Ciroth & Franze, 2011; García-Sánchez & Güereca, 2019; Padilla-Rivera et al., 2016; UNEP, 2020). Subsequently, reference scales could be compared to Likert scales. Regarding the latter, many researchers in social sciences treat Likert scales as interval ones and perform arithmetic operations (H. Wu & Leung, 2017).

In addition, one of the most valuable advantages of reference scale methods such as SAM is to convert qualitative data into quantitative data. Furthermore, the organizational approach taken in this S-LCA makes this method more similar to a social reporting approach (Sureau et al., 2020), which aims to facilitate decision-making. Therefore, performing simple arithmetic operations was not deemed an issue of concern in this study, and they were resorted to facilitate the analysis and presentation of results.

6.2. Generic assessment

One limitation of using databases built on multi-regional input-output tables is that economic sectors are aggregated and include many different activities. For example, the sector "Manufacture of chemicals and chemical products" includes all organic and inorganic chemicals, and it is not possible to separate or distinguish between, e.g., the manufacture of sodium chloride from hydrochloric acid. The social risks related to the production of each of those chemicals may differ significantly, regardless of the country of origin and the quantity used (Shemfe et al., 2018). In this regard, all the social flows from different processes are aggregated, and they are not specific to a specific production process. Thus, even though the two product systems use different chemicals as inputs, the social flows from those chemicals are the same.

Furthermore, this has important implications in the calculation of social risks of the foreground processes because the social flows were replicated from a sector with similar characteristics ("Market sewage and refuse disposal, sanitation and similar activities"), whose social flows represent an "average" of the social flows from sewage collection, distribution, wastewater treatment, and other activities. In other words, the social flows from the foreground processes representing the reference and original systems are not strictly representative of the social flows of wastewater treatment. In a further study, this can be improved by collecting data on each individual indicator, not relying on data from the database.

In addition to improving the representation of the social risks from the foreground processes, manually collecting data will benefit data quality assessment. Currently, only the Developer PSILCA database type includes a data quality assessment for each social indicator and allows the practitioner to modify the data quality. Moreover, the results might improve if more recent and accurate information is provided on each social indicator.

Specifically referring to the product systems analyzed in this study, three aspects may contribute to improving their social risk results. Firstly, since the original system is still being tested at a pilot scale and some of the technologies it employs are also new, it was not possible to have data representing a full-scale operation. Consequently, some inputs such as electricity, correspond to the operation of the system at a pilot scale, which uses more resources than a full-scale system. Once better approximations of the full-scale operation are available, the inputs can be corrected, and better results can be obtained. Secondly, the results can also be affected by the data quality, as mentioned above. For example, the risk level of social indicators can be improved or worsened (e.g., from high risk to very high risk with risk factors of 10 and 100, respectively) based on new or more recent information. Therefore, the results will represent (at least) the foreground system more accurately. Thirdly, the price of inputs may affect the results as they determine the social risks from the upstream processes. If there is an increase in the prices of inputs, the social risks will be increased, as well, and vice versa.

Another aspect that must be acknowledged is that using the activity variable "worker hours" to calculate social risks in subcategories or indicators that are not related to working conditions has limitations. What the activity variable in PSILCA represents—the number of hours of work necessary to produce 1 USD of output—is not related to how other stakeholders different than workers are affected. Specifically, the drinking water coverage in a country (an indicator of the "Access to material resources" subcategory, stakeholder "Local community") will not be determined by the hours worked to produce 1 USD of output in a sector. Thus, the social risk results (in mrh) of those subcategories that are not related to the stakeholder category "Workers" are difficult to interpret (Serreli et al., 2021). Finally, social risk results in PSILCA are only insightful when a comparison with other similar product systems is possible because there is no reference to decide how many impacts are too many (Serreli et al., 2021).

6.3. General learnings from the application of S-LCA at two levels of analyses

- If possible, engage and promote stakeholder participation along the stages of the S-LCA: in the Goal and Scope definition phase, stakeholder participation will allow for identifying the social aspects of high importance concerning a product system (Mathe, 2014). Therefore, they can assist in the selection of subcategories and social indicators, making the results even more valuable to them and facilitating data collection. Stakeholder engagement might not be limited to the stakeholders affected by an organization's activities but may also include the different organizations to be evaluated. As the interests of different stakeholders differ, and what is relevant to organizations might not necessarily be relevant to a product system, this should be done carefully.
- Formally introducing the study (and the practitioner) to the organizations involved (i.e., suppliers) may benefit data collection: sharing site-specific social inventory data requires trust between organizations and in the practitioner. Confidentiality agreements may also contribute to building trust. Furthermore, organizations may be more willing to participate if they understand the benefits of S-LCAs.
- Start preparing the reference scales early in the S-LCA to carry out the impact assessment more efficiently: from the experience of this thesis, impact assessment can be a complex and time-consuming task. Many RS methods are available, making the selection of one even more troublesome. Selecting a method and building the reference scales early prompt the researcher to focus on the necessary indicators, avoiding loops and unnecessary information, which saves time.
- Comparing site-specific results might be possible only to a certain extent: S-LCA studies (even in the same sector) differ in goals; life cycle stages and processes included; stakeholder categories, subcategories and indicators considered; RS method; and PRPs. For instance, depending on the BRs, an organization may or may not reach level 2. BRs are set differently per study; thus, two organizations assessed in the same subcategory may get different scores.
- The site-specific assessment results are valid or apply only under all the assumptions made and limitations of this study: that organizations had a poor performance in, for example, "Safe and healthy living conditions", does not automatically translate into

those organizations being harmful to the local community. These results should be interpreted in light of the indicators included and the BRs. If more, less, or different indicators are considered, the organizations' social performance results may differ greatly. Furthermore, the allocated results are based on the site-specific activity variables, which were calculated based on the total costs of treating 1 m^3 of wastewater. There might be other approaches for calculating the organizations' shares, affecting the results.

- A basic understanding of MRIO and IO tables is helpful for selecting the right CSSs: understanding how the (EORA) national IO tables were constructed might assist in matching the process under study to the correct CSS. This is particularly relevant for selecting "industries" or "commodities" processes.
- It is important to be consistent in the exchange rate employed: the database documentation is not very clear on which exchange rate is used in the database. Maintaining consistency in the exchange rate is important because the number of inputs in a process (in USD) is the base for calculating the social risks upstream of the value chain. If the inputs are in different exchange rates, the social risks might be over or undercalculated.
- Whenever possible, gather social inventory data at the generic level manually: although one of the main attributes of databases is providing generic social information on many sectors at once, some data points might be outdated and represent an "average" for a sector. Thus, collecting information on each social indicator may increase the data quality and better represent the socio-economic characteristics of the sector(s) under study.

7. Conclusions

The final chapter of this work discusses how this study has answered the research question and sub-questions, how it contributes to the literature, and its validity and reliability. Lastly, recommendations for further research are suggested.

7.1. Answer to the research question and sub-questions

1. What is the academic state of the art in social life cycle assessment and how has it been applied in the water sector?

The third chapter of this work presented a thorough overview of the past and current developments in S-LCA. Regarding the goal and scope definition, one of the debatable decisions is whether using a functional unit is necessary and relevant in S-LCA and whether the results can be presented in relation to it. Additionally, as the behavior of organizations is a primary cause of social impacts in the life cycle of products, an organizational perspective in the product system definition seems the most reasonable approach. Furthermore, some scholars suggested using a double-layer product system and system boundaries to avoid excluding technical processes or potentially affected stakeholders from the system (Zanchi et al., 2018).

A total of eleven S-LCAs in the water sector were reviewed and presented in section 3.5 and Table 3. In these works, the data was commonly gathered from interviews with stakeholders and expert interviews, questionnaires, direct observations through field visits, and secondary data sources such as company and government reports and databases. Additionally, a few studies used the S-LCA databases SHDB and PSILCA (Serreli et al., 2021; Shemfe et al., 2018; Tsalidis et al., 2020). Most of the reviewed articles used the Reference Scale S-LCIA approach by using existing methods or a combination of these or applying other methods to S-LCIA (e.g., AHP). In general, the results of most studies indicate that “Workers” and “Local community” are negatively affected by WWT systems. However, it is troublesome to generalize as different studies considered different stakeholder categories, subcategories, and indicators.

Some learnings from the application of S-LCA in WWT systems are that functional units only seem to assist in the definition of product systems since the results are rarely presented in relation to them. With few exceptions, the selection of stakeholder categories, impact subcategories, and social indicators was not adequately discussed in the research articles. Furthermore, it was noted that some studies do not transparently report on what reference scales they used and how the social performance scores were arrived at. These main findings were taken into consideration in the application of the S-LCA methodology in this thesis project.

2. How does the social performance of the Water Mining case study treating municipal wastewater compare to that of the current wastewater treatment plant in La Llagosta, Barcelona, Spain and how can negative social performances be improved?

Organizations A and D had the (relative) poorest performance in the reference system since they failed to meet the BRs in seven and six subcategories, respectively. Organization F failed to meet the BRs in six subcategories in the original system. Compared to the reference system, the original system performed better in all the impact subcategories, except for “Fair salary”. The reason is that in the reference system, some organizations achieved level 1, bringing the system’s score closer to 1. Nevertheless, except for “Equal opportunities/discrimination” for the original system, both systems did not meet the BR of four subcategories “Safe and healthy living conditions”, “Local employment”, “Public commitment to sustainability issues”, and “Promoting social responsibility”. These results were produced by considering each organization as having the same weight.

When the results were calculated based on the different shares of organizations and in relation to the functional unit, the original system’s performance was better than the reference system in most subcategories. The exception was “Equal opportunities/discrimination”, where the original system’s performance was worse than the reference system’s due to Organization F’s poor performance and large share. Calculating the results based on this approach also resulted in fewer “hotspot” impact subcategories in both systems. The reference system needs to improve in the subcategories “Safe and healthy living conditions” and “Local employment”, whereas the original system needs to improve in the latter.

Finally, tailored suggestions were proposed for each organization, except for Organization B, whose performance was in line with all the BRs. Regarding the CS operator, in view of the EU’s goals to ban toxic substances and the high opportunities for circularity in the construction sector, it was recommended to implement a hierarchy of chemicals to avoid the purchase of toxic ones in the procurement process. Additionally, as the CS operator is part of both product systems, improvements in the systems’ social performances can be achieved if, in addition to environmental and economic criteria, the CS operator considers social responsibility criteria in the selection of its suppliers.

3. What are the social risks along the value chain of the Water Mining case study treating municipal wastewater and how do they compare to those from the current WWTP’s?

The social risks totaled 2.7 mrh for the reference system and 13.7 mrh for the original system. The large difference is mainly attributed to the more inputs required in the original system to treat 1 m^3 of wastewater than in the reference system. Recall that the original system is operating at a pilot scale, and the quantity of inputs may be reduced in a full-scale operation. Furthermore, the subcategories for which the social risks were the highest in both systems were the same. Those subcategories were “Access to material resources”, “Fair salary”, “Freedom of association and collective bargaining”, “Contribution to economic development”, and “Corruption”. The results indicated that most of the social risks were produced in processes upstream of the supply chain of each product system. Furthermore, processes in Spain were identified as the ones contributing the most to the social risks.

It is worth noting that one indicator from the subcategory “Contribution to economic development” measured opportunities for social benefits. The result of the reference system in this indicator was 0.02 mrh, and those for the original system equaled 0.07 mrh.

Lastly, some suggestions were presented on how the organizations within each product system could avoid these social risks. Specifically, the organizations could ensure that their operations (efficiently) use sustainably sourced biomass (if any), the minimum wages paid to their employees meet the country’s living wages, there are support and grievance mechanisms for employees to report violations to their right to unionise, and there are appropriate measures for the prevention of corruption and bribery. Ideally, organizations should promote similar measures to their value chain actors in order to reduce these social risks.

What are the potential social impacts of a Water Mining municipal wastewater treatment system in relation to the wastewater treatment plant currently operating in La Llagosta, Barcelona, Spain?

The main research question was also addressed by answering the three research sub-questions. The potential social impacts, potentially resulting from organizations' social performance and the social risks along entire value chains were measured through site-specific and generic assessments, implementing the methodology proposed by UNEP (2020). For the social performance of both product systems to improve, suggestions were proposed so that organizations can become more socially sustainable.

7.2. Research contributions to the literature

The application of S-LCA in the assessment of a current WWTP and an improved system for municipal WWT following the methodology presented in the Guidelines and the Methodological Sheets advances the development of the method and the evaluation of WWT and resource recovery systems from the social perspective of sustainability. Applying S-LCA in different case studies contributes to the maturity of a framework with great potential to evaluate products along their life cycles. Additionally, increasing understanding of the social consequences of new circular systems for wastewater treatment provides opportunities to apply needed changes earlier in the project development and potentially enhance their social profiles. This is crucial for promoting the adoption of such systems, especially in those places with water scarcity, where water resources need to be used more efficiently and water reuse needs to increase.

Some specific contributions of the methodology applied in this thesis are the use of an activity variable that, unlike worker hours, is not specific to the impact subcategories related to working conditions. Furthermore, the multifunctionality problem of a WWT process was explicitly addressed in both the site-specific and the generic analyses. It was previously acknowledged that creating waste processes in PSILCA is troublesome (Serreli et al., 2021), yet this issue was overcome in this work. Additionally, the processes representing the reference and original systems are comparable to how waste processes and multifunctional processes are created in E-LCAs. Thus, the database directly calculated the social risk results using allocation factors. When those results were compared to manually calculated approximations, the differences found were negligible, indicating that the processes were created correctly.

Regarding the site-specific analysis, the impact assessment method used was one that was previously proven operational. Because of the multiple RS methods available in the literature, employing the one that has been applied in many case studies contributes to its standardization. Moreover, the adaptations to the SAM method made in this study facilitate a detailed and complete evaluation of each impact subcategory, guarantee the use of indicators that measure both commitments and actions of organizations, and integrate all the social indicators proposed in the Methodological Sheets. Furthermore, the developed reference scales are comparable to those promoted by the Life Cycle Initiative and Social Life Cycle Alliance (2022) and PSIA (M.J. Goedkoop, de Beer, Harmens, Saling, Morris, Florea, Hettinger, Indrane, Visser, Morao, Musoke-Flores, Alvarado, Rawat, et al., 2020).

Finally, in contrast to the reviewed S-LCAs in WWT systems, this research included and reported on all four phases of the S-LCA framework and performed all the steps in the interpretation phase, including two sensitivity analyses. In addition, the construction of the reference scales and how the scoring was performed were presented transparently.

7.3. Research reliability and validity

7.3.1. Research reliability

Reliability refers to how consistently a measure is achieved. The reliability of the method applied in the site-specific assessment was ensured in different ways. First, collecting primary data using questionnaires ensured that no subjectivity from the researcher affected the information gathered. As for secondary data, these were obtained from recognized secondary sources. Second, the social indicators were very specific, reducing any point of ambiguity. Third, additional definitions of the impact subcategories were provided to respondents to avoid misinterpretation of the questions. Fourth, each measurement of an organization's social performance consisted of the same steps: collecting data from company reports and other secondary sources (such as online news articles), and questionnaires. Furthermore, the reference scales were adequately and clearly defined. Thus, should another researcher perform the same steps in the collection of data and the impact assessment (see Figure 10), the results should not vary significantly (interrater reliability).

Similarly, the generic analysis through the PSILCA database was explained in detail in section 4.4.3. Following the same steps and using the same input data will generate the same results since a database is used. Additionally, the social risk results from an unallocated process were comparable to those from an allocated process when the former was manually multiplied by the corresponding allocation factor. This indicates consistency in the measurements.

7.3.2. Research validity

Validity is ensured if the measure is accurate and the method measures what it is supposed to measure. The social inventory data used for the assessment of organizations' social performances were obtained from primary and secondary data sources. In some cases, more than one employee from a given organization participated in the study, but this could not be guaranteed for all organizations. Regarding secondary data sources, company-related documents, websites, and recognized third-party online articles were used. Obtaining data from different means thus, assisted in reducing biased responses from the participants and guaranteed data triangulation, which allows for the validation of the data collected.

An S-LCA includes different stages of a product's life cycle and (potentially) different organizations, and assesses the effects of organizations' operations on more than one stakeholder category. This means that many sources of data (i.e., participants) are needed. In this study, the selected participants were employees who could provide relatively reliable information due to their positions in the organizations. Furthermore, it was aimed to have more than one employee participate in the study. Despite the above, the number of participants was too few, which should be considered in the interpretation of results and for further studies.

Furthermore, the RS method applied is a method that has already been used in a few case studies (Ramos Huarachi et al., 2020). Although the method has been modified, it can also be applied to other case studies. However, depending on the goal of each study, it may be needed to assess other subcategories or include other indicators, which will require establishing new reference scales. As this was based on the subcategory descriptions and indicators proposed in the Methodological Sheets (UNEP, 2021), the reference scales can be constructed in the same way as proposed in this study.

7.4.Recommendations for further research

Further research regarding this thesis project could employ new social indicators. For example, Opher et al. (2018) included an indicator related to household expenses. They argued that savings in using reused treated wastewater for domestic non-potable uses were seen as a positive aspect. This is especially relevant to the original system, where treated wastewater can be used for agricultural purposes, and public acceptance of treated wastewater use may be a deterrent factor. Other indicators that could be assessed are those included in previous S-LCA studies (García-Sánchez & Güereca, 2019; Padilla-Rivera et al., 2016), which were related to exposure to noise from machinery and bad odours. Additionally, site visits and more interviews can be performed with workers and other members representative of the rest of the stakeholder categories to make the results even more accurate for each product system. An additional sensitivity check regarding the value-added activity variable can be performed by estimating the value-added of each input from the value-added (per 1 USD) of the sector it represents. These values can be obtained from the PSILCA database or IO tables.

It is also possible to include new indicators in the PSILCA database. However, this will require further research by the practitioner as it involves a complex task. Furthermore, the third version of the database includes a new impact assessment method, through which raw social indicator values can be obtained for the entire product system. The limitation of this approach is that the indicators lose their risk assessment, and there is no link between them and the product system as no activity variable is used. Thus, there is room for further research in this area.

It was also argued that solving for multifunctionality in S-LCA—especially by partitioning—is even more of an artificial solution than in E-LCA. To overcome this and for the sake of maintaining a life cycle perspective (in reference scale approaches), different solutions can be ascertained. For example, Guinée et al. (2021) noted that if no direct causation or relation can be established between functional and non-functional flows (such as social flows), different solutions should be envisaged. One such solution could be system substitution. Basically, this will imply subtracting the social performance of a similar organization that produces a similar product. It needs to be a similar organization because subtracting an unmatched performance from another organization may cause a shifting of social effects between these organizations. The challenge then lies in finding similar organizations, as this can be time-consuming.

Further research is also needed in the assessment of systems that showcase a transition toward the bioeconomy, particularly their social aspects (Ramos Huarachi et al., 2020). Circular economy concepts neglect social equity (thus, impacts on stakeholders), which is problematic, as only focusing on one or two aspects of sustainability may lead to an unsustainable implementation of circular economy and circular economy systems (Kirchherr et al., 2017). Currently, it is unknown how these systems will steer progress to social equality regarding gender, racial, and other forms of diversity, intra- and inter-generational equity, and equal access to social opportunities (Murray et al., 2015). Therefore, as the way stakeholders interact evolves in the transition to circular systems, more and new social impacts may arise, increasing the importance of social impact assessments in circular economy systems (Mesa Alvarez & Ligthart, 2021).

References

Andrade, E. P., Bonmati, A., Esteller, L. J., & Vallejo, A. A. (2022). Assessment of social aspects across Europe resulting from the insertion of technologies for nutrient recovery and recycling in agriculture. *Sustainable Production and Consumption*, *31*, 52–66. https://doi.org/10.1016/J.SPC.2022.01.025

Aquacare. (2022). *Een betere wereld met BioPhree: Fosfor verwijdering en hergebruik*. https://www.aquacare.nl/nl/biophree-innovaties-in-fosforverwijdering.html

Arcese, G., Lucchetti, M. C., & Massa, I. (2017). Modeling Social Life Cycle Assessment framework for the Italian wine sector. *Journal of Cleaner Production*, *140*, 1027–1036. https://doi.org/10.1016/J.JCLEPRO.2016.06.137

Arcese, G., Lucchetti, M. C., & Merli, R. (2013). Social Life Cycle Assessment as a Management Tool: Methodology for Application in Tourism. *Sustainability 2013, Vol. 5, Pages 3275-3287*, *5*(8), 3275–3287. https://doi.org/10.3390/SU5083275

Arufe, F., Barroso, P., & Gil, A. (2022, April 12). *Ranking de las 1.000 mayores empresas en España del sector químico y plástico*. https://economia3.com/2022/03/23/474651-ranking-de-las-1000-mayores-empresas-en-espana-del-sector-quimico-y-plastico/

Asiaín, I. (2022, April 18). *Una multa histórica y más de 20 infracciones: el peaje "verde" que pagamos a la UE por incumplir las directivas*. https://www.elespanol.com/enclave-ods/historias/20220418/multa-historica-infracciones-pagamos-ue-incumplir-directivas/664433725_0.html

Asociación Española de Abastecimientos de Agua y Saneamiento [AEAS]/Asociación Española de Empresas Gestoras de Servicios de Agua Urbana [AGA]. (2020). *DATOS SOBRE LOS SERVICIOS DEL AGUA URBANA EN ESPAÑA. Resultados del XVI Estudio Nacional de Suministro de Agua Potable y Saneamiento en España 2020.* https://www.aeas.es/images/Doc_Es_Nacional/2020/2020-12-10_Nota_Estudio_Nacional_de_Suministro_de_Agua_Potable_y_Saneamiento_en_Espaa_2020_AEAS-AGA.pdf

Avesani, M. (2020). Sustainability, sustainable development, and business sustainability. In J. Ren & S. Toniolo (Eds.), *Life Cycle Sustainability Assessment for Decision-Making: Methodologies and Case Studies* (pp. 21–38). Elsevier. https://doi.org/10.1016/B978-0-12-818355-7.00002-6

Benoît-Norris, C. (2014). Data for social LCA. *International Journal of Life Cycle Assessment*, *19*(2), 261–265. https://doi.org/10.1007/S11367-013-0644-7/TABLES/1

Bhattacherjee, A. (2012). Social Science Research: Principles, Methods, and Practices. In *Textbooks Collection* (Second). Global Text Project. https://digitalcommons.usf.edu/oa_textbooks/3

Blom, M., & Solmar, C. (2009). *How to socially assess biofuels: a case study of the UNEP/SETAC Code of Practice for social- economical LCA.* http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1019458&dswid=-2147

Cao, C. (2017). Sustainability and life assessment of high strength natural fibre composites in construction. In *Advanced High Strength Natural Fibre Composites in Construction* (pp. 529–544). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-100411-1.00021-2

Carroll, A. B. (1991). The pyramid of corporate social responsibility: Toward the moral management of organizational stakeholders. *Business Horizons*, *34*(4), 39–48.

https://doi.org/10.1016/0007-6813(91)90005-G

Chhipi-Shrestha, G. K., Hewage, K., & Sadiq, R. (2015). 'Socializing' sustainability: a critical review on current development status of social life cycle impact assessment method. *Clean Technologies and Environmental Policy*, *17*, 579–596. https://doi.org/10.1007/S10098-014-0841-5

Ciroth, A. (2012). *Aggregation in Social LCA Case Studies*. https://www.greendelta.com/wp-content/uploads/2017/03/SETAC_CPH_ac_socialaggr.pdf

Ciroth, A., & Franze, J. (2011). *LCA of an Ecolabeled Notebook Consideration of Social and Environmental Impacts Along the Entire Life Cycle*. https://www.greendelta.com/wp-content/uploads/2017/03/LCA_laptop_final.pdf

Ciroth, A., & Franze, J. (2013). *Modeling, assessment, and aggregation of social indicators along the life cycle*. https://www.greendelta.com/wp-content/uploads/2020/06/social-assessment-prosuite_task_3_4_2013.pdf

Ciroth, A., Muller, S., Weidema, B., & Lesage, P. (2016). Empirically based uncertainty factors for the pedigree matrix in ecoinvent. *International Journal of Life Cycle Assessment*, *21*, 1338–1348. https://doi.org/10.1007/S11367-013-0670-5/TABLES/6

Consorci Besòs Tordera. (2022, February 25). *Inaugurada l'ampliació de l'EDAR la Llagosta que, amb una inversió de 14 milions d'euros, millorarà la qualitat de l'aigua efluent al riu Besòs - Consorci Besòs Tordera*. https://besos-tordera.cat/2022/02/inaugurada-lampliacio-de-ledar-la-llagosta-que-amb-una-inversio-de-14-milions-deuros-millorara-la-qualitat-de-laigua-efluent-al-riu-besos/

Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment, (1991) (testimony of Council of the European Union). http://data.europa.eu/eli/dir/1991/271/oj

Court of Justice of the European Union. (2018). *PRESS RELEASE No 120/18 Judgment in Case C-205/17 Commission v Spain*. https://curia.europa.eu/jcms/upload/docs/application/pdf/2018-07/cp180120en.pdf

Crane, A., Palazzo, G., Spence, L. J., & Matten, D. (2014). Contesting the Value of "Creating Shared Value": *California Management Review*, *56*(2), 130–153. https://doi.org/10.1525/CMR.2014.56.2.130

Crenna, E., Sozzo, S., & Sala, S. (2018). Natural biotic resources in LCA: Towards an impact assessment model for sustainable supply chain management. *Journal of Cleaner Production*, *172*, 3669–3684. https://doi.org/10.1016/J.JCLEPRO.2017.07.208

Curran, M. A. (2012). Sourcing Life Cycle Inventory Data. In *Life Cycle Assessment Handbook: A Guide for Environmentally Sustainable Products* (pp. 105–141). John Wiley & Sons, Ltd. https://doi.org/10.1002/9781118528372.CH5

Daskiran, F., Gulhan, H., Guven, H., Ozgun, H., & Ersahin, M. E. (2022). Comparative evaluation of different operation scenarios for a full-scale wastewater treatment plant: Modeling coupled with life cycle assessment. *Journal of Cleaner Production*, *341*, 130864. https://doi.org/10.1016/J.JCLEPRO.2022.130864

de Santo, E. (2019). *Developing and Applying a Social Life Cycle Assessment Methodology to Assess the Social Sustainability Performance of Organizations in the Dutch Chemical Process Industry* [Delft University of Technology]. http://resolver.tudelft.nl/uuid:4a9915ef-5284-4dce-8e75-1e45f6cd3663

Di Cesare, S., Silveri, F., Sala, S., & Petti, L. (2018). Positive impacts in social life cycle assessment: state of the art and the way forward. *The International Journal of Life Cycle Assessment* , *23*, 406–421. https://doi.org/10.1007/S11367-016-1169-7

Distefano, T., & Kelly, S. (2017). Are we in deep water? Water scarcity and its limits to economic growth. *Ecological Economics*, *142*, 130–147. https://doi.org/10.1016/J.ECOLECON.2017.06.019

Do Amaral, K. G. C., Aisse, M. M., & Possetti, G. R. C. (2019). Sustainability assessment of sludge and biogas management in wastewater treatment plants using the LCA technique. *Revista Ambiente & Água*, *14*(5). https://doi.org/10.4136/AMBI-AGUA.2371

Drexhage, J., & Murphy, D. (2010). *Sustainable Development: From Brundtland to Rio 2012*. https://www.e-education.psu.edu/emsc302/sites/www.e-education.psu.edu.emsc302/files/Sustainable Development_from Brundtland to Rio 2012 %281%29.pdf

Dreyer, L. C., Hauschild, M. Z., & Schierbeck, J. (2006). A Framework for Social Life Cycle Impact Assessment (10 pp). *The International Journal of Life Cycle Assessment 2006 11:2*, *11*(2), 88–97. https://doi.org/10.1065/LCA2005.08.223

Duchin, F., & Levine, S. H. (2008). Industrial Ecology. *Encyclopedia of Ecology*, 1968–1975. https://doi.org/10.1016/B978-008045405-4.00627-3

Dyllick, T., & Hockerts, K. (2002). Beyond the business case for corporate sustainability. *Business Strategy and the Environment*, *11*(2), 130–141. https://doi.org/10.1002/BSE.323

Dyllick, T., & Muff, K. (2015). Clarifying the Meaning of Sustainable Business: Introducing a Typology From Business-as-Usual to True Business Sustainability. *Organization & Environment*, *29*(2), 156–174. https://doi.org/10.1177/1086026615575176

ecoinvent. (2016). *ecoinvent 3.8 Dataset Documentation "market for biogas - CH."* https://v38.ecoquery.ecoinvent.org/Details/UPR/71690078-d93a-4060-9847-e1a637f1d098/8b738ea0-f89e-4627-8679-433616064e82

Ekener-Petersen, E., & Finnveden, G. (2013). Potential hotspots identified by social LCA—part 1: a case study of a laptop computer. *The International Journal of Life Cycle Assessment*, *18*, 127–143. https://doi.org/10.1007/S11367-012-0442-7

Ekener-Petersen, E., Höglund, J., & Finnveden, G. (2014). Screening potential social impacts of fossil fuels and biofuels for vehicles. *Energy Policy*, *73*, 416–426. https://doi.org/10.1016/J.ENPOL.2014.05.034

Ekener, E., Hansson, J., & Gustavsson, M. (2018). Addressing positive impacts in social LCA—discussing current and new approaches exemplified by the case of vehicle fuels. *International Journal of Life Cycle Assessment*, *23*, 556–568. https://doi.org/10.1007/S11367-016-1058-0/TABLES/4

Ekener, E., Hansson, J., Larsson, A., & Peck, P. (2018). Developing Life Cycle Sustainability Assessment methodology by applying values-based sustainability weighting - Tested on biomass based and fossil transportation fuels. *Journal of CleanEkener, E., Hansson, J., Larsson, A., & Peck, P. (2018). Developing Life Cycle Sustainability Assessment Methodology by Applying Values-Based Sustainability Weighting - Tested on Biomass Based and Fossil Transportation Fuels. Journal of Cl*, *181*, 337–351. https://doi.org/10.1016/j.jclepro.2018.01.211

El Economista. (2022). *Ranking Nacional de Empresas por Facturación*. https://ranking-empresas.eleconomista.es/ranking_empresas_nacional.html

Elkington, J. (1999). *Cannibals with forks : the triple bottom line of 21st century business*. New Society.

European Commission. (2017). *The European Pillar of Social Rights in 20 principles* . https://ec.europa.eu/info/strategy/priorities-2019-2024/economy-works-people/jobs-growth-and-investment/european-pillar-social-rights/european-pillar-social-rights-20-principles_en

European Commission. (2020). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Chemicals Strategy for Sustainability Towards a Toxic-Free Environment*. https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf

European Commission. (2021a). *Corporate sustainability reporting* . https://ec.europa.eu/info/business-economy-euro/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en

European Commission. (2021b, April 2). *Questions and Answers: Corporate Sustainability Reporting Directive proposal*. https://ec.europa.eu/commission/presscorner/detail/en/QANDA_21_1806

European Commission. (2022a). *COMMISSION STAFF WORKING DOCUMENT Restrictions Roadmap under the Chemicals Strategy for Sustainability*. https://ec.europa.eu/docsroom/documents/49734

European Commission. (2022b, April 6). *Urban Waste Water: Commission decides to refer SPAIN to the Court of Justice of the European Union over its failure to comply with the Urban Waste Water Directive*. https://ec.europa.eu/commission/presscorner/detail/en/IP_22_1923

European Parliament. (2022, March 15). *Companies to be more accountable for their social and environmental impact* . https://www.europarl.europa.eu/news/en/press-room/20220314IPR25409/companies-to-be-more-accountable-for-their-social-and-environmental-impact

Fan, Y., Wu, R., Chen, J., & Apul, D. (2015). A Review of Social Life Cycle Assessment Methodologies. In *Environmental Footprints and Eco-Design of Products and Processes* (pp. 1–23). Springer. https://doi.org/10.1007/978-981-287-296-8_1/COVER/

Faragò, M., Damgaard, A., Madsen, J. A., Andersen, J. K., Thornberg, D., Andersen, M. H., & Rygaard, M. (2021). From wastewater treatment to water resource recovery: Environmental and economic impacts of full-scale implementation. *Water Research*, *204*, 117554. https://doi.org/10.1016/J.WATRES.2021.117554

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., Koehler, A., Pennington, D., & Suh, S. (2009). Recent developments in Life Cycle Assessment. *Journal of Environmental Management*, *91*(1), 1–21. https://doi.org/10.1016/J.JENVMAN.2009.06.018

Flörke, M., Schneider, C., & McDonald, R. I. (2018). Water competition between cities and agriculture driven by climate change and urban growth. *Nature Sustainability 2017 1:1*, *1*(1), 51–58. https://doi.org/10.1038/s41893-017-0006-8

Foglia, A., Bruni, C., Cipolletta, G., Eusebi, A. L., Frison, N., Katsou, E., Akyol, Ç., & Fatone,

F. (2021). Assessing socio-economic value of innovative materials recovery solutions validated in existing wastewater treatment plants. *Journal of Cleaner Production*, *322*, 129048. https://doi.org/10.1016/J.JCLEPRO.2021.129048

Franze, J., & Ciroth, A. (2011). A comparison of cut roses from Ecuador and the Netherlands. *The International Journal of Life Cycle Assessment*, *16*, 366–379. https://doi.org/10.1007/S11367-011-0266-X

Frederick, H. H. (2018). The emergence of biosphere entrepreneurship: Are social and business entrepreneurship obsolete? *International Journal of Entrepreneurship and Small Business*, *34*(3), 381–419. https://doi.org/10.1504/IJESB.2018.092785

Frooman, J. (1999). Stakeholder Influence Strategies. *The Academy of Management Review*, *24*(2), 205. https://doi.org/10.2307/259074

Furness, M., Bello-Mendoza, R., Dassonvalle, J., & Chamy-Maggi, R. (2021). Building the 'Bio-factory': A bibliometric analysis of circular economies and Life Cycle Sustainability Assessment in wastewater treatment. *Journal of Cleaner Production*, *323*, 129127. https://doi.org/10.1016/J.JCLEPRO.2021.129127

Gallego-Valero, L., Moral-Parajes, E., & Román-Sánchez, I. M. (2021). Wastewater Treatment Costs: A Research Overview through Bibliometric Analysis. *Sustainability 2021, Vol. 13, Page 5066*, *13*(9), 5066. https://doi.org/10.3390/SU13095066

García-Sánchez, M., & Güereca, L. P. (2019). Environmental and social life cycle assessment of urban water systems: The case of Mexico City. *Science of The Total Environment*, *693*, 133464. https://doi.org/10.1016/J.SCITOTENV.2019.07.270

Garcia, X., & Pargament, D. (2015). Reusing wastewater to cope with water scarcity: Economic, social and environmental considerations for decision-making. *Resources, Conservation and Recycling*, *101*, 154–166. https://doi.org/10.1016/J.RESCONREC.2015.05.015

Garner, A., & Keoleian, G. A. (1995). *Industrial Ecology: An Introduction*.

Gaulier, G., & Zignago, S. (2010). *BACI: International Trade Database at the Product-Level. The 1994-2007 Version*. http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=37

Giovannoni, E., & Fabietti, G. (2013). What is sustainability? A review of the concept and its applications. In C. Busco, M. L. Frigo, A. Riccaboni, & P. Quattrone (Eds.), *Integrated Reporting: Concepts and Cases that Redefine Corporate Accountability* (pp. 21–40). Springer International Publishing. https://doi.org/10.1007/978-3-319-02168-3_2/COVER/

Goedkoop, M. J., de Beer, I. ., Harmens, R., Saling, P., Morris, D., Florea, A., Hettinger, A. L., Indrane, D., Visser, D., Morao, A., Musoke-Flores, E., Alvarado, C., Rawat, I., Schenker, U., Head, M., Collotta, M., Andro, T., Viot, J.-F., & Whatelet, A. (2020). *Methodology Report Product Social Impact Assessment - 2020*. https://www.social-value-initiative.org/wp-content/uploads/2021/04/20-02-Methodology-Report.pdf

Goedkoop, M.J., de Beer, I. ., Harmens, R., Saling, P., Morris, D., Florea, A., Hettinger, A. L., Indrane, D., Visser, D., Morao, A., Musoke-Flores, E., Alvarado, C., Rawat, I., Schenker, U., Head, M., Collotta, M., Andro, T., Viot, J.-F., & Whatelet, A. (2020). *Handbook for Product Social Impact Assessment*. https://www.social-value-initiative.org/wp-content/uploads/2021/04/20-01-Handbook2020.pdf

Goedkoop, M.J., de Beer, I. ., Harmens, R., Saling, P., Morris, D., Florea, A., Hettinger, A. L., Indrane, D., Visser, D., Morao, A., Musoke-Flores, E., Alvarado, C., Schenker, U., Andro, T., Viot, J.-F., & Whatelet, A. (2020). *Product Social Impact Assessment- Social Topics Report - 2020*.

Goedkoop, Mark J., Indrane, D., & de Beer, I. . (2018). *Handbook for Product Social Impact Assessment 2018*.

Gosling, S. N., & Arnell, N. W. (2016). A global assessment of the impact of climate change on water scarcity. *Climatic Change*, *134*(3), 371–385. https://doi.org/10.1007/S10584-013-0853-X/FIGURES/4

Greenland, S., Saleem, M., Misra, R., & Mason, J. (2022). Sustainable management education and an empirical five-pillar model of sustainability. *The International Journal of Management Education*, *20*(3), 100658. https://doi.org/10.1016/J.IJME.2022.100658

Grießhammer, R., Benoît, C., Dreyer, L. C., Flysjö, A., Mazijn, B., Méthot, A.-L., & Weidema, B. (2006). *Feasibility Study: Integration of social aspects into LCA*. https://lca-net.com/publications/show/feasibility-study-integration-social-aspects-lca/

Gude, V. G. (2017). Desalination and water reuse to address global water scarcity. *Reviews in Environmental Science and Bio/Technology 2017 16:4*, *16*(4), 591–609. https://doi.org/10.1007/S11157-017-9449-7

Guinée, J. B., Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., Koning, A. de, Oers, L. van, Wegener Sleeswijk, A., Suh, S., Udo de Haes, H. A., Bruijn, H. de, Duin, R. van, & Huijbregts, M. A. J. (2002). *Handbook on life cycle assessment. Operational guide to the ISO standards* (H. de Bruijn, R. van Duin, M. A. J. Huijbregts, J. B. Guinee, M. Gorree, R. Heijungs, G. Huppes, R. Kleijn, A. de Koning, L. van Oers, A. Wegener Sleeswijk, S. Suh, & H. A. Udo de Haes (eds.)). Springer Netherlands. https://doi.org/10.1007/0-306-48055-7

Guinée, J. B., Heijungs, R., & Frischknecht, R. (2021). Multifunctionality in Life Cycle Inventory Analysis: Approaches and Solutions. In *Life cycle inventory analysis: methods and data* (pp. 73–95). Springer, Cham. https://doi.org/10.1007/978-3-030-62270-1_4

Guinée, J. B., Heijungs, R., & Huppes, G. (2004). Economic allocation: Examples and derived decision tree. *The International Journal of Life Cycle Assessment 2004 9:1*, *9*(1), 23–33. https://doi.org/10.1007/BF02978533

Hannouf, M., & Assefa, G. (2018). Subcategory assessment method for social life cycle assessment: a case study of high-density polyethylene production in Alberta, Canada. *International Journal of Life Cycle Assessment*, *23*, 116–132. https://doi.org/10.1007/S11367-017-1303-1/TABLES/6

Hao, X., Wang, X., Liu, R., Li, S., van Loosdrecht, M. C. M., & Jiang, H. (2019). Environmental impacts of resource recovery from wastewater treatment plants. *Water Research*, *160*, 268–277. https://doi.org/10.1016/J.WATRES.2019.05.068

Harmens, R., Goedkoop, M. J., Alvarenga, R. A. F., Boone, L., Cadena Martinez, E., Zanchi, L., Zamagni, A., Sonderegger, T., Moreno Ruiz, E., Saling, P., & Cordella, M. (2022). *ORIENTING D1.2 Critical evaluation of social approaches*. https://orienting.eu/wp-content/uploads/2022/01/D1.2-Social-approaches_final-revision.pdf

Hayter, S., & Stoevska, V. (2011). *Social Dialogue Indicators International Statistical Inquiry 2008-09*. http://laborsta.ilo.org/applv8/data/TUM/TUD and CBC Technical Brief.pdf

He, C., Liu, Z., Wu, J., Pan, X., Fang, Z., Li, J., & Bryan, B. A. (2021). Future global urban water scarcity and potential solutions. *Nature Communications*, *12*, 1–11. https://doi.org/10.1038/s41467-021-25026-3

Hristov, J., Barreiro-Hurle, J., Salputra, G., Blanco, M., & Witzke, P. (2021). Reuse of treated water in European agriculture: Potential to address water scarcity under climate change. *Agricultural Water Management*, *251*, 106872. https://doi.org/10.1016/J.AGWAT.2021.106872

Huertas-Valdivia, I., Ferrari, A. M., Settembre-Blundo, D., & García-Muiña, F. E. (2020). Social Life-Cycle Assessment: A Review by Bibliometric Analysis. *Sustainability*, *12*(15), 6211. https://doi.org/10.3390/SU12156211

Hunkeler, D. (2006). Societal LCA Methodology and Case Study (12 pp). *The International Journal of Life Cycle Assessment 2006 11:6*, *11*, 371–382. https://doi.org/10.1065/LCA2006.08.261

Inflation Tool. (2022). *Inflation Calculator*. https://www.inflationtool.com/euro/2015-to-present-value?amount=1&year2=2022&frequency=yearly

Inglett, P. W., Reddy, K. R., & Corstanje, R. (2005). ANAEROBIC SOILS. In *Encyclopedia of Soils in the Environment* (pp. 72–78). Elsevier. https://doi.org/10.1016/B0-12-348530-4/00178-8

Instituto Nacional de Estadística [INE]. (2021). *Ocupados por ramas de actividad, por tipo de ocupación, por situación profesional y por tipo de puesto laboral*. https://www.ine.es/ss/Satellite?L=es_ES&c=INESeccion_C&cid=1259931459725&p=%5C&pagename=ProductosYServicios%2FPYSLayout&param1=PYSDetalle&param3=1259924822888

International Finance Corporation [IFC]. (2012). *IFC Performance Standards on Environmental and Social Sustainability*. https://documents1.worldbank.org/curated/en/586771490864739740/pdf/113849-WP-ENGLISH-IFC-Performance-Standards-PUBLIC.pdf

International Labour Organization [ILO]. (2015). *Compendium of International Labour Conventions and Recommendations*. https://www.ilo.org/wcmsp5/groups/public/---ed_norm/---normes/documents/publication/wcms_413175.pdf

International Labour Organization [ILO]. (2017). *8.Freedom of Association and Collective Bargaining* . https://www.ilo.org/global/topics/dw4sd/themes/freedom-of-association/lang--en/index.htm

International Labour Organization [ILO]. (2022). *ILO Declaration on Fundamental Principles and Rights at Work*. https://www.ilo.org/wcmsp5/groups/public/---ed_norm/---declaration/documents/normativeinstrument/wcms_716594.pdf

International Organization for Standardization [ISO]. (2006a). *ISO 14040 Environmental management-Life cycle assessment-Principles and framework*.

International Organization for Standardization [ISO]. (2006b). *ISO 14044 Environmental management—Life cycle assessment—Requirements and guidelines*. https://wapsustainability.com/wp-content/uploads/2020/11/ISO-14044.pdf

International Organization for Standardization [ISO]. (2010). *ISO 26000 Guidance on social responsibility*.

Irimie, S.-I., Gal, J., & Dumitrescu, C. D. (2014). Analysis of a Dynamic Regional System for the Operationalizing of the Sustainable Development Concept. *Procedia - Social and Behavioral Sciences*, *124*, 331–338. https://doi.org/10.1016/J.SBSPRO.2014.02.493

Jørgensen, A., Dreyer, L. C., & Wangel, A. (2012). Addressing the effect of social life cycle assessments. *The International Journal of Life Cycle Assessment 2012 17:6*, *17*(6), 828–839. https://doi.org/10.1007/S11367-012-0408-9

Jørgensen, A., Lai, L. C. H., & Hauschild, M. Z. (2010). Assessing the validity of impact pathways for child labour and well-being in social life cycle assessment. *International Journal of Life Cycle Assessment*, *15*, 5–16. https://doi.org/10.1007/S11367-009-0131-3/FIGURES/1

Karimidastenaei, Z., Avellán, T., Sadegh, M., Kløve, B., & Haghighi, A. T. (2022). Unconventional water resources: Global opportunities and challenges. *Science of The Total Environment*, *827*, 154429. https://doi.org/10.1016/J.SCITOTENV.2022.154429

Kehrein, P., Loosdrecht, M. van, Osseweijer, P., Garfí, M., Dewulf, J., & Posada, J. (2020). A critical review of resource recovery from municipal wastewater treatment plants – market supply potentials, technologies and bottlenecks. *Environmental Science: Water Research & Technology*, *6*(4), 877–910. https://doi.org/10.1039/C9EW00905A

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/J.RESCONREC.2017.09.005

Kolk, A. (2016). The social responsibility of international business: From ethics and the environment to CSR and sustainable development. *Journal of World Business*, *51*(1), 23–34. https://doi.org/10.1016/J.JWB.2015.08.010

KPMG. (2021). *Corporate Sustainability Reporting Directive*. https://home.kpmg/nl/en/home/topics/environmental-social-governance/corporate-sustainability-reporting-directive.html

Kruse, S. A., Flysjö, A., Kasperczyk, N., & Scholz, A. J. (2008). Socioeconomic indicators as a complement to life cycle assessment—an application to salmon production systems. *The International Journal of Life Cycle Assessment*, *14*, 8–18. https://doi.org/10.1007/S11367-008-0040-X

Kühnen, M., & Hahn, R. (2017). Indicators in Social Life Cycle Assessment: A Review of Frameworks, Theories, and Empirical Experience. *Journal of Industrial Ecology*, *21*(6), 1547–1565. https://doi.org/10.1111/JIEC.12663

Kumar, R. (2011). *RESEARCH METHODOLOGY: a step-by-step guide for beginners* (Third Ed.). SAGE Publications Ltd. www.sagepublications.com

Kummu, M., Guillaume, J. H. A., De Moel, H., Eisner, S., Flörke, M., Porkka, M., Siebert, S., Veldkamp, T. I. E., & Ward, P. J. (2016). The world's road to water scarcity: shortage and stress in the 20th century and pathways towards sustainability. *Scientific Reports 2016 6:1*, *6*(1), 1–16. https://doi.org/10.1038/srep38495

Labuschagne, C., Brent, A. C., & Van Erck, R. P. G. (2005). Assessing the sustainability performances of industries. *Journal of Cleaner Production*, *13*(4), 373–385. https://doi.org/10.1016/J.JCLEPRO.2003.10.007

Lackner, S., Gilbert, E. M., Vlaeminck, S. E., Joss, A., Horn, H., & van Loosdrecht, M. C. M. (2014). Full-scale partial nitritation/anammox experiences – An application survey. *Water Research*, *55*, 292–303. https://doi.org/10.1016/J.WATRES.2014.02.032

Lehmann, A., Zschieschang, E., Traverso, M., Finkbeiner, M., & Schebek, L. (2013). Social aspects for sustainability assessment of technologies—challenges for social life cycle assessment (SLCA). *The International Journal of Life Cycle Assessment 2013 18:8*, *18*, 1581–1592. https://doi.org/10.1007/S11367-013-0594-0

Life Cycle Initiative. (n.d.). *What is Life Cycle Thinking?* Retrieved July 20, 2022, from https://www.lifecycleinitiative.org/starting-life-cycle-thinking/what-is-life-cycle-thinking/

Life Cycle Initiative, & Social Life Cycle Alliance. (2022). *Pilot projects on Guidelines for Social Life Cycle Assessment of Products and Organizations 2022*. https://www.lifecycleinitiative.org/wp-content/uploads/2022/05/Pilot-projects-on-UNEP-SLCA-Guidelines-12.5.pdf

Liu, J., Yang, H., Gosling, S. N., Kummu, M., Flörke, M., Pfister, S., Hanasaki, N., Wada, Y., Zhang, X., Zheng, C., Alcamo, J., & Oki, T. (2017). Water scarcity assessments in the past, present, and future. *Earth's Future*, *5*(6), 545–559. https://doi.org/10.1002/2016EF000518

Lorenzo-Toja, Y., Vázquez-Rowe, I., Amores, M. J., Termes-Rifé, M., Marín-Navarro, D., Moreira, M. T., & Feijoo, G. (2016). Benchmarking wastewater treatment plants under an eco-efficiency perspective. *Science of The Total Environment*, *566–567*, 468–479. https://doi.org/10.1016/J.SCITOTENV.2016.05.110

Ma, B., Wang, S., Cao, S., Miao, Y., Jia, F., Du, R., & Peng, Y. (2016). Biological nitrogen removal from sewage via anammox: Recent advances. *Bioresource Technology*, *200*, 981–990. https://doi.org/10.1016/J.BIORTECH.2015.10.074

Maister, K., Di Noi, C., Ciroth, A., & Srocka, M. (2020). *PSILCA v.3 Database documentation*. https://www.openlca.org/wp-content/uploads/2020/06/PSILCA_V3_manual.pdf

Malandrakis, G., Gkitsas, S., & Bara, E. Z. (2019). The role of digital stories and civic actions on student-teachers' understanding about social sustainability in urban settings. *Https://Doi.Org/10.1080/13504622.2019.1669141*, *25*(10), 1524–1551. https://doi.org/10.1080/13504622.2019.1669141

Marcal, J., Bishop, T., Hofman, J., & Shen, J. (2021). From pollutant removal to resource recovery: A bibliometric analysis of municipal wastewater research in Europe. *Chemosphere*, *284*, 131267. https://doi.org/10.1016/J.CHEMOSPHERE.2021.131267

Martínez-Blanco, J., Lehmann, A., Muñoz, P., Antón, A., Traverso, M., Rieradevall, J., & Finkbeiner, M. (2014). Application challenges for the social Life Cycle Assessment of fertilizers within life cycle sustainability assessment. *Journal of Cleaner Production*, *69*, 34–48. https://doi.org/10.1016/J.JCLEPRO.2014.01.044

Mathe, S. (2014). Integrating participatory approaches into social life cycle assessment: the SLCA participatory approach. *The International Journal of Life Cycle Assessment*, *19*, 1506–1514. https://doi.org/10.1007/S11367-014-0758-6

Mazzi, A. (2020). Introduction. Life cycle thinking. In J. Ren & S. Toniolo (Eds.), *Life Cycle Sustainability Assessment for Decision-Making: Methodologies and Case Studies* (pp. 1–19). Elsevier. https://doi.org/10.1016/B978-0-12-818355-7.00001-4

McCombes, S. (2019). *Sampling Methods | Types, Techniques & Examples*. https://www.scribbr.com/methodology/sampling-methods/

McDonough, W., & Braungart, M. (2002). Design for the Triple Top Line: New Tools for

Sustainable Commerce. *Corporate Environmental Strategy*, *9*(3), 251–258. https://doi.org/10.1016/S1066-7938(02)00069-6

Mesa Alvarez, C., & Ligthart, T. (2021). A social panorama within the life cycle thinking and the circular economy: a literature review. *The International Journal of Life Cycle Assessment 2021 26:11*, *26*(11), 2278–2291. https://doi.org/10.1007/S11367-021-01979-X

Meseguer-Sánchez, V., Gálvez-Sánchez, F. J., López-Martínez, G., & Molina-Moreno, V. (2021). Corporate Social Responsibility and Sustainability. A Bibliometric Analysis of Their Interrelations. *Sustainability 2021, Vol. 13, Page 1636*, *13*(4), 1636. https://doi.org/10.3390/SU13041636

Milne, M. J., & Gray, R. (2013). W(h)ither Ecology? The Triple Bottom Line, the Global Reporting Initiative, and Corporate Sustainability Reporting. *Journal of Business Ethics*, *118*(1), 13–29. https://doi.org/10.1007/S10551-012-1543-8

Ministerio de Trabajo y Economía Social [MITES]. (2021a). *Convenio Colectivo*. https://www.mites.gob.es/es/guia/texto/guia_12/contenidos/guia_12_24_3.htm

Ministerio de Trabajo y Economía Social [MITES]. (2021b). *Estadística de Accidentes de Trabajo del año 2020*. https://www.mites.gob.es/es/estadisticas/monograficas_anuales/EAT/2020/index.htm

Ministerio de Trabajo y Economía Social [MITES]. (2021c). *La sindicación de los trabajadores*. https://www.mites.gob.es/es/guia/texto/guia_11/contenidos/guia_11_23_1.htm

Ministerio para la Transición Ecológica y el Reto Demográfico [MITECO]. (n.d.). *ESPAÑA CIRCULAR 2030 Estrategia Española de Economía Circular*. Retrieved July 21, 2022, from https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/economia-circular/espanacircular2030_def1_tcm30-509532_mod_tcm30-509532.pdf

Muhammad Anwar, S. N. B., Alvarado, V., & Hsu, S. C. (2021). A socio-eco-efficiency analysis of water and wastewater treatment processes for refugee communities in Jordan. *Resources, Conservation and Recycling*, *164*, 105196. https://doi.org/10.1016/J.RESCONREC.2020.105196

Müller, A. B., Avellán, T., & Schanze, J. (2020). Risk and sustainability assessment framework for decision support in “water scarcity – water reuse” situations. *Journal of Hydrology*, *591*, 125424. https://doi.org/10.1016/J.JHYDROL.2020.125424

Murray, A., Skene, K., & Haynes, K. (2015). The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. *Journal of Business Ethics* , *140*(3), 369–380. https://doi.org/10.1007/S10551-015-2693-2

Neslen, A. (2022, April 25). *EU unveils plan for ‘largest ever ban’ on dangerous chemicals*. *9*(23). https://doi.org/10.1021/ACSSUSCHEMENG.0C09435

Norris, C. B. (2012). Social Life Cycle Assessment: A Technique Providing a New Wealth of Information to Inform Sustainability-Related Decision Making. In M. A. Curran (Ed.), *Life Cycle Assessment Handbook: A Guide for Environmentally Sustainable Products* (pp. 433–451). John Wiley & Sons, Ltd. https://doi.org/10.1002/9781118528372.CH20

O’Brien, M., Doig, A., & Clift, R. (1996). Social and environmental life cycle assessment (SELCA). *The International Journal of Life Cycle Assessment 1996 1:4*, *1*, 231–237. https://doi.org/10.1007/BF02978703

Omer, A., Elagib, N. A., Zhuguo, M., Saleem, F., & Mohammed, A. (2020). Water scarcity in the Yellow River Basin under future climate change and human activities. *Science of The Total Environment*, *749*, 141446. https://doi.org/10.1016/J.SCITOTENV.2020.141446

Opher, T., Shapira, A., & Friedler, E. (2018). A comparative social life cycle assessment of urban domestic water reuse alternatives. *The International Journal of Life Cycle Assessment 2017 23:6*, *23*(6), 1315–1330. https://doi.org/10.1007/S11367-017-1356-1

Organisation for Economic Cooperation and Development [OECD]. (2011). *OECD Guidelines for Multinational Enterprises*. https://www.oecd.org/daf/inv/mne/48004323.pdf

Padilla-Rivera, A., & Güereca, L. P. (2019). A proposal metric for sustainability evaluations of wastewater treatment systems (SEWATS). *Ecological Indicators*, *103*, 22–33. https://doi.org/10.1016/J.ECOLIND.2019.03.049

Padilla-Rivera, A., Morgan-Sagastume, J. M., Noyola, A., & Güereca, L. P. (2016). Addressing social aspects associated with wastewater treatment facilities. *Environmental Impact Assessment Review*, *57*, 101–113. https://doi.org/10.1016/J.EIAR.2015.11.007

Parent, J., Cucuzzella, C., & Revéret, J. P. (2010). Impact assessment in SLCA: sorting the sLCIA methods according to their outcomes. *The International Journal of Life Cycle Assessment 2010 15:2*, *15*, 164–171. https://doi.org/10.1007/S11367-009-0146-9

Pedersen, C. S. (2018). The UN Sustainable Development Goals (SDGs) are a Great Gift to Business! *Procedia CIRP*, *69*, 21–24. https://doi.org/10.1016/J.PROCIR.2018.01.003

Pesqueira, J. F. J. R., Pereira, M. F. R., & Silva, A. M. T. (2020). Environmental impact assessment of advanced urban wastewater treatment technologies for the removal of priority substances and contaminants of emerging concern: A review. *Journal of Cleaner Production*, *261*, 121078. https://doi.org/10.1016/J.JCLEPRO.2020.121078

Petti, L., Maria Lie Ugaya, C., & Di Cesare, S. (2014). Systematic review of Social-Life Cycle Assessment (S-LCA) case studies. *Proceedings of the 4th International Seminar in Social LCA, Pre-procee*, 34–41.

Petti, L., Serreli, M., & Di Cesare, S. (2018). Systematic literature review in social life cycle assessment. *The International Journal of Life Cycle Assessment 2016 23:3*, *23*(3), 422–431. https://doi.org/10.1007/S11367-016-1135-4

Pipino, L. L., Lee, Y. W., & Wang, R. Y. (2002). Data quality assessment. *Communications of the ACM*, *45*(4), 211–218. https://doi.org/10.1145/505248.506010

Planelles, M. (2022, February 4). *El Gobierno admite que seguirá pagando la multa por los vertidos de aguas fecales hasta al menos 2025 | Clima y Medio Ambiente* . https://elpais.com/clima-y-medio-ambiente/2022-02-04/el-gobierno-admite-que-seguira-pagando-la-multa-por-los-vertidos-de-aguas-fecales-hasta-al-menos-2025.html

Pollok, L., Spierling, S., Endres, H. J., & Grote, U. (2021). Social Life Cycle Assessments: A Review on Past Development, Advances and Methodological Challenges. *Sustainability 2021, Vol. 13, Page 10286*, *13*(18), 10286. https://doi.org/10.3390/SU131810286

Porter, M. E., & Kramer, M. R. (2011). Creating Shared Value How to reinvent capitalism-and unleash a wave of innovation and growth. In *Harvard Business Review*. https://moodle.luniversitenumerique.fr/pluginfile.php/6274/mod_folder/content/0/8. La valeur partagée - Micheal Porter.pdf

Preethi, Kavitha, S., Banu, J. R., Arulazhagan, P., & Gunasekaran, M. (2020). Environmental impacts and sustainability assessment of food loss and waste valorization: value chain analysis of food consumption. In *Food Waste to Valuable Resources: Applications and Management* (pp. 359–388). Academic Press. https://doi.org/10.1016/B978-0-12-818353-3.00017-1

PricewaterhouseCoopers [PwC]. (2018). *La gestión del agua en España. Análisis y retos del ciclo urbano del agua*. https://www.pwc.es/es/publicaciones/energia/assets/gestion-agua-2018-espana.pdf

Publications Office of the European Union. (2021). *Equal opportunities*. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=LEGISSUM:equal_opportunities

Rafiaani, P., Kuppens, T., Dael, M. Van, Azadi, H., Lebailly, P., & Passel, S. Van. (2018). Social sustainability assessments in the biobased economy: Towards a systemic approach. *Renewable and Sustainable Energy Reviews*, *82*, 1839–1853. https://doi.org/10.1016/J.RSER.2017.06.118

Ramirez, P. K. S., Petti, L., Haberland, N. T., & Ugaya, C. M. L. (2014). Subcategory assessment method for social life cycle assessment. Part 1: Methodological framework. *International Journal of Life Cycle Assessment*, *19*, 1515–1523. https://doi.org/10.1007/S11367-014-0761-Y/FIGURES/3

Ramos Huarachi, D. A., Piekarski, C. M., Puglieri, F. N., & de Francisco, A. C. (2020). Past and future of Social Life Cycle Assessment: Historical evolution and research trends. *Journal of Cleaner Production*, *264*, 121506. https://doi.org/10.1016/J.JCLEPRO.2020.121506

Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Schmidt, W. P., Suh, S., Weidema, B. P., & Pennington, D. W. (2004). Life cycle assessment: Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environment International*, *30*(5), 701–720. https://doi.org/10.1016/J.ENVINT.2003.11.005

Ricart, S., Villar-Navascués, R. A., Hernández-Hernández, M., Rico-Amorós, A. M., Olcina-Cantos, J., & Moltó-Mantero, E. (2021). Extending Natural Limits to Address Water Scarcity? The Role of Non-Conventional Water Fluxes in Climate Change Adaptation Capacity: A Review. *Sustainability 2021, Vol. 13, Page 2473*, *13*(5), 2473. https://doi.org/10.3390/SU13052473

Richter, B. D., Abell, D., Bacha, E., Brauman, K., Calos, S., Cohn, A., Disla, C., O'Brien, S. F., Hodges, D., Kaiser, S., Loughran, M., Mestre, C., Reardon, M., & Siegfried, E. (2013). Tapped out: how can cities secure their water future? *Water Policy*, *15*(3), 335–363. https://doi.org/10.2166/WP.2013.105

Ruscalleda Beylier, M., Balaguer, M. D., Colprim, J., Pellicer-Nàcher, C., Ni, B. J., Smets, B. F., Sun, S. P., & Wang, R. C. (2011). Biological Nitrogen Removal From Domestic Wastewater. In *Comprehensive Biotechnology* (Third, Vol. 6, pp. 285–296). Pergamon. https://doi.org/10.1016/B978-0-444-64046-8.00360-8

Russo Garrido, S., Parent, J., Beaulieu, L., & Revéret, J. P. (2018). A literature review of type I SLCA—making the logic underlying methodological choices explicit. *International Journal of Life Cycle Assessment*, *23*, 432–444. https://doi.org/10.1007/S11367-016-1067-Z/FIGURES/4

Salinas-Rodríguez, S. G., Schippers, J. C., Amy, G. L., Kim, I. S., & Kennedy, M. D. (2021). Seawater Reverse Osmosis Desalination: Assessment and Pre-treatment of Fouling and Scaling. In *Seawater Reverse Osmosis Desalination: Assessment and Pre-treatment of Fouling and Scaling*. IWA Publishing. https://doi.org/10.2166/9781780409863

Schönherr, N., Findler, F., & Martinuzzi, A. (2017). Exploring the interface of CSR and the Sustainable Development Goals. *Transnational Corporations*, *24*(3), 33–47. https://doi.org/10.18356/CFB5B8B6-EN

Serreli, M., Petti, L., Raggi, A., Simboli, A., & Iuliano, G. (2021). Social life cycle assessment of an innovative industrial wastewater treatment plant. *International Journal of Life Cycle Assessment*, *26*(9), 1878–1899. https://doi.org/10.1007/S11367-021-01942-W/FIGURES/13

Shanmugam, K., Gadhamshetty, V., Tysklind, M., Bhattacharyya, D., & Upadhyayula, V. K. K. (2022). A sustainable performance assessment framework for circular management of municipal wastewater treatment plants. *Journal of Cleaner Production*, *339*, 130657. https://doi.org/10.1016/J.JCLEPRO.2022.130657

Shemfe, M. B., Gadkari, S., & Sadhukhan, J. (2018). Social Hotspot Analysis and Trade Policy Implications of the Use of Bioelectrochemical Systems for Resource Recovery from Wastewater. *Sustainability 2018, Vol. 10, Page 3193*, *10*(9), 3193. https://doi.org/10.3390/SU10093193

Silva, V. L., & Sanjuán, N. (2019). Opening up the black box: A systematic literature review of life cycle assessment in alternative food processing technologies. *Journal of Food Engineering*, *250*, 33–45. https://doi.org/10.1016/J.JFOODENG.2019.01.010

Simoes, A. J. G., & Hidalgo, C. A. (2011). The Economic Complexity Observatory: An Analytical Tool for Understanding the Dynamics of Economic Development. *Workshops at the Twenty-Fifth AAAI Conference on Artificial Intelligence*. https://www.aaai.org/ocs/index.php/WS/AAAIW11/paper/view/3948/4325

Social Accountability International [SAI]. (2014). *Social Accountability (SA) 8000*. https://sa-intl.org/wp-content/uploads/2020/02/SA8000-Side-By-Side-2008-and-2014-Latest.pdf

Sorigué. (n.d.). *Ampliación de la EDAR de La Llagosta en dos fases y mantenimiento del sistema de saneamiento*. Retrieved July 21, 2022, from https://www.sorigue.com/es/ampliacion-de-la-edar-de-la-llagosta-en-dos-fases-y-mantenimiento-del-sistema-de-saneamiento

Sorigué. (2020, May 20). *Sorigué valida innovadoras tecnologías para el tratamiento sostenible de aguas en un proyecto europeo*. https://www.sorigue.com/es/sala-de-prensa/actualidad/sorigue-valida-innovadoras-tecnologias-tratamiento-sostenible-aguas-proyecto-europeo

Sorigué. (2021, March 18). *Sorigué completes the first phase of the La Llagosta WWTP remodelling*. https://www.sorigue.com/en/press-room/news/sorigue-completes-first-phase-la-llagosta-wwtp-remodelling

Starik, M., & Kanashiro, P. (2013). Toward a Theory of Sustainability Management: Uncovering and Integrating the Nearly Obvious. *Organization & Environment*, *26*(1), 7–30. https://doi.org/10.1177/1086026612474958

Steurer, R., Langer, M. E., Konrad, A., & Martinuzzi, A. (2005). Corporations, Stakeholders and Sustainable Development I: A Theoretical Exploration of Business–Society Relations. *Journal of Business Ethics 2005 61:3*, *61*(3), 263–281. https://doi.org/10.1007/S10551-005-7054-0

Stevenson, A., & Maheshwari, S. (2022, May 27). *Global Brands Seek Clarity on Xinjiang*. https://www.nytimes.com/2022/05/27/business/cotton-xinjiang-forced-labor-retailers.html

Stuchtey, M. (2015, May 1). *Rethinking the water cycle*. https://www.mckinsey.com/business-functions/sustainability/our-insights/rethinking-the-water-cycle

Subramanian, K., Chau, C. K., & Yung, W. K. C. (2018). Relevance and feasibility of the existing social LCA methods and case studies from a decision-making perspective. *Journal of Cleaner Production*, *171*, 690–703. https://doi.org/10.1016/J.JCLEPRO.2017.10.006

Sureau, S., Neugebauer, S., & Achten, W. M. J. (2020). Different paths in social life cycle impact assessment (S-LCIA)—a classification of type II impact pathway approaches. *International Journal of Life Cycle Assessment*, *25*, 382–393. https://doi.org/10.1007/S11367-019-01693-9/FIGURES/3

Tsalidis, G. A., Gallart, J. J. E., Corberá, J. B., Blanco, F. C., Harris, S., & Korevaar, G. (2020). Social life cycle assessment of brine treatment and recovery technology: A social hotspot and site-specific evaluation. *Sustainable Production and Consumption*, *22*, 77–87. https://doi.org/10.1016/J.SPC.2020.02.003

Tsalidis, G. A., & Korevaar, G. (2019). Social Life Cycle Assessment of Brine Treatment in the Process Industry: A Consequential Approach Case Study. *Sustainability*, *11*(21), 5945. https://doi.org/10.3390/SU11215945

UN General Assembly. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development*. https://www.refworld.org/docid/57b6e3e44.html

UNEP/SETAC. (2013). *The Methodological Sheets for Sub-categories in Social Life Cycle Assessment (S-LCA)*. https://www.lifecycleinitiative.org/wp-content/uploads/2013/11/S-LCA_methodological_sheets_11.11.13.pdf

UNEP/SETAC Life Cycle Initiative. (2009). *Guidelines for Social Life Cycle Assessment of Products. Social and Socio-Economic LCA Guidelines Complementing Environmental LCA and Life Cycle Costing, Contributing to the Full Assessment of Goods and Services within the Context of Sustainable Developme*. UNEP/SETAC Life Cycle Initiative. https://wedocs.unep.org/bitstream/handle/20.500.11822/7912/-Guidelines for Social Life Cycle Assessment of Products-20094102.pdf?sequence=3&amp%3BisAllowed=

UNEP. (2020). *Guidelines for Social Life Cycle Assessment of Products and Organizations 2020* (C. Benoît Norris, M. Traverso, S. Neugebauer, E. Ekener, T. Schaubroeck, S. Russo Garrido, M. Berger, S. Valdivia, A. Lehmann, M. Finkbeiner, & G. Arcese (eds.)). United Nations Environment Programme (UNEP). https://www.lifecycleinitiative.org/library/guidelines-for-social-life-cycle-assessment-of-products-and-organisations-2020/

UNEP. (2021). *Methodological Sheets for Subcategories in Social Life Cycle Assessment (S-LCA) 2021*. https://www.lifecycleinitiative.org/wp-content/uploads/2021/12/Methodological-Sheets_2021_final.pdf

United Nations. (1948). *Universal Declaration of Human Right*. https://www.un.org/sites/un2.un.org/files/2021/03/udhr.pdf

Valdivia, S., Backes, J. G., Traverso, M., Sonnemann, G., Cucurachi, S., Guinée, J. B., Schaubroeck, T., Finkbeiner, M., Leroy-Parmentier, N., Ugaya, C., Peña, C., Zamagni, A., Inaba, A., Amaral, M., Berger, M., Dvarioniene, J., Vakhitova, T., Benoit-Norris, C., Prox, M., … Goedkoop, M. (2021). Principles for the application of life cycle sustainability assessment. *International Journal of Life Cycle Assessment*, *26*, 1900–1905. https://doi.org/10.1007/S11367-021-01958-2/FIGURES/1 van der Waal, J. W. H., & Thijssens, T. (2020). Corporate involvement in Sustainable Development Goals: Exploring the territory. *Journal of Cleaner Production*, *252*, 119625. https://doi.org/10.1016/J.JCLEPRO.2019.119625

van Hooijdonk, A. (2020). *Wetsus test nieuwe fosfaatterugwintechnieken in EU Water Mining project* . https://www.waterforum.net/wetsus-test-nieuwe-fosfaatterugwintechnieken-in-eu-water-mining-project/

van Vliet, M. T. H., Jones, E. R., Flörke, M., Franssen, W. H. P., Hanasaki, N., Wada, Y., & Yearsley, J. R. (2021). Global water scarcity including surface water quality and expansions of clean water technologies. *Environmental Research Letters*, *16*(2), 024020. https://doi.org/10.1088/1748-9326/ABBFC3

Vavik, T., & Keitsch, M. M. (2010). Exploring relationships between universal design and social sustainable development: some methodological aspects to the debate on the sciences of sustainability. *Sustainable Development*, *18*(5), 295–305. https://doi.org/10.1002/SD.480

Villar-García, A. del. (2016). Reuse of Reclaimed Water: Estimating the Costs of Production and Utilization. *Agua y Territorio / Water and Landscape*, *8*, 70–79. https://doi.org/10.17561/AT.V0I8.3297

Water Mining. (2020a). *Next generation water-smart management systems: Large scale demonstrations for a circular economy & society. Part B.*

Water Mining. (2020b). *WATER MINING*. https://watermining.eu/

Weidema, Bo P. (1998). Multi-user test of the data quality matrix for product life cycle inventory data. *The International Journal of Life Cycle Assessment*, *3*, 259–265. https://doi.org/10.1007/BF02979832

Weidema, Bo Pedersen, & Wesnæs, M. S. (1996). Data quality management for life cycle inventories—an example of using data quality indicators. *Journal of Cleaner Production*, *4*(3–4), 167–174. https://doi.org/10.1016/S0959-6526(96)00043-1

Weingaertner, C., & Moberg, Å. (2014). Exploring Social Sustainability: Learning from Perspectives on Urban Development and Companies and Products. *Sustainable Development*, *22*(2), 122–133. https://doi.org/10.1002/SD.536

Wetsus. (2020). *Water mining*. https://www.wetsus.nl/european-projects/water-mining/

Whiteman, G., Walker, B., & Perego, P. (2013). Planetary Boundaries: Ecological Foundations for Corporate Sustainability. *Journal of Management Studies*, *50*(2), 307–336. https://doi.org/10.1111/J.1467-6486.2012.01073.X

World Commission on Environment and Development. (1987). *Report of the World Commission on Environment and Development: Our Common Future*.

Wu, H., & Leung, S. O. (2017). Can Likert Scales be Treated as Interval Scales?—A Simulation Study. *Journal of Social Service Research*, *43*(4), 527–532. https://doi.org/10.1080/01488376.2017.1329775

Wu, R., Yang, D., & Chen, J. (2014). Social Life Cycle Assessment Revisited. *Sustainability*, *6*(7), 4200–4226. https://doi.org/10.3390/SU6074200

Wu, S. R., Chen, J., Apul, D., Fan, P., Yan, Y., Fan, Y., & Zhou, P. (2015). Causality in social life cycle impact assessment (SLCIA). *International Journal of Life Cycle Assessment*, *20*, 1312–1323. https://doi.org/10.1007/S11367-015-0915-6/TABLES/3

Wu, Y., Luo, J., Zhang, Q., Aleem, M., Fang, F., Xue, Z., & Cao, J. (2019). Potentials and challenges of phosphorus recovery as vivianite from wastewater: A review. *Chemosphere*, *226*, 246–258. https://doi.org/10.1016/J.CHEMOSPHERE.2019.03.138

XE.com Inc. (2022). *Historical Rates Tables - USD*. https://www.xe.com/currencytables/?from=USD&date=2015-12-31#table-section

Yawar, S. A., & Seuring, S. (2015). Management of Social Issues in Supply Chains: A Literature Review Exploring Social Issues, Actions and Performance Outcomes. *Journal of Business Ethics 2015 141:3*, *141*(3), 621–643. https://doi.org/10.1007/S10551-015-2719-9

Zalasiewicz, J. (2018). *The unbearable burden of the technosphere*. https://en.unesco.org/courier/2018-2/unbearable-burden-technosphere

Zamagni, A., Amerighi, O., & Buttol, P. (2011). Strengths or bias in social LCA? *The International Journal of Life Cycle Assessment 2011 16:7*, *16*, 596–598. https://doi.org/10.1007/S11367-011-0309-3

Zanchi, L., Delogu, M., Zamagni, A., & Pierini, M. (2018). Analysis of the main elements affecting social LCA applications: challenges for the automotive sector. *The International Journal of Life Cycle Assessment 2016 23:3*, *23*, 519–535. https://doi.org/10.1007/S11367-016-1176-8

Zhang, C., Guisasola, A., & Baeza, J. A. (2022). A review on the integration of mainstream P-recovery strategies with enhanced biological phosphorus removal. *Water Research*, *212,* 118102. https://doi.org/10.1016/J.WATRES.2022.118102

Appendices

Table of Contents

Appendix I

S-LCA: Interpretation stage

Materiality principle

This step is related to the identification of significant issues in the S-LCA. In S-LCA, this regards identifying processes, life cycle phases, stakeholder categories, social impacts, risks or performances of significance (UNEP, 2020). The term "significant" in this context relates to the materiality concept, which establishes that a material social issue is of such importance that it may affect the study's conclusions (UNEP, 2020). Contribution analysis, which determines the shares of processes or stakeholders in the overall social performance, can be used as a materiality assessment (UNEP, 2020).

Completeness check

The completeness, consistency, and sensitivity checks are part of the evaluation element of the interpretation phase (ISO, 2006b). The evaluation aims to support and improve the reliability of the results and should be performed in line with the goal and scope of the study (ISO, 2006b). In the completeness check, it is ensured that all the relevant issues have been addressed in each phase of the LCA; that is, ensuring that all the relevant data has been collected in accordance with the stakeholders considered, the results have been met, and conclusions can be drawn from the assessment (UNEP, 2020).

If there is incomplete or missing data or some research questions remain unanswered, previous steps might need to be reviewed and missing data should be found. Otherwise, the goal and scope should be revised and included in the conclusions (ISO, 2006b; UNEP, 2020).

Consistency check

Whether the data used, the assumptions made, and the methods applied in the S-LCI and S-LCIA phases align with the study's goal and scope and are applied consistently throughout the study is the primary goal of the consistency check (ISO, 2006b; UNEP, 2020). According to the Guidelines, consistency in S-LCA implies considering whether the applied procedures align with the social indicators selected, the impact assessment method selected, and the type of results produced (UNEP, 2020). In the interpretation phase, the consistency check is, in essence, a qualitative step that makes the researcher reflect on how robust the choices made in the study are and report them transparently (UNEP, 2020).

Sensitivity and data quality check

According to the Guidelines, this step also includes an uncertainty analysis, which can be either quantitative or qualitative. Quantitative analysis in S-LCA helps evaluate uncertainty in scores and the aggregation of, e.g., subcategories and stakeholder categories (UNEP, 2020). The resulting uncertainty ranges are helpful in determining whether two product systems differ statistically (UNEP, 2020). Qualitative methods regard the assessment of data and modelling uncertainties through, for example, the use of a pedigree matrix (UNEP, 2020).

The degree to which the assumptions made in the study (assumptions regarding data, activity variables, evaluation of the social performance, aggregation and weighting) affect the conclusions of the S-LCA is determined through the sensitivity check (UNEP, 2020). A few methods are available for performing a sensitivity check, one of which is conducting a sensitivity analysis (UNEP, 2020). Some aspects on which a sensitivity analysis may be conducted in S-LCA are data assumptions, reference scales, activity variables, allocation method, aggregation and weighting criteria. Regarding how a sensitivity analysis is performed, first, some variation in the selected variable or choice in the S-LCA model has to be applied. Then, the assessment needs to be performed, and the changes in results should be critically analyzed and documented (UNEP, 2020).

Appendix II

Online interview protocol for Case Study 5: [Organization's name]

First of all, I would like to thank you for your participation in this study. The main objective of my research is to perform a Social Life Cycle Assessment (Social-LCA) for the Water Mining project. The purpose of Social-LCA is to determine the social impacts of products along their life cycle. Social impacts include the direct and indirect effects of business operations on different aspects such as social equity, community development, human rights, labor rights, health, safety, education, security, and cultural diversity throughout the value chain.

You have been chosen for participation in this study as your company is part of the value chain for the Case Study 5 of the Water Mining project, and due to your position in the company you might be able to provide us information about certain social issues.

The objective of this questionnaire is two-fold:

1. to learn about what social indicators are important and relevant from your perspective as a main stakeholder of the Water Mining project, so that I understand what social impacts are important to focus on
2. to learn about how your company performs on the selected social criteria

The results will be presented as part of "Task 8.2: Social Impact Assessment, and Stakeholders' analysis and public acceptance". As a result of this online interview and the future findings of my research, you may gain an insight into the social sustainability performance of your company and know better how to assess it. Furthermore, I aim to be able to offer your company with relevant information which can lead to improving its social performance. Thus, the final results of the research can be useful to your business and all your stakeholders.

You may contact Akemi Kokubo at a.m.b.kokuboroche@student.tudelft.nl and a.m.b.kokubo.roche@umail.leidenuniv.nl for any clarification regarding the objective of Task 8.2, the meaning of impact subcategories, or any other question.

Thank you for your participation! Once finished, please send this questionnaire with your answers to Akemi Kokubo at the email addresses provided above.

1 Social life cycle assessment framework

The Social-LCA framework consists of 1) stakeholder categories, 2) impact categories, 3) impact subcategories and 4) indicators as shown in Figure 1.

- Stakeholder categories regard clusters of stakeholders that are expected to have similar interests due to the investigated product system.
- A social impact category is a class that covers certain social issues of interest to stakeholders and decision-makers.
- An impact subcategory is an indicator that represents a (social) impact, linked to a particular impact category, and in that context, can be called an "impact (sub)category indicator".
- An indicator is a measurement or value which gives you an idea of what something is like.

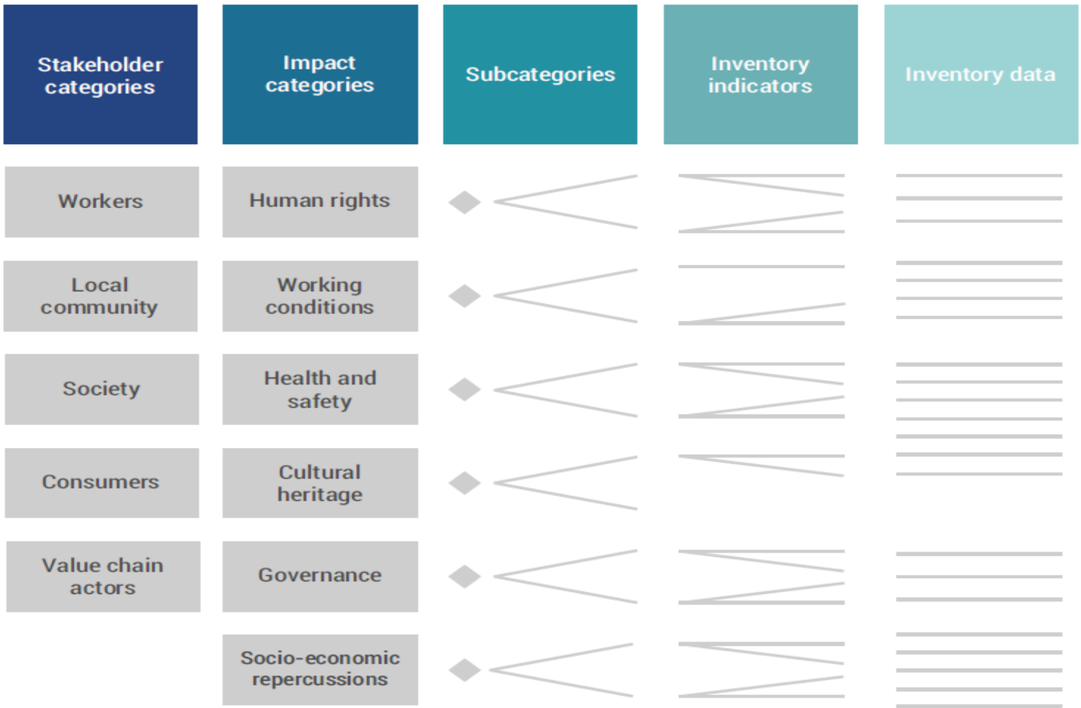

Figure 1. Structure of Social Life Cycle Assessment impacts

2 Social sustainability performance

The second section consists of a questionnaire for data collection. Data collection regards a limited list of impact subcategories. Please use a different font color for your answers.

1. *Stakeholder: Workers*

1.1. Freedom of association and collective bargaining

1.1.1. To what extent do you think freedom of association and collective bargaining is important to your organization?

1.1.2. Is there a special policy regarding freedom of association? If so, please elaborate.

1.1.3. Would you say that the presence of unions within the organization is adequately supported?

1.1.4. Are workers free to join unions of their own choosing or can they only choose specific ones?

1.1.5. Do any workers in your organization belong to a union?

1.1.6. Do employee/union representatives contribute to decision-making processes in the organization?

1.1.7. Have there been violations of freedom of association and/or collective bargaining agreements? Have there been actions taken and what were they?

1.1.8. What is the percentage of employees covered by a collective bargaining agreement?

1.2. Equal opportunities/discrimination

1.2.1. To what extent do you think equal opportunities are important to your organization?

1.2.2. Does the organization have a management system, policy, or actions to prevent discrimination and promote equal opportunities for workers? If so, please elaborate.

1.2.3. Has there been/is there any incident of discrimination/unequal opportunities at the organization? Have there been/are there actions taken and what are they?

1.2.4. Can you give some explanation about the composition and breakdown of employees according to gender, age group, minority group, etc., at the organization?

1.2.5. What is the ratio of basic salary of men to women by employee category?

1.2.6. Through what channels are the announcements of open positions made (e.g., national/regional newspapers, public job databases on the internet, employment services)?

1.3. Health and safety (of workers)

1.3.1. To what extent do you think the health and safety of the workers are important to your organization?

1.3.2. Does the organization have a policy/guidelines or program related to the health and safety of employees? If so, please elaborate

1.3.3. *Are there any preventative measures and emergency protocols regarding accidents and injuries? If so, please elaborate.*

1.3.4. *Do you know what is the average of injuries and/or fatal accidents in the organization in the past 3 years?*

1.4. <u>Fair salary</u>

1.4.1. *To what extent do you think that fair salary is important to your organization?*

1.4.2. *What is the average wage paid to employees?*

1.4.3. *How much is the minimum wage paid to employees?*

1.4.4. *Are there employees (lowest paid workers) with more than one job?*

1.4.5. *Are there any doubts among employees regarding what is being discounted from their salaries?*

1.4.6. *Are salaries regularly paid and do employees always receive a payment slip?*

1.5. <u>Working hours</u>

1.5.1. *To what extent do you think that the number of hours worked per employee (per day or week) is important to your organization?*

1.5.2. *Are there policies in place that stipulate the number of hours of work per level of employment and the overtime work arrangements?*

1.5.3. *On average, how many hours per day/week do employees work?*

1.5.4. *Are employees given flexibility in terms of hours of work?*

1.5.5. *Do you know if there have ever been issues of violation of overtime work arrangements?*

1.5.6. *On average, how many hours of overtime work does an employee work per week?*

1.5.7. *Is overtime work paid at a premium rate?*

2. *Stakeholder: Consumers*

2.1. <u>End of life responsibility</u>

2.1.1. To what extent do you think end-of-life responsibility is important to your organization?

2.1.2. Are there internal management systems that provide clear information to consumers on end-of-life options (such as product responsibility performance indicators, take back policy, design for disassembly, design for recycling)?

2.1.3. Are there any labeling regulations the organization must abide by?

2.1.4. If <u>yes</u> to the previous question: do you feel the organization abides by those regulations?

3. *Stakeholder: Local Community*

3.1. <u>Access to material resources</u>

3.1.1. To what extent do you think access to material resources is important to your organization?

3.1.2. Is there an internal management system that ensures the sustainable use of natural resources, the prevention of pollution and the recycling of wastes? If so, please elaborate

3.2. <u>Safe and healthy living conditions</u>

3.2.1. To what extent do you think safe and healthy living conditions of the community is important to your organization?

3.2.2. Is there a management effort to minimize the use of hazardous substances? If so, please elaborate

3.2.3. Does the organization contribute to the health of local communities in other ways? (e.g., through environmental risk management systems, participation with local organizations in communicating the potential health and safety impacts of their operations on surrounding communities, etc.)

3.2.4. Does the organization promote local community health and safety to actors in the value chain?

3.2.5. Has there been/are there any instances where the health and safety of a community has been at risk due to the organization's activities?

3.3. <u>Local employment</u>

3.3.1. To what extent do you think local employment is important to your organization?

3.3.2. Is it part of the company's policy to hire locally?

3.3.3. Approximately what percentage of workers do you think are local (from the local/nearby community)?

3.3.4. Does the company have a preference for locally based suppliers?

3.3.5. What share of the suppliers are local?

4. *Stakeholder: Society*

4.1. Public commitments to sustainability issues

4.1.1. *To what extent do you think public commitment to sustainability issues is important to your organization?*

4.1.2. *Would you say that managing sustainability issues is part of the organization's policy, strategy and goals?*

4.1.3. *Can you give examples of how your organization shows a public commitment to sustainability?*

4.1.4. *Does the organization implement principles or other codes of conduct such as UN principles or the Global Compact?*

4.1.5. *Have there been any instances in the past three years where the organization could not follow through with a sustainability commitment?*

4.2. Contribution to economic development

4.2.1. *To what extent do you think contribution to economic development is important to your organization?*

4.2.2. *Does your organization contribute to the economy, and if so, how?*

4.2.3. *Have there been any instances of damage or blocking of economic development?*

5. *Stakeholder: Value chain actors (excluding consumers)*

5.1. Promoting social responsibility

5.1.1. To what extent do you think promoting social responsibility is important to your organization?

5.1.2. Is there an explicit code of conduct that protects the human rights of workers among suppliers or other value chain actors?

5.1.3. Does the organization perform audits with regard to the social responsibility of value chain actors?

5.1.4. Does the organization participate in any initiatives that promote social responsibility in the value chain (e.g., consciousness-raising programs or counselling)?

Thank you for your participation!

Appendix III

(Site-specific) Classification results

Stakeholder category	**Impact subcategory**	**Social indicator**
Workers	Freedom of association and collective bargaining	Presence of a policy on freedom of association Percentage of employees covered by a collective bargaining agreement Employee/union representatives are invited to contribute to the planning of larger changes in the company The presence of unions within the organization is adequately supported Workers are free to join unions of their choosing Percentage of workers that belong to a union Evidence of violations of freedom of association and/or collective bargaining agreements and corrective actions taken
	Equal opportunities/discrimination	Presence of formal policies on equal opportunities Evidence of incidents of discrimination and corrective actions taken Presence of a management system that pro-actively promotes non-discrimination Composition of governance bodies and breakdown of employees per category according to gender, age group, minority group, membership or other indicators of diversity Ratio of basic salary of women to men by employee category Announcement of open positions in national/regional newspapers, public job databases, on the internet, employment services or other publicly available media
	Occupational health and safety	Presence of formal policy concerning health and safety Presence of preventative measures and emergency protocols regarding accidents and injuries (e.g., ISO 45000) Presence of a management system that pro-actively and continuously improves the health and safety of workers Records of the number/percentage of occupational injuries or fatal accidents
	Fair salary	Presence of a statement confirming that the wages paid comply at least with minimum legal wages, industry standards or collective bargaining agreements The average wage paid to employees is similar to the sector average The minimum wage paid to employees is in line with minimum legal wages Presence of suspicious deduction on wages

		Regular and documented payments of workers
	Working hours	Presence of a policy that provides clear communication of working hours and overtime arrangements Number of hours effectively worked by employees The organization provides flexibility Amount of overtime worked on average Overtime work is paid at a premium rate Evidence that overtime arrangements have been violated
Consumer	End-of-life responsibility	Presence of internal management systems ensure that clear information is provided to consumers on end-of-life options Existence of labelling regulations that apply to the product(s) Evidence that the organization abides by the labelling regulations
Local Community	Access to material resources	Presence of an environmental management system that ensures the sustainable use of natural resources, the prevention of pollution and the recycling of wastes Presence of a management system that continuously and significantly improves the local community's access to material resources
	Safe and healthy living conditions	Evidence that the organization contributes to the health of local communities Evidence that the safe and healthy living conditions of the community have been at risk caused by the organization's activities Presence of a management system that addresses the health and safety of local communities beyond the requirements set in the local laws Management effort to minimize the use of hazardous substances
	Local employment	Presence of a policy of local hiring preferences Percentage of workforce hired locally The organization has a preference for locally-based suppliers The company works with local suppliers and smallholders even when lowest price and speedy delivery is not guaranteed
Society	Public commitment to sustainability issues	Managing sustainability issues is part of the company's policy, strategy and goals Presence of publicly available documents as promises or agreements on sustainability issues The organization is a signatory of Principles or other codes of conduct (e.g. Sullivan Principles, Caux Round Table, UN principles, Global Compact etc.) There is no record of proven cases that the organization has violated its commitments to sustainability within the last three years

Value Chain Actors	Promoting social responsibility	Presence of explicit code of conduct that protects human rights of workers among value chain actors Evidence of audits by the organization concerning social responsibility of value chain actors in the last year Support to suppliers in terms of consciousness-raising and counselling concerning the social responsibility issues

Appendix IV

Inputs, country of origin, and EORA sector category of the reference and original systems

Inputs	Country of origin		EORA sector
	Country	Reference	
Reference system			
Wastewater	Spain	-	Waste Flow
Sodium hypochlorite	Spain	Organization A (personal communication)	Manufacture of chemicals and chemical products
Polymer for sludge conditioning	France	Organization B (personal communication)	Manufacture of chemicals and chemical products
Polyaluminum chloride	Spain	Organization C (company website)	Manufacture of chemicals and chemical products
Antifoaming	Spain	Organization D (company website)	Manufacture of chemicals and chemical products
Electricity	Spain	Organization E (company website)	Production and distribution of electricity
Original system			
Wastewater	Spain	-	Waste Flow
Sodium bicarbonate	Spain	(Simoes & Hidalgo, 2011)	Manufacture of chemicals and chemical products
Ferrous chloride tetrahydrate	Spain	(Gaulier & Zignago, 2010)	Manufacture of chemicals and chemical products
Hydrochloric acid	Spain	(Simoes & Hidalgo, 2011)	Manufacture of chemicals and chemical products
Sodium hydroxide	Spain	(Simoes & Hidalgo, 2011)	Manufacture of chemicals and chemical products
Electricity	Spain	Organization E (company website)	Production and distribution of electricity

Appendix V

Reference scales

Note: the PRP in level 2 should represent the BR definition.

Freedom of association and collective bargaining (Workers)

Reference scale: FACB1		
Basic requirement: Workers have the right to elect a representative and bargain collectively their interests (ILO, 2015, Conventions 87 and 154; IFC, 2012, paras. 10, 13–14).		
Level	Performance Reference Point	Note/reference
1	Employee/union representatives are invited to contribute to the planning of larger changes in the company, which will affect the working conditions	(UNEP, 2021)
2	Presence of a policy on freedom of association and the percentage of employees covered by a collective bargaining agreement	The source of the first indicator is Ramirez et al. (2014 as cited in Hannouf & Assefa, 2018). The second indicator is new, and it aims to substitute the indicator “availability of collective bargaining agreement and meeting minutes” from UNEP (2021).
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Reference scale: FACB2		
Basic requirement: Respect the workers' right to form unions/associations freely to promote and respect their interests. Discrimination should not happen against members of this union/association (ILO, 2015, Conventions 87 and 98; IFC, 2012, paras. 13–14).		
Level	Performance Reference Point	Note/reference
1	-	
2	Presence of unions within the organization is adequately supported and workers are free to join unions of their choosing. (optional) Percentage of workers that belong to a union. There is evidence that there have been violations of freedom of association and/or collective bargaining agreements but corrective actions have been taken.	(UNEP/SETAC, 2013; UNEP, 2021) Meeting the first two indicators is required to meet the BR. The third indicator aims to provide evidence that workers are members of unions (de Santo, 2019). The fourth indicator aims to assess whether workers are conditioned on the right to collective bargaining (UNEP, 2021).
3	There is evidence that there have been violations of freedom of association and/or collective bargaining agreements but no corrective actions have been taken. The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Equal opportunities/discrimination (Workers)

Reference scale: EODI1		
Basic requirement: The organisation shall not engage in or support discrimination in hiring, remuneration, access to training, promotion, termination or retirement based on race, national or territorial or social origin, caste, birth, religion, disability, gender, sexual orientation, family responsibilities, marital status, union membership, political opinions, age or any other condition that could give rise to discrimination. The organisation shall not interfere with the exercise of personnel's rights to observe tenets or practices or to meet needs relating to race, national or social origin, religion, disability, gender, sexual orientation, family responsibilities, union membership, political opinions or any other condition that could give rise to discrimination (SAI, 2014, p. 11, criteria 5.1, 5.2).		
Level	Performance Reference Point	Note/reference
1	The company or facility has a management system in place that pro-actively promotes non-discrimination in its organization, for instance by trainings/education programs and events to raise awareness and employee committees to address certain issues	(M.J. Goedkoop, de Beer, Harmens, Saling, Morris, Florea, Hettinger, Indrane, Visser, Morao, Musoke-Flores, Alvarado, Schenker, et al., 2020, p. 20)
2	Presence of formal policies on equal opportunities. In case that there have been incidents of discrimination, corrective actions were taken.	(UNEP, 2021)
3	There is evidence that there have been incidents of discrimination, but no corrective actions have been taken. The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Reference scale: EODI2		
Basic requirement: The organisation shall not engage in or support discrimination in hiring, remuneration, access to training, promotion, termination or retirement based on race, national or territorial or social origin, caste, birth, religion, disability, gender, sexual orientation, family responsibilities, marital status, union membership, political opinions, age or any other condition that could give rise to discrimination (SAI, 2014, p. 11, criterion 5.1).		
Level	Performance Reference Point	Note/reference
1	The composition of employees by gender is better than that of the sector (e.g., if the sector is dominated by male workers, the organization makes efforts to increase the share of female workers).	Distribution of women workers in the sector.
2	There is information on the composition of governance bodies and breakdown of employees per category according to gender, age group, minority group, membership or other indicators of diversity. Additionally, to meet the BR, the composition of employees by gender is similar to that of the sector.	(UNEP, 2021)
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	If the share of female and male workers is about the same, the context is positive. If compared to other sectors, this sector employs more women or men, the context is negative.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Reference scale: EODI3		
Basic requirement: The organization shall not engage in or support discrimination in hiring, remuneration, access to training, promotion, termination or retirement based on race, national or territorial or social origin, caste, birth, religion, disability, gender, sexual orientation, family responsibilities, marital status, union membership, political opinions, age or any other condition that could give rise to discrimination (SAI, 2014, p. 11, criterion 5.1). The organization should promote and ensure the principle of equal remuneration of women and men workers for work of equal value (ILO, 2015, Convention 100).		
Level	Performance Reference Point	Note/reference
1	The ratio of basic salary of women to men is higher than the sector's.	Ratio of basic salary of women to men in country-specific sector.
2	The ratio of basic salary of women to men by employee category is similar to that of the sector.	(UNEP, 2021)
3	The ratio of basic salary of women to men is lower than the sector (i.e., the BR is not met) and the context is negative. OR There is no data and the context is positive.	To assess whether the context is positive or negative, PSILCA's distribution of risk level is adopted; if the ratio in the sector is <20%, the situation is positive; if it is ≥ 20%, the situation is negative.
4	The ratio of basic salary of women to men is lower than the sector (i.e., the BR is not met) and the context is positive. OR There is no data and the context is negative.	Ibid.

Reference scale: EODI4		
Basic requirement: The organisation shall not engage in or support discrimination in hiring, remuneration, access to training, promotion, termination or retirement based on race, national or territorial or social origin, caste, birth, religion, disability, gender, sexual orientation, family responsibilities, marital status, union membership, political opinions, age or any other condition that could give rise to discrimination (SAI, 2014, p. 11, criterion 5.1).		
Level	Performance Reference Point	Note/reference
1	-	
2	Open positions are announced through national/regional newspapers, public job databases, on the internet, employment services or other publicly available media.	(UNEP, 2021)
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Health and safety (Workers)

Reference scale: OHSA1		
Basic requirement: Adequate general occupational safety measures are taken. The organization shall provide a safe and healthy workplace environment (IFC, 2012, para. 23; ILO, 2015, Convention 155; SAI, 2014, criterion 3.1). Documents related to procedures to detect, prevent, minimise, eliminate or otherwise respond to potential risks to the health and safety of personnel should be delivered and available (SAI, 2014, criterion 3.7)		
Level	Performance Reference Point	Note/reference
1	The company has a management system in place to pro-actively and continuously improve the health and safety of workers, beyond an acceptable level and can show tangible results of these efforts.	(M. J. Goedkoop, de Beer, Harmens, Saling, Morris, Florea, Hettinger, Indrane, Visser, Morao, Musoke-Flores, Alvarado, Rawat, et al., 2020; Life Cycle Initiative & Social Life Cycle Alliance, 2022)
2	Presence of formal policy concerning health and safety and preventative measures and emergency protocols exist regarding accidents and injuries (e.g., ISO 45000)	(UNEP, 2021)
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Reference scale: OHSA2		
Basic requirement: The organisation shall keep records of all health and safety incidents, accidents and diseases that occur in the workplace and in all residences and property provided by the organisation (IFC, 2012, para. 23; SAI, 2014, criterion 3.7).		
Level	Performance Reference Point	Note/reference
1	-	
2	The organization keeps records of the number/percentage of occupational injuries or fatal accidents. Additionally, to meet the BR, the reported number of occupational accidents is similar to that of the sector.	(UNEP, 2021)
3	The organization keeps records of the number/percentage of occupational injuries or fatal accidents. However, the reported number of accidents is higher than the sector average or the values provided are not given in comparable units. The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is assessed based on the average number of accidents in the sector. If the sector average is higher than the total average of all sectors in a country, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Fair salary (Workers)

Reference scale: FSAL1		
Basic requirement: Wages should comply at least with minimum legal wages, industry standards or collective bargaining agreements (SAI, 2014, criterion 8.1)		
Level	Performance Reference Point	Note/reference
1	The average wage paid to employees is higher than the sector average (by >50%)	Average wage paid in the sector.
2	Presence of a statement confirming that the wages paid comply at least with minimum legal wages, industry standards or collective bargaining agreements. Furthermore, the average wage paid to employees is similar to the sector average. (Optional) The minimum wage paid to employees is in line with minimum legal wages.	New indicators. The first is based on UNEP's (2021) indicator "Lowest paid worker, compared to the minimum wage".
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Reference scale: FSAL2		
Basic requirement: Wages should be paid in legal regular intervals (ILO, 2015, Convention 95). Deduction on wages should only be made under conditions stipulated by law, and workers should be informed of the conditions under which such deductions may be made (ILO, 2015, Convention 95).		
Level	Performance Reference Point	Note/reference
1	-	
2	Workers are paid regularly, and their payments are documented. Moreover, there are no indications of suspicious deductions from employees' wages.	(UNEP, 2021)
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Working hours (Workers)

Reference scale: WHOU1		
Basic requirement: Working time should not exceed 8 hours per day or 40-48 hours per week (ILO, 2015, Conventions 1 and 47).		
Level	Performance Reference Point	Note/reference
1	Employees are given flexibility and the organization promotes work-life balance.	(Life Cycle Initiative & Social Life Cycle Alliance, 2022; UNEP, 2021)
2	Presence of policy that provides clear communication of working hours and overtime arrangements. Additionally, the number of hours worked per employee does not exceed 40-48 hours per week.	(Hannouf & Assefa, 2018; UNEP, 2021)
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Reference scale: WHOU2		
Basic requirement: Overtime should be voluntary, not exceeding 12 hours per week (SAI, 2014, criterion 7.3). Overtime should be paid at a premium rate (not less than 1.25 times the normal rate) (ILO, 2015, Convention 1; SAI, 2014, criterion 8.4).		
Level	Performance Reference Point	Note/reference
1	-	
2	The number of overtime hours on average does not exceed maximum legal limits and overtime work is paid at a premium rate. (optional) There is no evidence that overtime arrangements have been violated.	New indicators. The third one is adapted from UNEP (2021).
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

End-of-life responsibility (Consumers)

Reference scale: EOLR1		
Basic requirement: Consumer education should raise awareness about the impact of consumption choices on others and on sustainable development. In educating consumers, an organization, when appropriate, should address proper disposal of wrapping, waste, and products (ISO, 2010, p. 60). When dealing with consumers, enterprises should provide accurate, verifiable and clear information that is sufficient to enable consumers to make informed decisions, including information on the prices and, where appropriate, content, safe use, environmental attributes, maintenance, storage and disposal of goods and services (OECD, 2011, p. 51).		
Level	Performance Reference Point	Note/reference
1	-	
2	Presence of internal management systems ensure that clear information is provided to consumers on end-of-life options.	(UNEP, 2021)
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Reference scale: EOLR2		
Basic requirement: When dealing with consumers, enterprises should ensure that the goods and services they provide meet all agreed or legally required standards for consumer health and safety, including those pertaining to health warnings and safety information (OECD, 2011, p. 51).		
Level	Performance Reference Point	Note/reference
1	-	
2	Existence of labelling regulations that apply to the product(s) and evidence that the organization abides by them.	(UNEP, 2021)
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Access to material resources (Local community)

Reference scale: AMRE1		
Basic requirement: Organizations should establish effective resource efficiency and pollution prevention policies, waste management systems and procedures to avoid, or where avoidance is not possible, minimize adverse impacts on human health and the environment (IFC, 2012, p. 23).		
Level	Performance Reference Point	Note/reference
1	The company or facility has an effective management system in place to continuously and significantly improve the local community's access to material resources (e.g., by reducing the use of non-renewable raw materials).	Adopted from PSIA Social Topics report (M.J. Goedkoop, de Beer, Harmens, Saling, Morris, Florea, Hettinger, Indrane, Visser, Morao, Musoke-Flores, Alvarado, Schenker, et al., 2020)
2	Presence of an environmental management system that ensures the sustainable use of natural resources, the prevention of pollution and the recycling of wastes (e.g., ISO 50001, ISO 14001).	Adapted from UNEP (2021)
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Safe and healthy living conditions (Local community)

Reference scale: SHLC1		
Basic requirement: Organizations should, within the framework of laws, regulations and administrative practices in the countries in which they operate take due account of the need to protect the environment, public health and safety, and generally to conduct their activities in a manner contributing to the wider goal of sustainable development (OECD, 2011, p. 42). Organizations should evaluate the risks and impacts of their operations on the health and safety of the local communities and establish preventive and mitigation measures (IFC, 2012, para. 5).		
Level	Performance Reference Point	Note/reference
1	The company or facility has a management system in place to address the health and safety of local communities beyond the requirements set in the local laws and this results in better than average performance on EHS.	(M.J. Goedkoop, de Beer, Harmens, Saling, Morris, Florea, Hettinger, Indrane, Visser, Morao, Musoke-Flores, Alvarado, Schenker, et al., 2020)
2	The organization contributes to the health of local communities (e.g., through environmental risk management systems, participation with local organizations in communicating the potential health and safety impacts of their operations on surrounding communities, etc.) and there is no evidence that the safe and healthy living conditions of the community has been at risk due to the organization’s activities.	(de Santo, 2019; Ramirez et al., 2014; UNEP, 2021)
3	There is evidence that due to the organization’s activities, the safe and healthy living conditions of the local community has been put at risk. The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Reference scale: SHLC2		
Basic requirement: Organizations should avoid or minimize the release of hazardous materials (IFC, 2012, para. 13)		
Level	Performance Reference Point	Note/reference
1	-	
2	Management effort to minimize use of hazardous substances.	(UNEP, 2021)
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Local employment (Local community)

Reference scale: LEMP1		
Basic requirement: An organization should analyse the impact of its investment decisions on employment creation and, where economically viable, make direct investments that alleviate poverty through employment creation; consider participating in local and national skills development programmes, including apprenticeship programmes, programmes focused on particular disadvantaged groups, lifelong learning programmes and skills recognition and certification schemes; and consider helping to develop or improve skills development programmes in the community where these are inadequate, possibly in partnership with others in the community (ISO, 2010, p. 65). In their operations, to the greatest extent practicable, employ local workers and provide training with a view to improving skill levels (OECD, 2011, p. 36).		
Level	Performance Reference Point	Note/reference
1	-	
2	Presence of a policy of local hiring preferences and the percentage of workforce hired locally is at least 50%.	(UNEP, 2021)
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Reference scale: LEMP2		
Basic requirement: An organization should consider giving preference to local suppliers of products and services and contributing to local supplier development where possible (ISO, 2010, p. 67).		
Level	Performance Reference Point	Note/reference
1	The company works with local suppliers and smallholders even when lowest price and speedy delivery is not guaranteed.	(Mark J. Goedkoop et al., 2018)
2	The organization has a preference for locally-based suppliers.	(UNEP, 2021)
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Public commitment to sustainability issues (Society)

Level	Performance Reference Point	Note/reference
Reference scale: PCSI1		
Basic requirement: An organization should, at appropriate intervals, report about its performance on social responsibility to stakeholders affected. The organization should provide a fair and complete picture of its social responsibility performance in a sustainability context, including achievements and shortfalls and the ways in which the shortfalls will be addressed (ISO, 2010, p. 77).		
Level	Performance Reference Point	Note/reference
1	-	
2	Managing sustainability issues is part of the company's policy, strategy and goals and there are publicly available documents as promises or agreements on sustainability issues. Additionally, the organization is a signatory of Principles or other codes of conduct (e.g. Sullivan Principles, Caux Round Table, UN principles, Global Compact etc.) and there is no record of proven cases that the organization has violated its commitments to sustainability within the last three years.	(de Santo, 2019; Hannouf & Assefa, 2018; UNEP, 2021)
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Promoting social responsibility (Value chain actors)

Reference scale: PSRE1		
Basic requirement: An organization should make reasonable efforts to encourage organizations in its sphere of influence to follow responsible labour practices (ISO, 2010, p. 35)		
Level	Performance Reference Point	Note/reference
1	-	
2	Presence of explicit code of conduct that protects human rights of workers among value chain actors.	(UNEP, 2021)
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

Reference scale: PSRE2		
Basic requirement: An organization should make reasonable efforts to encourage organizations in its sphere of influence to follow responsible labour practices. Reasonable efforts could include making unannounced visits and inspections; and exercising due diligence in supervising contractors and intermediaries (ISO, 2010, p. 35).		
Level	Performance Reference Point	Note/reference
1	-	
2	There is evidence of audits by the organization with regard to social responsibility of value chain actors in the last year. Additionally, the organization supports its suppliers in terms of consciousness-raising and counselling concerning social responsibility issues.	(UNEP, 2021)
3	The organization does not meet what is stipulated in level 2 and the context is negative. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is positive.	The context is determined by the behavior of peers. If peers in the sector do not meet the BR, the context is negative and vice versa.
4	The organization does not meet what is stipulated in level 2 and the context is positive. OR No indication that the organization meets what is stipulated in level 2 has been found (no data), and the context is negative.	Ibid.

References

de Santo, E. (2019). *Developing and Applying a Social Life Cycle Assessment Methodology to Assess the Social Sustainability Performance of Organizations in the Dutch Chemical Process Industry* [Delft University of Technology]. http://resolver.tudelft.nl/uuid:4a9915ef-5284-4dce-8e75-1e45f6cd3663

Gaulier, G., & Zignago, S. (2010). *BACI: International Trade Database at the Product-Level. The 1994-2007 Version*. http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=37

Goedkoop, M. J., de Beer, I. ., Harmens, R., Saling, P., Morris, D., Florea, A., Hettinger, A. L., Indrane, D., Visser, D., Morao, A., Musoke-Flores, E., Alvarado, C., Rawat, I., Schenker, U., Head, M., Collotta, M., Andro, T., Viot, J.-F., & Whatelet, A. (2020). *Methodology Report Product Social Impact Assessment - 2020*. https://www.social-value-initiative.org/wp-content/uploads/2021/04/20-02-Methodology-Report.pdf

Goedkoop, M.J., de Beer, I. ., Harmens, R., Saling, P., Morris, D., Florea, A., Hettinger, A. L., Indrane, D., Visser, D., Morao, A., Musoke-Flores, E., Alvarado, C., Schenker, U., Andro, T., Viot, J.-F., & Whatelet, A. (2020). *Product Social Impact Assessment- Social Topics Report - 2020*.

Goedkoop, Mark J., Indrane, D., & de Beer, I. . (2018). *Handbook for Product Social Impact Assessment 2018*.

Hannouf, M., & Assefa, G. (2018). Subcategory assessment method for social life cycle assessment: a case study of high-density polyethylene production in Alberta, Canada. *International Journal of Life Cycle Assessment*, *23*, 116–132. https://doi.org/10.1007/S11367-017-1303-1/TABLES/6

International Finance Corporation [IFC]. (2012). *IFC Performance Standards on Environmental and Social Sustainability*. https://documents1.worldbank.org/curated/en/586771490864739740/pdf/113849-WP-ENGLISH-IFC-Performance-Standards-PUBLIC.pdf

International Labour Organization [ILO]. (2015). *Compendium of International Labour Conventions and Recommendations*. https://www.ilo.org/wcmsp5/groups/public/---ed_norm/---normes/documents/publication/wcms_413175.pdf

International Organization for Standardization [ISO]. (2006). *ISO 14044 Environmental management—Life cycle assessment—Requirements and guidelines*. https://wapsustainability.com/wp-content/uploads/2020/11/ISO-14044.pdf

International Organization for Standardization [ISO]. (2010). *ISO 26000 Guidance on social responsibility*.

Life Cycle Initiative, & Social Life Cycle Alliance. (2022). *Pilot projects on Guidelines for Social Life Cycle Assessment of Products and Organizations 2022*. https://www.lifecycleinitiative.org/wp-content/uploads/2022/05/Pilot-projects-on-UNEP-SLCA-Guidelines-12.5.pdf

Organisation for Economic Cooperation and Development [OECD]. (2011). *OECD Guidelines for Multinational Enterprises*.

https://www.oecd.org/daf/inv/mne/48004323.pdf

Ramirez, P. K. S., Petti, L., Haberland, N. T., & Ugaya, C. M. L. (2014). Subcategory assessment method for social life cycle assessment. Part 1: Methodological framework. *International Journal of Life Cycle Assessment*, *19*, 1515–1523. https://doi.org/10.1007/S11367-014-0761-Y/FIGURES/3

Simoes, A. J. G., & Hidalgo, C. A. (2011). The Economic Complexity Observatory: An Analytical Tool for Understanding the Dynamics of Economic Development. *Workshops at the Twenty-Fifth AAAI Conference on Artificial Intelligence*. https://www.aaai.org/ocs/index.php/WS/AAAIW11/paper/view/3948/4325

Social Accountability International [SAI]. (2014). *Social Accountability (SA) 8000*. https://sa-intl.org/wp-content/uploads/2020/02/SA8000-Side-By-Side-2008-and-2014-Latest.pdf

UNEP/SETAC. (2013). *The Methodological Sheets for Subcategories in Social Life Cycle Assessment (S-LCA)*. https://www.lifecycleinitiative.org/wp-content/uploads/2013/11/S-LCA_methodological_sheets_11.11.13.pdf

UNEP. (2020). *Guidelines for Social Life Cycle Assessment of Products and Organizations 2020* (C. Benoît Norris, M. Traverso, S. Neugebauer, E. Ekener, T. Schaubroeck, S. Russo Garrido, M. Berger, S. Valdivia, A. Lehmann, M. Finkbeiner, & G. Arcese (eds.)). United Nations Environment Programme (UNEP). https://www.lifecycleinitiative.org/library/guidelines-for-social-life-cycle-assessment-of-products-and-organisations-2020/

UNEP. (2021). *Methodological Sheets for Subcategories in Social Life Cycle Assessment (S-LCA) 2021*. https://www.lifecycleinitiative.org/wp-content/uploads/2021/12/Methodological-Sheets_2021_final.pdf