A Social life cycle assessment of Urban Wastewater Treatment Systems with Resources Recovery

A Case Study of the WATER MINING Project in Portugal

By

Mª do Carmo Vasconcelos Mantero Morais Vieira Vasconcelos

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in Industrial Ecology

Faculty of Technology, Policy and Management

First supervisor:	Dr. John Posada Duque
Second supervisor:	Dr. Gijsbert Korevaar
Daily supervisor:	Dr. George Tsalidis

Executive Summary

Global water-related impacts are in constant aggravation due to climate change, increased water demand, intensive human activities, and deterioration of the quality of water bodies. Under this paradigm, humanity must adapt and implement measures to ensure both the quality of water bodies and the sustainable management of resources.

As a result, unexploited water resources, such as wastewater, have been a focus of attention among researchers. Wastewater Treatment (WWT) technologies stands as an important step to promote water reuse and potentially recover raw materials with added value.

While WWT technologies have been assessed at the environmental and economic levels, their social repercussions are not extensively studied. Hence, the present master thesis project resorts to the Social Life Cycle Assessment (S-LCA) framework to execute an evaluation of the social performance of an innovative WWT system for resource recovery in Portugal. S-LCA was conducted at the organizational level, assessing the social performance of organizations in the value chain through the evaluation of the social effects on Workers, Consumers, Local Community, Society and value chain actors. In addition, a generic assessment was performed to identify hotspot areas of the Portuguese water sector, following the S-LCA framework.

The systems under analysis integrate a Water Mining (WM) project case study, where an innovative urban WWT technology is implemented. In the two systems defined, the wastewater is treated with the Nereda technology and safely discharged in the environment. Nevertheless, while in the reference system the sludge generated from the treatment is stored or forward to landfill, in the novel system a new biobased raw material is recovered.

Regarding the generic assessment, a total of eleven impact subcategories were listed as critical areas regarding the operation of companies in the WWT sector. These were further investigated in the site-specific assessment conducted at the plant level. The results of the site-specific assessment indicate that the organisations included in the assessment performed well for both systems under analysis. However, organizations' individual performances reflect that improvements are necessary mainly in the subcategories "equal opportunities/discrimination" and "community engagement". Other subcategories where organizations need to improve are "promoting social responsibility", "social benefits/social security", "local employment", "health and safety of consumers", "safe and healthy living conditions" and "public commitment to sustainability issues". For each organization that did not reach the satisfactory performance level in a certain subcategory, improvement recommendations were proposed.

In general, the novel system performs better in all impact subcategories when compared to the reference system. Nonetheless, this result is intrinsically connected to system characteristic and model decisions such as weighting factors definition and multifunctionality matters, which remain as rather abstract concepts that do not complete reflect reality.

The main challenges faced during the study concern the accessibility and availability of site-specific and generic data. In terms of site-specific assessment, the high similarity of the reference and novel systems in terms of organizations involved hindered the comparison of the two systems.

To conclude, the S-LCA methodology allowed the identification of social hotpots areas as well as the evaluation of the reference and novel systems social performance, contributing for the elaboration of strategies to improve social sustainability along the value chain of innovative WWT technologies.

"What the work of art looks like isn't too important.

It has to look like something if it has physical form.

No matter what form it may finally have, it must begin with an idea."

Pires Vieira

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List of Abbreviations

AHP - Analytical Hierarchy Process

BES - Bio electrochemical system

BR - Basic Requirement

CS - Case study

CSR - Corporate Social Responsibility

E-LCA - Environmental Life Cycle Assessment

FU - Functional Unit

IA - Impact assessment

IP - Impact Pathway

LCC – Life Cycle Costing

LCSA - Life Cycle Sustainability Assessment

PRP - Performance Reference Point

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

SDGs - Sustainable Development Goals

TBL - Triple Bottom Line

UNEP - United Nations Environment Programme

UN - United Nations

WM - Water Mining

WWT - Wastewater treatment

WWTP - Wastewater treatment plant

1. Introduction

Water is intrinsic to human essence. Water plays a vital role not only in terms of human health but also in economic development, peace and security.

According to the United Nations, climate change effects will primarily be experienced through water related impacts. Human activities and natural disasters are progressively putting pressure on water resources. As such, water availability has become less predictable in many places. In fact, increased incidences of flooding contribute to the destruction of water and sanitation facilities, as well as to water sources contamination. On the other hand, in some regions water scarcity is intensified by droughts, affecting people's health and productivity (United Nations General Assembly, 2005). As water availability becomes more uncertain, an increase in water demand is expected due to a continuous growth in the world's population along with an improvement in quality of life (Makarigakis & Jimenez-Cisneros, 2019).

Under this paradigm, humanity must make decisions to increase the quality of water bodies and to increase sustainability in the management of the resources. The topic is particularly relevant from a social dimension point of view if taken into consideration that water-related impacts are unevenly distributed and hold disproportionate effects to individuals and communities around the globe (Wutich et al., 2022).

The design and implementation of more sustainable Wastewater Treatment (WWT) technologies is an important step towards a sustainable development. WWT promotes the maximisation of water reuse combined with the maximum potential to recover raw materials with added value, simultaneously contributing to minimize waste and costs. Furthermore, WWT technologies can contribute decisively to ensure access to clean water and sanitation services, which are key aspects to achieve the sustainable development goals (SDG) defined by the World Summit on Social Development.

The SDGs are based on three pillars of sustainability: economic development, social development and environment protection (United Nation Assembly, 2005). According to (Shemfe et al., 2018), these three sustainability strands should be assessed when designing and/or implementing new products or production systems.

Life Cycle Sustainability Assessment (LCSA) covers the three dimensions mentioned above, combining environmental life cycle assessment (E-LCA), life cycle costing (LCC), and social life cycle assessment (S-LCA) (Ramos Huarachi et al., 2020). As part of LCSA tools, S-LCA is described as the most efficient technique for assessing the social impacts of products throughout their life cycles (Ramos Huarachi et al., 2020). The importance of assessing social and socioeconomic impacts, in a similar way to how E-LCA approaches environmental impacts, was recognized during the 90s. However, the integration of social aspects in engineering methods is a challenging effort, particularly for sustainability practitioners (Ramos Huarachi et al., 2020).

With the development of new technologies, the need to study their social performance also arises. In this sense, S-LCA emerges as a valuable tool to address the social impacts of a product or production system, contributing to the improvement of social conditions and of the overall socio-economic performance of a product, system or service throughout its life cycle for all its

stakeholders (UNEP, 2020). Additionally, it can be used as an auxiliary tool to support the measures and goals set by a company regarding the social performance of its products and/or services.

In this context, the present MSc thesis project resorts to the S-LCA approach in order to perform an evaluation of the social performance of innovative WWT systems for resource recovery in Portugal, at the plant level. The project aims to contribute to the access to clean water and sanitation by bringing the social dimension and the evaluation of innovative wastewater treatment technologies.

1.1 Sustainability Definition

The word 'sustainability' comes from the latin term sustinere (tenere, to hold; sub, under). The verb "to sustain" can also mean holding, supporting, or endure. Therefore, it indicates the capacity to maintain over a long period of time.

According to some authors (Mebratu, 1998; Mitlin, 1992), the idea of sustainable development first appeared in the early 1970s, when various publications warned that the Western development model needed to be constrained. Ever since, the term sustainability has grown significantly in importance in academic studies of environmental problems, environmental management laws, as well as in industrial and agricultural output, among other fields (Ruggerio, 2021).

The topic gained even more attention since its introduction in the report "Our Common Future" published in 1987 by The World Commission on Environment and Development (WCED), the idea of sustainable development has developed into a standard for environmental science research and taken on a paradigmatic nature for development. By the time, the WCED defined sustainable development as "development that meets the demands of the present without compromising the ability of future generations to meet their own needs." (WCED, 1987). The definition was received by most of the international community as the new paradigm for development.

According to literature, the concepts of sustainability and sustainable development are frequently related, and both terms are consequently used interchangeably in academic and scientific contexts (Ruggerio, 2021; Purvis et al., 2019). However, other schools of thought defend the idea that sustainable development is a paradoxical idea given the impossibility of sustaining limitless economic expansion on a finite planet. This stance raises awareness for the, not only epistemological, but also social, political, economic, cultural, and environmental problems caused by basing local and international environmental policies and activities on an inconsistent idea (Ruggerio, 2021). (Brown et al., 1987), defend that the context in which the term is used and whether it is used from a social, economic, or ecological standpoint have a significant impact on the meaning of the term.

Sustainability is often described by the interaction of three dimensions – economic, social, and environmental - the three pillars of sustainability. The concept was first introduced by John Elkington in 1994 as the triple bottom line (TBL) (Lozano, 2008). The author wrote that "Sustainable development involves the simultaneous pursuit of economic prosperity, environmental quality, and social equity".

According to (Hansmann et al., 2012), the TBL of sustainability, which encompasses economic or financial considerations, environmental protection and stewardship, as well as community

and individual human well-being, is at the heart of the concept. This entails enhancing social and economic well-being while keeping environmental consequences within nature's carrying capacity. With this approach, the best answers to any kind of problem will result in long-term gains for all three (Arowoshegbe & Emmanuel, sem data). Some authors do not agree with the TBL and proposed different approaches to describe sustainability. For example, in 1995 the Commission on Sustainable Development (CSD) defined four sustainability dimensions as political-institutional, natural, economic, and social (Kaur & Garg, 2019). Additionally, institutional dimension was emphasised by (Valentin & Spangenberg, 2000) as the one that can facilitate the connection between different dimensions and serve as a complement to them. After that, to address issues with community identity and tradition preservation and to develop native belief systems and customary values of various cultures, the Canadian International Development Agency (CIDA) mentioned the incorporation of culture as one of the sustainable development dimensions and introduced cultural diversity as one of the sustainability dimensions (Todd & Geissler, 1999).

Although there is no universal consensus on the definition of sustainability and its dimensions, the three-dimensional concept of the TBL is widely accepted throughout the literature (Purvis et al., 2019) and used in several sustainability definitions. As a matter of the fact, practitioners of main sustainability assessment tools have reached a consensus on their use (UNEP, 2020). For the purpose of this work, the TBL approach will be considered, following a brief description of what the concept entails.

1.1.1 The three pillars of sustainability

According to Elkington (1987), the economic pillar refers to the effect of an organization's business activities on the financial system. It relates to the economy's potential as sustainability subsystem to endure and develop in order to support future generations. It focuses on the financial value that an organisation brings to the surrounding system in a way that benefits it and supports its ability to support future generations. (Arowoshegbe & Emmanuel, sem data).
The social line of TBL refers to using ethical business methods that are beneficial to the community, human capital, and labour. The notion behind these actions is that they benefit society and "give back" to the community. These procedures can involve paying equitable wages and offering health insurance, for example. Beyond the moral imperative of doing "good" for society, a business' performance and sustainability may suffer if social responsibility is ignored (Arowoshegbe & Emmanuel, sem data).
Finally, the environmental pillar of sustainability is related to actions that do not harm the environment and do not compromise the resources available to future generations. It has to do with conserving energy, cutting greenhouse gas emissions, limiting the ecological footprint, etc (Arowoshegbe & Emmanuel, sem data).

In theory, the three pillars should be addressed as one, and the three dimensions are interconnected and balanced. (Sverdrup & Svensson, 2004) defend that in order to achieve an integrated sustainability, the three dimensions should be treated equally. Otherwise, complete sustainability cannot be claimed if only one or two dimensions are considered, and decisions are likely to be made without critical knowledge and factors. Moreover, (Kyburz-Graber et al., 2006) draws attention to the fact that stakeholders' interests often discord within a single pillar (ie, social conflicts; economic conflicts; environmental conflicts; or preferences), and therefore, finding a balance between their concerns regarding one pillar is sometimes prioritised in relation to balance social, economic, and environmental aspects.

As mentioned above, the three pillars are interrelated and might influence each other positively or negatively. In fact, throughout the years different views on how these interactions occur have emerged, if in terms of trade-offs or by mutual reinforcements (Purvis et al., 2019). Along with Hansmann et al. (2012), even while it may impede short-term economic growth, attaining ecological goals in the present (for example, through stringent ecological legislation and the conservation of natural resources) may have synergistic positive impacts on the economic status of future generations. Furthermore, supporting social and human capital can also contribute to foster integrated sustainability. However, the authors emphasize that in order to realise this potential, the creation of such capital must be connected to sustainability learning at all levels: individual, organisational, and social.

Frequently, priority is given to the environmental and economic dimensions when debating about sustainability (Vallance et al., 2011). (Pullman et al., 2009), mention how the pressure to accomplish environmental sustainability was growing on businesses by the time. Consequently, different tools to assess environmental and economic performance of organisations, products, or services have emerged. Examples of such tools are life cycle assessment, addressed in the present study, analytical hierarchy process, the fuzzy set approach, the balance scorecard, and data envelopment analysis (Qorri et al., 2018). Recently, organisations have also turned their attention to socially related topics, such as social sustainability and corporate social responsibility (CSR). CSR entails the efforts of corporations to rule following adequate social performance standards and responsible practises while meeting their financial and legal obligations (Ashrafi et al., 2018). At the organizational level, this involves analysing the social impacts of a particular development project or policy and assessing whether it is likely to promote or hinder the well-being of the affected individuals and communities.

1.2 Brief Introduction to S-LCA

According to the UNEP/SETAC Guidelines (UNEP, 2020) (hereafter referred as “Guidelines”), S-LCA is defined as being “a social impact (actual and potential impacts) assessment technique that aims to assess the social and socio-economic aspects of products and their positive and negative impacts along their life cycle encompassing extraction and processing of raw materials, manufacturing, distribution, use, re-use, maintenance, recycling, and final disposal” (UNEP, 2020). Additionally, S-LCA can also be used to support decision making and to compare processes and stages of a system, as well as between two or several systems.

Over the last few years, research efforts to harmonise the S-LCA methodology have been made. Consequently, the UNEP/SETAC Guidelines for S-LCA of products were published. However, the method is still under development (Ramos Huarachi et al., 2020).

The UNEP/SETAC Guidelines introduce two distinct levels of analysis: (i) hotspot level and (ii) site-specific level. On the hotspot level, more generic data to the case study is applied, usually on a national level. Social hotspots are then identified as locations and/or activities in the life cycle that negatively contribute to social well-being. The site-specific level of analysis makes use of data collected from the involved stakeholders (UNEP, 2020).

The S-LCA methodology is based on the ISO 14040 - 14044 framework for E-LCA (UNEP, 2020). As such, four phases are included: Goal and scope, (Social) Life Cycle Inventory (S-LCI), (Social) Life Cycle Impact Assessment (S-LCIA), and Interpretation. In particular, the UNEP/SETAC Guidelines will be followed, since that is the most widely recognised approach (Serreli et al., 2021).

In Section 3, a general and brief overview of the S-LCA method applied in this study is provided, including a description on what each phase on an S-LCA entails.

1.3 Research object: Water Mining Faro-Olhão case study

1.3.1 WATER MINING Project

The WATER MINING (WM) project integrates the Horizon 2020 research and innovation programme of the European Union, and is coordinated by TU Delft.

The project embraces the challenge of helping to ensure access to clean water and sanitation by developing energy efficient technologies for treating wastewater from urban and industrial areas and desalination, enhancing the extraction of valuable products from residues generated during the process (Water Mining, 2020).

The development of new WWT technologies is a key component of the WM project. In addition to the technical challenge, one of the main tasks of the project is to evaluate the technologies developed technologies in terms of sustainability performance (Water Mining, 2020). The project requirements include the assessment of the performance on each of the three sustainability dimensions – economic, environmental, and social. Economic and environmental performance will be evaluated by means of LCC and E-LCA. The assessment of local and regional social impacts will be conducted through the Social Life Cycle Impact Assessment (S-LCA) method, as required.

Additionally, the project aims to increase public awareness regarding water management, promote new circular economy business models within the wastewater cycle, attract public and private funding for the upscaling of the technologies developed, and develop adequate policy and regulatory measures to support its implementation (Water Mining, 2020).

The ultimate goal of the project is to increase access to clean water and sanitation for all through the identification of new sources of usable water. As such, administrative bodies that are interested in improving their water management may also be interested in the outcomes of the project, positively impacting those who live in their regions.

Finally, the project offers business opportunities for companies interested in implementing the project's methodologies and joining the market generated by new sources of valuable products.

1.3.2 The Water Mining Case Study in Faro-Olhão WWT plant, Portugal

In the WM project, water is seen in three different forms: (i) resource, (ii) consumable and (iii) durable. In the perspective of water as a consumable, and to achieve the goals of the Water Mining project, large-scale demonstrations were designed within the WM project in the Netherlands, Portugal, and Cyprus.

The scope of this thesis will be the Portuguese case study only, where an innovative method of treating wastewater is currently in place – Nereda technology.
The Nereda technology is an innovative method of treating wastewater, allowing both a significant reduction of the operating expenditure (OPEX) and high levels of nutrient recovery. Thanks to this emerging technology, it has been possible to reduce the WWTP carbon footprint by 50% and energy savings up to 50% are expected.

The Faro-Olhão wastewater treatment plant (WWTP) is located on the Algarve in southern Portugal, to the east of the city of Faro. The plant provides a service to a population of 113 200,

being able to support a maximum flow of 28 820 cubic metres (m3) per day. The sludge line is designed for production of approximately 8 000 kg/day (Águas do Algarve, 2022).

Currently, in the Portuguese case study, the recovery and production of a bio-based product from the residues of wastewater treatment - biopolymer called Kaumera Gum - for posterior application, is being tested. In the second half of 2022, a pilot plant for kaumera extraction will be installed in the WWTP of Faro-Olhão (Water Mining, 2020).

The pilot installation consists of four portable containers (Figure 1). One key component of the installation is a 20ft container with separation equipment (disc centrifuge (5) and decanter centrifuge (3)). This container is stacked on a larger 40 ft container with general equipment like pumps, tanks and control cabinet (6). Two additional containers harbour a steam generator to heat the sludge (7) and chemical storage and dosing equipment (8). Finally, two reactors for extraction (2) and for cooling and precipitation of the Kaumera (4) are part of the installation. The WM pilot is containerized and transportable, making it easily adjustable to different wastewater treatment plants.

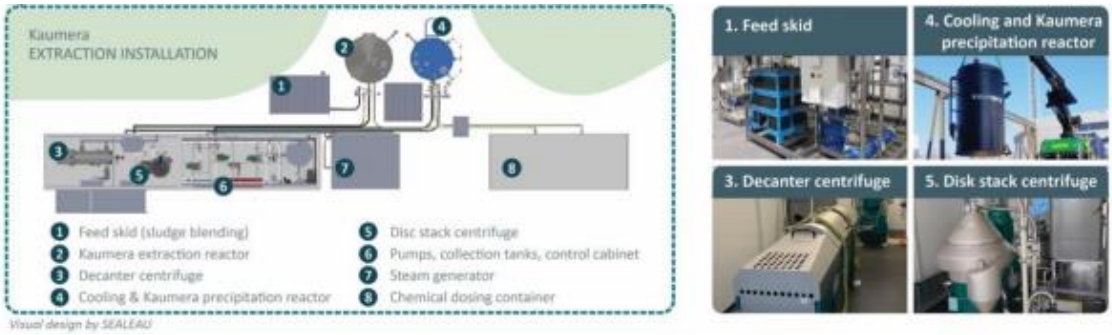

Figure 1. Representation of the Kaumera extraction installation in the Faro-Olho WWTP. Source: Water Mining, 2020.

1.3.3 Technological context

The WWT sector is recently facing a new paradigm. For a long period of time, the conventional activated sludge (CAS) process was used as the standard WWT method (Giesen et al., 2013). Despite the fact that the CAS process is capable of extensively remove biological nitrogen and phosphorous, disadvantages such as intensive energy usage, slow settlement of flocculent biomass, and large system environmental footprint (Pronk et al., 2017) triggered the development of more sustainable and efficient solutions.

Nereda technology, developed at Delft University of Technology (TU Delft) in the early 2000's, presents promising results to overcome some of the disadvantages mentioned above (Pronk et al., 2017). The Nereda technology is based on specific characteristics of aerobic granular biomass, including high biomass retention and nutrient removal.

The aerobic granules are formed by two distinct zones. An anaerobic inner core and an aerobic outer layer. When aerated, an oxygen gradient is formed between these two zones.

In the aerobic outer layer of the granules, nitrifiers and heterotrophic bacteria multiply, enabling the breakdown of organics (removal of COD) and nitrification (conversion of ammonia to nitrite/nitrate), respectively. In the anoxic core of the granules, nitrates that have been produced as a result of nitrification are simultaneously converted to nitrogen gas by denitrification. The aerobic granules' PAOs allow for improved biological phosphorus removal, which involves phosphate uptake during aeration and subsequent removal of phosphate-rich

waste sludge from the system. Therefore, without the requirement for separate anaerobic and anoxic compartments or tanks, aerobic granular sludge can perform biological nutrient removal in a single tank (Pronk et al., 2017).

Comparatively, activated sludge systems that can remove phosphorus and nitrogen through biological means need at least three tanks (anaerobic, anoxic, and anaerobic) and frequent recycling between the tanks (Niermans et al., 2014).

The Nereda system operates in a cyclical process consisting of three stages: (i) simultaneous influent and effluent withdrawal; (ii) aeration/reaction; and (iii) settling (Figure 2), all occurring in a single reactor.

Granulation can be accomplished using an incremental start-up procedure using either granular seed sludge from another Nereda plant or activated sludge for seeding.

Conventional pretreatment is performed before Nereda systems, which includes screening, grit removal, and, depending on the application, FOG (fats, oils, and greases) removal. Primary sedimentation is optional. While lower and deeper reactor depths are feasible, typical reactor depths range from 5.5 to 9 meters. The Nereda system does not require supplementary settling tanks or substantial sludge recycles (Niermans et al., 2014).

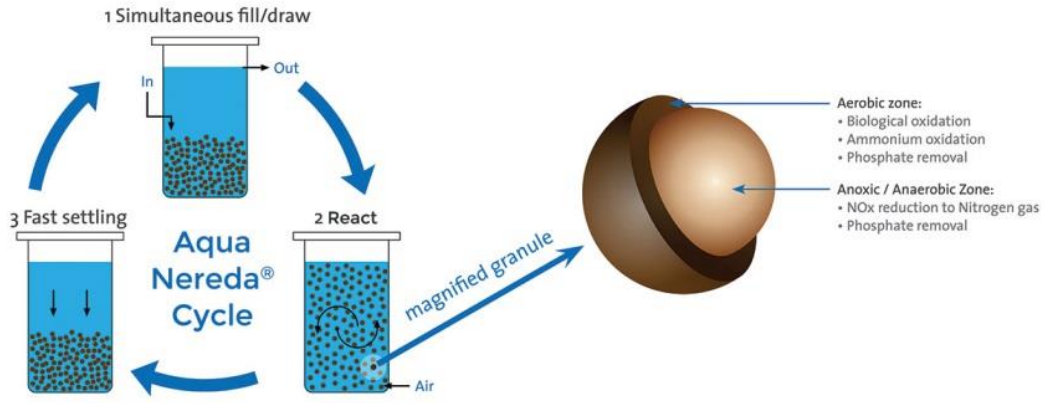

Figure 2. Phases of Nereda process cycle. Source: Niermans et al. (2014).

Compared to CAS systems, Nereda technology results in a reduction of energy consumption of 20-50% and overall treatment system footprint by 25–75%, due to higher biomass concentrations in the reactor and the elimination of secondary settling tanks (Pronk et al., 2017).

Recent research at TU Delft revealed the opportunity to recover alginate-like exopolysaccharides (ALE) from aerobic granular sludge. ALE extraction for excess Nereda sludge was patented as Kaumera Nereda Gum, a new bio-based raw material. It was found that sludge granules contain between 20 to 30% of ALE. Turning WWT services into resource production systems is essential to achieve a circular water economy. The Nereda technology shows the opportunity of incorporating a Kaumera extraction unit.

The recovery of Kaumera has been shown to a contribute for the reduction of 20–35% of sludge production that needs treatment, resulting in a favourable impact on energy use and CO2 emissions.

Due to its unique properties, multiple potential applications are being studied for Kaumera. The characteristics of Kaumera Nereda Gum can be altered by mixing it with another raw material. In this sense, Kaumera is an amplifier and connector of properties, for example, as a component of lightweight composites. Because of this, numerous application possibilities are ensured. In addition, the water can be both repelled and retained by the kaumera. This opens up a wide range of possibilities, such as in horticulture or agriculture, with potential use cases and benefits for these industries including the reduction of fertiliser leaching in agriculture and the better fertilizer absorption by crops. The water-repellent qualities of Kaumera also make it a superior coating for concrete flooring, which can be useful for construction businesses.

1.4 Problem Statement and research questions

Until now, the literature shows the application of S-LCA studies from manufacturing to energy and agriculture, or even information & communication sectors (Di Cesare et al., 2018; Ekener et al., 2018; Ramos Huarachi et al., 2020; Tsalidis et al., 2020). However, only eleven studies focus on WWT systems (Serreli et al., 2021) (see Chapter 2). Furthermore, no studies were found for the particular case of WWT for the recovery of Kaumera. In addition, there are limited S-LCA studies (Rugani et al., 2014; Subramanian et al., 2018) that have a prospective approach for emerging technologies.

E-LCA and S-LCA differ, among others, on the fact that social impacts in product life cycles can also be positive. Social conditions do not simply need to be protected from deterioration, which is the main concern of most S-LCAs that end up focussing on negative impacts (Serreli et al., 2021). Instead, social conditions must be actively sought to improve. Another key difference is that the data that each of the studies is interested in building upon are different. While the focus of an E-LCA is the evaluation of environmental impacts, and hence focussing on collecting mostly quantitative data, the S-LCA measures the social and socioeconomic impacts, automatically though not exclusively, comprising more semiqualitative and qualitative data (UNEP, 2020).

The following problem statement will be used in the present research proposal.

A knowledge gap in S-LCA literature regarding the application of the framework to the Nereda technology for WWT has been observed, given the innovative feature of the technology and the pioneering nature of the Portuguese case study. So far it has not been found any record of studies that lean over what are the social benefits of WWT for resource recovery.

As such, the current study aims at performing the first S-LCA in WWT industry with a circular economy perspective, with a particular focus on what are the social benefits of WWT for resource recovery in Portugal and respective indicators, and which hot-spots of the WWT S-LCA system influence the results of the study.

Following the stated research problem, the main research question is proposed below:

What is the social performance of the Water Mining urban WWT system and how does it compare with the current WWT system applied in Faro-Olhão, Portugal?

The research question will be answered by applying the S-LCA methodology proposed by the UNEP/SETAC Guidelines. The following sub questions will logically lead the study to answer the main research question:

1. Based on the generic approach of the S-LCA, what social impacts will be prioritized in the site-specific assessment?

2. What are the social impacts of the Faro-Olhão WWT system identified through the S-LCA and how can these be improved?
3. What are the social impacts along the value chain of the WM system, and can they be compared to those from the current WWTP?

1.5 Research Relevance

The master thesis study intends to quantify the social performance of a WWT system for resource recovery in Portugal. Since no studies that analysed the social performance of WWT with Nereda technology were found in the literature, the current proposal is a valuable contribution to the academic field. Furthermore, the social assessment of the implementation of WM technologies at the plant level may contribute to the identification of potential necessary improvements, before the full-scale application of the proposed technologies.

The current project is relevant for the field of industrial ecology since it enhances the concept of circular economy within the WWT industry, by addressing a WWT technology that allows resources recovery, namely the Kaumera. The societal relevance of the current research is intrinsically related with the goal of the study. By identifying the social performance of the WM system, recommendations and strategies to promote the benefits and reduce the negative effects can be drawn. As a consequence, the study lies down the path for WM system to deliver an increased value proposition for the entire water value chain, which is a sector that plays a vital role in any society. In this sense, a clear contribution to the improvement of social conditions and socio-economic performance is observed.

1.6 Thesis Structure

The remainder of this thesis is organized as follows.

Chapter 2 presents a literature review on S-LCA and the wastewater treatment sector that sets the stage for the upcoming assessment.

Chapter 3 presents the UNEP/SETAC S-LCA method, the framework that is on the basis of the performed assessment, and explains its main characteristics, its structure and the most relevant phases of the framework.

Chapter 4 presents a detailed explanation of the application of the methodology for the specific case study of the water mining project in Portugal, going through the framework's main phases of the framework and explaining the process of both the generic and site-specific assessment while exposing the necessary assumptions.

Chapter 5 starts by presenting the results of each assessment, providing an extensive explanation of the outcomes, while Chapter 6 leans over the initial interpretation, including consistency and completeness verifications, as well as considerations on different sensitivity analysis that help on the understanding of the results.

Chapter 7 discusses the application of the guidelines and the suitability of the key modelling decisions throughout the framework, highlighting main features, limitations, and areas of improvement of the applied methodology.

Finally, Chapter 8 presents the insights regarding a self-reflection and applicability of the S-LCA method to the WM case study, and Chapter 9 summarises the achievements of this master thesis, addressing the research questions and sub questions stated above, before mentioning

potential topics for future research that might be relevant to pursue after the assessment presented in the current project.

2. S-LCA and the wastewater treatment sector – a literature review

The application of S-LCA to study the social impacts of a product or service has increased in recent years, along with the development of this tool. The majority of S-LCA studies have been conducted within the manufacturing sector, with the chemical manufacturing sector as the main focus of attention. In addition, the utilities sector has also been addressed.

Regarding social analysis performed to the wastewater sector, the number of studies tackling the topic is not extensive (Serreli et al., 2021). Until now, S-LCA studies have mainly addressed products and not industrial waste. Nevertheless, Serreli et al. (2021) recognizes the relevance of WWT services both from an environmental and social point of view.

A study by (Padilla-Rivera et al., 2016) quantified social performance to assess and compare two distinct WWTPs in Mexico in both urban and rural locations. Based on the UNEP/SETAC Guidelines, twenty-five indicators were defined and classified according to the stakeholders involved – Community and Society, Workers, Consumers and Supply chain actors - to measure social performance. The assessment allowed the identification of key stakeholders involved in the WWT service as well as barriers in both facilities. Overall, the urban facility showed better performance, showing better results for three of the four stakeholders (local community and society, workers, and consumers). According to the authors, this result might be connected to the better socioeconomic context of the urban municipality.

(Opher et al., 2018) performed an analysis on the site-specific level to assess the social benefits and impacts of four alternatives to urban domestic non-potable water reuse. Alternative 1 (base case scenario) entails a central WWT with no urban reuse and discharged to nature. In alternative 2 the central WWT is kept but with the reuse of WWTP's tertiary effluent. As for alternative 3, a semi-distributed greywater treatment and reuse is assessed at a cluster scale. Lastly, in alternative 4 a distributed greywater treatment and reuse, within each apartment building is studied. The impacts of the four alternatives were evaluated on the public, community, and consumer stakeholders. Moreover, an analytic hierarchy process (AHP) was applied to attribute weights to social categories and subcategories based on expert judgment. The results indicate that a distributed system (alternatives 3 and 4) is more advantageous in terms of water savings and urban landscape. While alternative 3 show social benefits on community engagement, the other options showed a lack of it. Alternative 1 scored highest in the categories: public equality, consumer health concerns, and consumption habits. The final scores indicate that the social benefits of distributed greywater treatment are significantly greater than those of centralised WWT. In terms of method, the authors recognize quantifying qualitative indicators and homogenizing indicators results into a uniform comparable scale as a challenging task in a S-LCA. In that sense, participatory approaches are advised to enhance experts and stakeholders' participation.

Shemfe et al. (2018) examined the potential social risks along the supply chain of bioelectrochemical systems (BES) and its components for resource recovery from wastewater treatment in the UK. In particular, the recovery of copper and formic acid was addressed. The assessment was performed according to the UNEP / SETAC Guidelines. Results show that around 75% of the components were imported from the European Union but the social risk revealed to be independent of the magnitude or country of imports. In terms of impact categories, "Labour and Decent Work" was signaled as the most critical impact category in all countries of imports.

To conclude, the authors recognise BESs as a promising technology for resource recovery from wastewater. To properly understand potential societal concerns, it is advised that future study efforts should focus on stakeholder participation.

Amaral et al. (2019) performed a LCSA to assess the treatment and disposal of biological sludge and biogas in a WWT facility in Brazil, accounting for the impacts at the level of workers, consumers, local communities, and society stakeholders. Four different scenarios were designed in order to perform the sustainability assessment. In the base scenario, the sludge is sanitized and used for agriculture purposes while the biogas is destroyed in an open flare. In scenario 1, the biogas is used to dry the sludge, which is then applied in agriculture. Finally, in scenarios 2 and 3 the sludge is combusted, and the heat generated is applied to dry the dewatered sludge. While in Scenario 2 the produced ashes used in agriculture, in scenario 3 the ashes are discarded in a sanitary landfill. Scenario 2 obtained the best score on the social dimension. In terms of social impacts, biological risk obtained the worst score in the social assessment on the four scenarios. For the overall sustainability assessment, Scenario 1 presented the highest score.

Recently, the social impacts of the water system in Mexico City were analysed by (García-Sánchez & Güereca, 2019) performing an S-LCA to the entire urban water system, from water abstraction to wastewater treatment. The analysis focused on the impact generated on workers. The author used working hours, fair wages, health and safety conditions, social security, and professional development as subcategories. Main results indicate that the transport stage had the best social performance score and that the total system presented regular performance in health and safety conditions. Considering the social dimension of the Mexican water system and in line with the definition of decent work from the current SDGs, the authors suggest tougher regulations regarding workers health and safety conditions.

In a study by (Padilla-Rivera & Güereca, 2019), a sustainability assessment framework is proposed for WWTPs. A life cycle thinking approach was applied to evaluate the environmental, social and economic aspects of four WWTPs (two in Mexico and two in the USA). In addition, a fuzzy logic analysis, was used to develop a Sustainability Global Index (SGI) to rank the four alternatives. The study considered four stakeholders, including workers, consumers, community and society, and supply chain. In terms of the sustainability analysis, the facilities located in the USA achieved the highest SGI. Regarding the social dimension, the two facilities in the USA showed better results, mainly due to a better wage salary and decent working hours. On the other hand, the facilities in Mexico obtained very low performances in most of the social indicators. According to the authors, the poor social performance of the Mexican facilities might be related to socio-economic context of the country, which presents a weaker education system and working conditions when compared to the America facilities.

(Foglia et al., 2021)performed a cost benefit analysis and S-LCA to evaluate the economic and social impacts of innovative WWT and resource recovery technologies (SMARTechs). The analysis was carried out on WWTPs in Europe and in the Mediterranean basin that use SMARTechs. More specifically, nine SMARTechs were investigated on both economic and social dimensions. In general, when compared to a baseline scenario (no SMARTech), the implementation of SMARTechs result in benefits both to at the environmental and social levels. Besides, the authors highlight a global positive social impact of all the SMARTechs concerning technical characteristics and social acceptance.

(Muhammad Anwar et al., 2021) suggests a socio-eco-efficiency analysis (SEEA) framework for the evaluation and comparison of different wastewater treatment techniques. The SEEA

framework combines the social factors assessed by an S-LCA utilizing AHP, with the economic and environmental components examined by an eco-efficiency analysis (EEA). The framework was used to compare four WWT scenarios in a refugee camp in Jordan. Very briefly, scenario 1 represents the novel WWT operation and scenario 2 implements a simplified piped network. Scenario 3 is similar to scenario 2 incorporating effluent water reuse. From the AHP, the authors concluded that the indicators that hold the highest weight in the analysis are 'Lower incidence of water-related illnesses', 'Increased diligence of residents in reducing damages', and 'Adequate ownership of water, sanitation, and hygiene facilities. Results indicate scenario 3 as the most efficient at the social, environmental, and economic levels.

With regard to the treatment of wastewater from industrial processes, the S-LCA studies by (Serreli et al., 2021; Tsalidis & Korevaar, 2019) stand out.

Serreli et al. (2021) performed a socioeconomic assessment to a full-scale plant designed to treat three different types of wastewater generated by a microelectronic company. The use of the PSILCA database to assess WWT services was performed for the first time by Serreli et al. (2021), with the evaluation of 65 social indicators regarding WWTPs. Results show that the most abundant wastewater stream is responsible for the highest impacts. In terms of the stakeholders, local community and value chain actors are the most impacted. The indicator "Contribution to environmental load" is where the result for the Local Community comes from. The Value Chain Actors stakeholder is most impacted by the indicators "Corruption" and "Social responsibility along the supply chain." The author concludes that most social risks originate from upstream sectors.

Lastly, the social impacts of a Zero Liquid discharge technology used to recover clean water, magnesium, and sodium from an industrial brine treatment systems were assessed by Tsalidis and Korevaar (2019) within the scope of the Zero Brine project. In addition, the study aims to investigate the applicability of the S-LCA framework in industrial decision-making processes. The authors conducted a S-LCA to a case study of the Zero Brine project at two levels of analysis: hotspot and site-specific. Their findings indicate that the implementation of the zero-brine system would results in societal benefits on both levels of analysis. In particular, on the subcategories pertaining to the Workers stakeholder (e.g., "Health and safety," "Freedom of association and collective bargaining," and "Fair salary"). In terms methodology, data collection and the selected scoring system were considered sources the main of uncertainty when converting qualitative data into quantitative data. Finally, the authors considered S-LCA a complex but suitable tool for decision makers to use.

Table 1 provides an overview of the S-LCA studies conducted within the wastewater and resource recovery sector. The stakeholders included in the studies as well as the functional units are specified.

Table 1. Overview of S-LCA studies performed to the wastewater and resource recovery sector.

Author	Goal of the Study	Stakeholder addressed	Functional Unit
Padilla-Rivera et al (2016)	Evaluation of the social implications related to WWTPs in Mexico. The methodology is based on sustainability indicators as a framework for measuring wastewater management and its progress towards sustainability. This approach can disclose the hotspots in social issues related to sustainability, which in turn can lead to strategies and policies to support the development of sustainable WWTPs.	Workers; Consumers; Community and society; Supply chain	Not defined
Opher et al (2018)	Evaluate the social benefits and impacts of four distinct water management approaches adapted to an urban environment. The general framework and approach of S-LCA was applied.	Public; Local community; Consumer	The supply, reclamation, and reuse of water consumed by the city during 1 year.
Shemfe et al. (2018)	Examine the potential social risks of bioelectrochemical systems (BESs) for wastewater treatment along its supply chain, addressing two resource recovery functions: copper recovery and formic acid production.	Workers; Society; Local community; Value chain actors; Society	1 kg Cu recovery and 1 kg formic acid production
Amaral et al (2019)	Evaluate the sustainability (environmental, social and economic assessment) of different destination routes for biological sludge and biogas coming from anaerobic WWTPs, to support the selection of technologies to be used in future WWTPs and to assure the adequacy of those in existence.	Workers; Consumers; Local community and society	1 m3 of treated effluent
García-Sánchez and Güereca (2019)	Assess the environmental and social performance of the water system in Mexico City with LCA. The study aims to identify the stages and processes with significant environmental and social impacts and analyze the implications of moving toward a sustainable water system.	Workers	1 m3 of water for human consumption
Padilla-Rivera & Güereca (2019)	Develop an integrated sustainability assessment tool that evaluates the social, economic and environmental performance of WWTPs.	Workers; Consumers; Community and society; Supply chain	1 m3 of water for human consumption
Foglia et al. (2021)	Assess the economic and social aspects of innovative resource recovery technologies built in sixteen bottom-up scenarios, where different SMARTechs are implemented. The study used CBA and S-LCA as methodologies to evaluate the impacts of wastewater-based resource recovery technologies.	Workers; City/Society; Consumers; Value chain actors	Not defined
Muhammad Anwar et al. (2021)	The objectives of this study are: (i) to develop a socio-eco-efficiency analysis (SEEA) framework as a decision-making aid tool in accordance with the tripartite sustainability model for water and wastewater treatment, and (ii) to compare the environmental, economic, and social implications of different water services in Jordan as a case study.	Local community; Consumers	1 m3 of treated wastewater
Tsalidis & Korevaar (2019)	Apply S-LCA on the hotspot and site-specific levels to quantify, for the first time, the societal effects of recovering magnesium in a dewatering company's plant in The Netherlands, instead of importing it from Russia.	Workers; Consumer; Local community; Society; Value chain actors	1400 m3 of ultra-pure demineralized water, 114 kg salt, and 0.92 kg magnesium
Serreli et al. (2021)	Assess the socio-economic impacts of a full-scale plant designed to treat different types of wastewater generated by a microelectronics company. The assessment of a new technology developed to treat the wastewater generated during the production of electronic components and semiconductors has been carried out through the PSILCA (Product Social Impact Life Cycle Assessment) database implementation.	Workers; Local community; Society; Consumers; Value chain actors	Annual amount of wastewater generated
Tsalidis et al. (2020)	The societal benefits and risks in emerging brine treatment systems were quantified. A S-LCA was performed at the hotspot and site-specific levels on four case studies of the Zero Brine project. The hotspot analysis aims to complement decision making regarding of purchasing equipment and the site-specific analysis aims to identify current social impacts in order to improve.	Society and Local community; Society and Value chain actors; Consumer;	1 Zero Brine full scale plant
Tsalidis et al. (2021)	Perform a S-LCA in order to investigate how the expansion of system boundaries affects both the completeness of social scoring and the social performance of products. The methodology was applied to two case studies.	Workers; Consumers	Not defined
Sadhukhan et al. (2019)	Perform a sustainability assessment of marine biorefinery systems is performed via an analysis of economic, environmental and social aspects of macroalgal biorefinery systems for the recovery of products and resources.	Labour rights and decent work, health and safety, human rights, governance, community infrastructure	Not defined

3. The UNEP/SETAC S-LCA Method

This section gives a brief description of the four phases that an S-LCA entails.

3.1 Goal and Scope definition

In the first phase of an S-LCA study, namely the definition of the goal and scope, the methodological framework, object, and purpose are decided. Decisions made at this stage are of superior importance because they determine the execution and ultimately the study's results (UNEP, 2020).

3.1.1 Goal definition

During this first step, the goal or the goals of the study are defined by answering a set of questions. In this phase, the intended use of the study, the target audience, the assessment objectives (e.g., support of decision making) and the relevant stakeholders should be detailed in this phase.

According to (Zanchi et al., 2018), the study's perspective depends on the party's bearing responsibility for the consequences of a decision or actions, which is an important element that affects S-LCA applications. In addition, considering that S-LCA studies are used in the decision-making process, it is important to highlight that company and social perspectives often differ and stakeholders are possibly interested in different types of information or results. For that to be effectively addressed, a detailed definition of the study's goal is necessary but often not thoroughly addressed by researchers (Zanchi et al., 2018).

3.1.2 Scope definition

The scope encompasses the object and the methodological framework of the study, comprising its target depth and breadth and being in close alignment with the goal set in the previous step. During the scope definition, the main features of the product system under study are described, namely the functions of the product system, the functional unit (FU), the system boundary, the stakeholder categories, the social impact (sub)categories and indicators (UNEP, 2020).

3.1.3 Functional unit

The function offered by the product or service under examination is the object of an LCA study. This is defined by the functional unit, in terms that it can be objectively measured and in consistency with the Goal and Scope of the study.

During the process of defining the functional unit, the consumer's perception, desires and choices in respect to the product are captured. The main function and product utility in technical or social terms (e.g., functionality, quality, price, location) is taken into consideration during the definition of the functional unit, which is relevant for enabling a comparative assessment of two or more products on an equivalent basis (UNEP, 2020).

Interestingly, while in E-LCA the definition of FU is already a complex task given the multiple functions a product might have, in S-LCA this becomes even more challenging (Pollok et al., 2021). According to (Dreyer et al., 2006), since in an S-LCA the analysis of the impacts is carried out in an organisational and not on a process level, the physical link between the impacts and the product's function is not direct neither easily quantifiable. In reality, social impacts do not often rely on quantifiable physical flows but on social flows and phenomena, which are mainly of qualitative nature (Pollok et al., 2021). Therefore, the connection of social impacts (or impact

indicators) to the FU or the normalisation of the data according to it is not straightforward. Indeed, the UNEP/SETAC Guidelines clarify that when dealing with semiquantitative and qualitative data, the social impacts will not be expressed in relation to the functional unit. In this respect, some authors support a non-FU based S-LCA perspective.

For instance, a FU defined for an airplane as a "100 km travelled by a 70 kg passenger with 30 kg luggage and an aircraft load factor of 80% on a generic flight profile" (Barke et al., 2020) can hardly be linked to social effects, such as workers' freedom of association. Additionally, causal relationships are mostly unknown. The example from Barke et al. (2020) illustrates the conflict that arises when a functional unit and a company perspective are implemented within the same framework.

In fact, how to link social indicators to functional unit in a S-LCA, is one of the main subjects discussed by researchers (Parent et al., 2010; Zanchi et al., 2018). Most S-LCA studies define a functional unit, particularly when S-LCA is conducted within the context of a larger sustainability analysis, where consistency with E-LCA and LCC is needed (UNEP, 2020). However, several works assert that the functional unit is only used to better understanding of the scope of the assessment (Zanchi et al., 2018).

Dreyer et al. (2006) suggests the development of mechanisms to link the social profiles of organisations to the product under study. In particular, a share factor or activity variable can be used to express the weight of a company in the product system, reflecting the importance of that company in the life cycle. Other solution, suggested by Parent et al. (2010), is to relate the elementary flows or social stressors to the functional unit so the indicators results are proportional to the functional unit themselves. In this case, a quantitative causal effect chain carries a link between inventory data and functional unit over an impact pathway.

3.1.4 Reference flow

According to the UNEP/SETAC Guidelines, the reference flow refers to a specific product or service that is consumed or produced by the product system. The relationship between the reference flow and the functional unit in an S-LCA is that the reference flow is the quantity of a product or service that is under analysis, while the functional unit is the unit of measurement used to express that quantity.

3.1.5 Product system

A product system in a social LCA contributes to the definition of the scope of the assessment and it comprises a set of activities, inputs, and processes that are required to produce a certain product or perform a given service. The product system may include all the stages of the product's life cycle that are relevant for the assessment. According to Parent et al. (2010), process databases or input-output models can be used to identify the economic activities and processes behind the production of a product.

In E-LCA there is a direct link between physical inputs or outputs and the environmental impacts on the surrounding environments (Parent et al., 2010). Therefore, environmental impacts are closely related to processes performance, which requires a clear identification of these in those in the product system. On the contrary, the focus of an S-LCA is on activities in the life cycle of a product that affect people. In that sense, as social impacts are primarily independent of the physical conditions of an industrial process (except direct health impacts on workers), a process level analysis is not the most indicated for a S-LCA (Dreyer et al., 2006). In turn, social impacts on people are considered conditioned by the conduct of companies in the product chain (Dreyer

et al., 2006) . The group of people directly or indirectly affected by a company's business activity is then considered the company stakeholders (e.g. workers, local community, consumer) (UNEP, 2020). This type of analysis is termed an organization-oriented approach, where the product system includes individual companies involved with industrial processes that occur throughout a product life cycle. In this way, S-LCA involves a number of individual company assessments, where the impacts at the stakeholders level are measured and the results should be aggregated to produce the social life cycle profile of the product under study (Dreyer et al., 2006).

Currently, there is no generally accepted consensus on how to properly define the product system in an S-LCA context. Zanchi et al. (2018) recommends a combination of the technology-oriented and the organization-oriented approaches. Furthermore, the author explains that the product system definition influences the type of data required (company, sector or country levels) as well as the system boundaries, which should indicate the double layer of the system under evaluation.

3.1.6 System boundaries

The system boundaries define the unit processes of a product system that will be included in the assessment. They establish the beginning and end points of the life cycle assessment.

The ideal system boundary should be from cradle to grave (UNEP, 2020), but this is not always possible due to goals, resources, or data availability. The term "cradle-to-grave" refers to the entire life cycle evaluation, from the extraction of resources (the "cradle") to the use and disposal phases (the "grave"). An evaluation of a product's life cycle from resource extraction (the cradle) to the factory gate is known as "cradle-to-gate" (i.e., before it is transported to the consumer). And finally, when an LCA considers only one part of the whole production chain it is called gate-to-gate.

The exclusion of unit processes from the system boundaries should be clearly justified. A cut-off criterion can be applied based on processes social significance, identical elements, and available resources (UNEP, 2020). Based on the social significance criteria, processes that have more potential for social concern are included. The identical elements criteria, leaves out similar processes in comparative S-LCAs. One should be aware that the use of cut-off might lead to the exclusion of sensitive issues. In fact, this criteria are not currently applied in a consistent manner in S-LCA (UNEP, 2020).

Zanchi et al. (2018) highlights two approaches to define system boundaries. The first entails the inclusion of only those parts of the life cycle which are directly influenced by the company performing the assessment. On the other hand, the second approach includes the entire life cycle, excluding the processes which are deemed as nonsignificant for the conclusions of the study. Most research focuses on the stages that are deemed to be more important and for which more precise data can be gathered (Zanchi et al., 2018).

In addition, the same author recognises two perspectives of the system that should be considered when setting the boundary of the system. While the physical perspective is based on the technological processes or economic flows that characterise the value chain, the effect perspective addresses the interaction between companies, stakeholders and the relations among stakeholders involved in the life cycle, as a result of the activities carried out (Zanchi et al., 2018).

3.1.7 Stakeholder Categories

The essence of a S-LCA is to improve the social conditions of stakeholders (Tokede & Traverso, 2020). In that sense, stakeholders entail the groups that may be impacted by the actions of organisations participating in the life cycle of a product, service, or organization under review. Therefore, groups that might be affected by the conduct of the organizations within the system boundaries ought to be addressed. Six stakeholder groups are suggested by the UNEP / SETAC Guidelines: workers, consumers, local communities, society, children, and other value chain actors UNEP, 2020). According to (Petti, Serreli, et al., 2018), workers is the stakeholder more considered in S-LCA studies, followed by the local community. As oppose, value chain actors and consumers are the stakeholders less addressed.

It is important to reflect on the stakeholders that will be addressed on a specific study. Practitioners suggest that one can also choose to develop new stakeholder categories or subdivide existing ones, if relevant to the product, service, or organization (UNEP, 2020). Another option is to exclude groups that are not deemed to influenced by the activities under study. Either the inclusion or exclusion of groups, that choice should be based on the relevance of the group to the goal of the study.

3.1.8 Impact categories, subcategories and indicators

Impact categories cover social issues of concern to stakeholders (e.g., human rights, working conditions, cultural Heritage, Governance and socio-economic repercussions). Furthermore, impact categories are used to logically group impact subcategories and to support impact assessment and interpretation (UNEP, 2020).

Impact subcategories encompass socially relevant themes or attributes and can also be directly grouped per stakeholder. In turn, impact indicators establish the link between social data, impact categories, and subcategories (Figure 3) (Subramanian et al., 2018). Impact subcategories are assessed using impact indicators, for which inventory data is needed. Moreover, social indicator can be either quantitative or qualitative. A subcategory can be assessed through more than one indicator, and, usually, these are context-dependent (UNEP, 2020).

The isn’t a standardised set of indicators, instead indicators are mostly selected based on their relevance in sector, on literature review, or generic assessment results (Bonilla-Alicea & Fu, 2021).

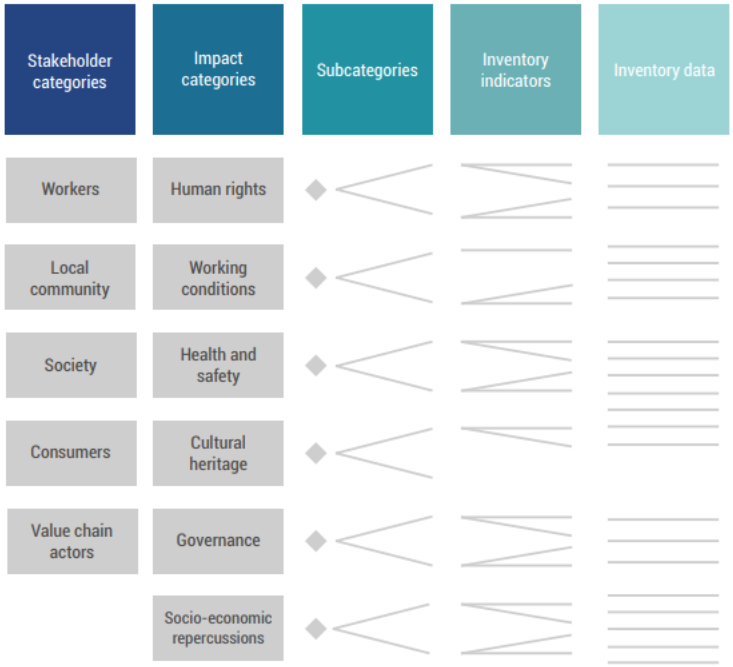

Figure 3. Impact Categories, subcategories and indicators. Source: UNEP, 2020.

3.2 Life Cycle Inventory

The objective of the Social Life Cycle Inventory (S-LCI) is to collect and organise data for unit processes within the system boundaries in order to perform the impact assessment (Bonilla-Alicea & Fu, 2021). Data collection can be the most time-consuming, energy-intensive, and challenging step of an S-LCA. The need for information on the one hand, combined with its reduced availability on the other, is a major limitation that one might encounter during the S-LCI phase (UNEP, 2020).

To tackle this problem, the Guidelines suggest prioritizing and evaluating the relative importance of all product system activities. Thus, the data-gathering process involves several layers of collection based on the priorities of the assessment set in the goal and scope definition. Depending on the goal of the study generic or case-specific data may be used. In particular, three types of data are suggested in a S-LCA: (i) data on activity variables, which is applied to assign a socially relevant weight to unit processes when dealing with qualitative and semiquantitative indicators that cannot be referred to the functional unit directly; (ii) data on social conditions or stressors that will be converted into impacts (the inventory data); and (iii) data necessary to compare the local situation to an international set of thresholds (Parent et al., 2010; Toniolo et al., 2020).

Frequently, site-specific assessments prioritise primary data, while generic assessment uses more secondary data. According to the UNEP/SETAC Guidelines, primary data can be collected through direct contact with organisations and companies, as well as on-site observation of production processes and interviews or surveys with affected stakeholders. Secondary data, on the contrary, can be gathered through a literature review, a web search, or existing databases. Databases can be used to better understand of the social conditions of a country or a sector,

and they offer generic data on indicators (Parent et al., 2010). The Product Social Impact Life Cycle Assessment (PSILCA) is an example of a database that has been directly adapted to the needs of S-LCA and developed in accordance with the Guidelines.

3.3 Life cycle Impact Assessment

The goal of the social life cycle impact assessment (S-LCIA) phase of an S-LCA is to quantify, comprehend, and assess the potential social impacts of a product system over the course of the product's life cycle. It can be used to estimate future potential social impacts of an emerging or non-existent system, or to investigate past or present potential social impacts linked to a system (UNEP, 2020). From an organizational point of view, the SLCIA involves the social repercussions on stakeholders derived from companies conduct (Dreyer et al., 2006).

During the S-LCIA a characterization process is used to aggregate the inventory results within the same impact category. According to UNEP/SETAC Guidelines, in S-LCA the characterisation models might be a simple aggregation step, combining text or qualitative inventory information into a single summary or summing quantitative social and economic inventory data within a category. Nevertheless, characterization models can also be more complex.

A fundamental step of an S-LCA is the choice of the type of impact assessment that will be used, as it will have implications on data collection during the inventory phase. However, there is no consensus regarding impact assessment methods neither application standards (Arcese et al., 2018). In fact, since the first appearance of S-LCA scientific research to develop the associated theoretical framework has increased. Over the years, the number of S-LCA papers has increased, developing theoretical viewpoints on the topic by combining knowledge from the UNEP/SETAC Guidelines with various contributions in the literature. This led to different impact assessment approaches (Arcese et al., 2018).

In general, two main impact assessment approaches in S-LCIA are identified: the Reference Scale (RS) Approach, also known as Type I, and the Impact Pathway also known as Type II. The next sections describe the two families of S-LCIA independently. Throughout the years, the two impact assessment approaches experienced distinct development and implementation trends. While RS approaches are operational at present and several case studies exist, IP studies mostly pertain to the field of research (UNEP, 2020). According to Ramos Huarachi et al. (2020), the main difference between the RS and IP approaches is the characterisation method used to assess the indicator results, producing distinct outcomes. While RS approaches assess social performance, IP approaches measure social impacts.

Researchers do not promote one approach over the other (Petti, Serreli, et al., 2018; Serreli et al., 2021). However, the choice between type I and type II approaches is based on the characterization models, indicators, data availability and the aim of the study.

The sections below describe the RS and IP approaches individually.

3.3.1 Type I Impact Assessment method - Reference scale

Reference Scale Assessments are based on data, information or judgment, and typically yield results that are primarily related with practices of the organizations that stand within the system boundaries, considering frequently their immediate evaluation, i.e., no additional effects propagation is considered. As a result, the RS approach seldom establishes a connection between the activity and its potential impacts in the long run. Instead, the approach focusses on

available data to infer the magnitude and importance of social effects in a precise location along the impact pathway relationship (Russo Garrido et al., 2018).

Macombe et al. (2013) stated that this approach evaluates social performance of organizations along a value chain instead of social impacts, defending that social impacts could only be understood through a thorough analysis of causality chains. Furthermore, Russo Garrido et al. (2018) explains that the definition of type I S-LCIA should be based on the fact that it aims to qualify whether the data collected about an observed situation corresponds to a negative or a positive performance or to a high or low risk of encountering negative performance or to varying degrees in between those two extremes (Russo Garrido et al., 2018).

The RS approach relies on context-dependent Performance Reference Points (PRPs) to evaluate the social performance of processes and organization within the product system. Concretely, PRPs can be targets, thresholds or objectives defined by local legislations, international standards or industry best practices and are designated as normative reference points. In addition, PRPs can also be based on other reference points such as country or industry average values (UNEP, 2020). The use of PRPs enables the conversion of qualitative data collected through site visits, interviews or surveys into measurable semiquantitative data. By this means, subcategory indicator results are aggregated in impact category results (characterisation) affecting different stakeholders (Pollok et al., 2021).

The Guidelines introduce six type of performance reference points for the RS approach: 1) based on specific norms, practices, and best practices; 2) based on norms, practices, best practices, and the socio-economic context of unit processes; 3) the generic form is maintained and the scale is not specified; 4) based on comparisons with the sector average or distribution; 5) based on a combination of specific norms and positioning on a distribution; 6) based on a combination of expert knowledge and even portions of a distribution (UNEP, 2020).

There are many different RS methods that can be grouped into one of the following categories: (1) checklist methods, (2) scoring methods, or (3) database approaches. Checklist methods use ticks and dashes to identify the presence of an impact. Consequently, it does not provide the magnitude of impacts and is mainly applied to reduce the list of subcategories and indicators to the most relevant ones or to define the importance of one impact category over another. On the contrary, database methods use databases (e.g., SHDB or PSLICA) and social risks levels (low, medium, high or very high risk) of countries, sector or stakeholders.

Scoring methods are the most common type I method used (UNEP, 2020; Pollok et al., 2021). In this case, impacts are evaluated based on scores that represent different impact levels. The reference scales established for scoring are usually ordinal, with each level corresponding to a PRP (UNEP, 2020). In addition, the RS for scoring can include negative or/and positive impacts associated with the different impact levels. The levels can be either numerical or non-numerical (e.g., colour code) (UNEP, 2020).

The review by (Ramos Huarachi et al., 2020) reveals a great diversity of scoring methods or frameworks for the RS impact assessment approach. In this sense, scoring methods are not a commonly accepted approach in S-LCA (Fan et al., 2018). Researchers suggest the use of established impact assessment methods or a framework to enhance standardization (Ramos Huarachi et al., 2020). In terms of limitations, scoring methods for the S-LCIA RS approach can also lack accuracy if indicators do not properly reflect their corresponding subcategories, such difficulty can be easily solved by defining indicators that are as representative of the social constructions as possible. Given that the Methodological Sheets (UNEP, 2021) and other S-LCA

studies may be used as resources, this is a rather simple approach. Additionally, a scoring system that takes into account a wide range of characteristics ca be adopted to increase accuracy.

3.3.2 Type II Impact Assessment Method - Impact Pathway

According to the UNEP/SETAC Guidelines and in line with ISO 14044 (ISO, 2006), IP S-LCIA approach is based on social mechanisms or impact pathways that describe cause-effect-chains, establishing a link that represents the relation between a cause and its effect. In S-LCA, social mechanisms comprise social impact categories, impact category indicators, and characterization models (ISO, 2006). Inventory results are classified in impact categories, and based on a characterisation models, impact indicator results are calculated at midpoint or endpoint levels. Midpoint indicators relate to impacts that are midway through the cause-effect chain, while endpoint indicators correspond to the impact at the end of the cause-effect chain. This method resembles E-LCA, where inputs (e.g., CO2 emissions) are connected to midpoint impacts (e.g., environmental issues like global warming) and with additional endpoint impacts, for example, impact on human health (Pollok et al., 2021; Sureau et al., 2020).

In the IP approach, the use of a social impact pathway allows for the assessment of actual or potential long-term social impacts of a product system at different points along the impact pathway (Russo Garrido et al., 2018; Sureau et al., 2020). In this regard, type II has a more empirical approach; however, it is difficult to implement because social sciences typically have poorly constructed causal models (Sureau et al., 2020; Tokede & Traverso, 2020).

Most Type II methods are quantitative, experimental, or statistical and attempt to foresee outcomes based on quantifiable cause-effect correlations or regression-based directional relationships between the product system and the ensuing potential/actual societal repercussions (Pollok et al., 2021). According to Sureau et al. (2020), IP methods are highly heterogeneous and there isn't an established classification of the methods neither a standard regarding application of these. Researchers have proposed broad classifications of the type II method (Pollok et al., 2021). For example, Wu et al. (2014) differentiate between "multiple qualitatively constructed pathways with expert knowledge" and "single and quantitative pathways" (Wu et al., 2014). Additionally, (Chhipi-Shrestha et al., 2015) differentiate methods that use environmental LCI databases to estimate social impacts from empirical methods, which use empirical formulas or rules to assess social impacts. A recent study by Sureau et al. (2020) classifies type II impact pathway approaches into three main routes: (1) studies that propose single impact pathways or frameworks gathering several impact pathways; (2) research or test known pathways empirically, mainly linking income data with health issues at a macroscale, and (3) methods that employ well-known impact pathways, characterisation models or factors from other research publications, or impact calculations at the midpoint or endpoint levels.

The main challenge with IP methods is that they frequently call for quantitative data, which are rarely available because the causes of social and socioeconomic effects are often unknown or too complex to be modelled quantitatively. Furthermore, human interactions naturally include the ambiguity of behavioural effects (Pollok et al., 2021).

3.4 Interpretation

The Social Life Cycle Interpretation is the final phase of a S-LCA. In this step, the results of the S-LCIA phase are checked and discussed in depth, forming a basis for conclusions,

recommendations and decision making, aligned with the goal and scope definition. Furthermore, the results are analysed at distinct levels (e.g., life cycle phases, impact categories, impacts subcategories, stakeholder categories, process level). This is a critical phase of an S-LCA that enables the presentation of the results and originates suggestions and potential improvements associated with the subject under study. The Interpretation phase is based on the requirements of ISO 14044 (ISO, 2006), and it comprises of the following steps: completeness check; consistency check; sensitivity and data quality check; materiality assessment and conclusions, limitations, and recommendations.

4. Methodology

4.1 Goal and scope definition

4.1.1 Goal definition

The primary objective of this research is to determine the social performance associated with the implementation of innovative WWT and resource recovery technologies in Portugal. In particular, the social risks related to the implementation of Nereda technology and Kaumera Gum recovery in the Faro-Olhão WWTP will be assessed at the organizational level by assessing the social sustainability performance of the main organizations in the Water Mining system. A secondary objective of the study is to assess the social context of the Portuguese water sector and, consequently, to understand what social impacts should be prioritised in the site-specific case study at Faro-Olhão.

As previously mentioned, the study integrates the EU project Water Mining, which means that the results will complete the sustainability assessment that is being conducted by other academic partners. The main target audience include the project partners, particularly organizations and the academia involved in the study, as well as water sector related companies, politicians and regulators, scientific researchers on social sustainability topics and the general public. Finally, recommendation for potential improvements of negative performance will be provided to the organisations addressed. The study's findings and its conclusions, as well as the suggested actions, may be used by the involved organizations during decision-making processes to improve its social systems.

4.1.2 Scope definition

4.1.2.1 Function and functional unit

Section 3.1.3 presented an overview on the controversy around the use of functional unit in a S-LCA. For the purpose of the study, it was decided to use a functional unit given two main factors: (i) the ability to compare different product alternatives on an equivalent basis, and (ii) to calculate the weighting factors (section 4.2.3).

The main function of the product system addressed by the current S-LCA is to treat urban wastewater in order to achieve the environmental standards required by law before it reaches the final destination. The functional unit defines quantitatively the object of a study. As such, it is defined as 1 m3 of urban wastewater treated at the Faro-Olhão WWT pant in Portugal.

The following reference flows will be considered:

i. 1 m3 of urban wastewater treated at the Faro-Olhão WWT plant in Portugal with the current system in place.
ii. 1 m3 of urban wastewater treated at the Faro-Olhão WWT plant with the WM system.

4.1.2.2 Product system

The definition of the product system is based on the organizational level of the study. To achieve the goal of the thesis a site-specific assessment is conducted at the organizational level. For this purpose, two product systems were considered. The reference system concerns the WWT plant operating at the business-as-usual conditions, meaning using the Nereda technology to treat the water only. On the other side, the novel system represents the WWT plant and the integration of the WM pilot plant to recover Kaumera from the Nereda sludge.

Additionally, a generic assessment at the national level was performed with less detail, to understand the social context of the Portuguese water sector. In this case, no product system was defined, but the water sector as a whole was deemed to be investigated.

4.1.2.3 System Boundaries

The system boundaries are crucial to define which components of the product system will be included in the system being evaluated.

To begin with, it is important to give a general overview of the urban water cycle to highlight the stage of the life cycle that is the subject of this study and to provide the reader with a general understanding of the life cycle stages involved in the urban water cycle. On figure 3, the main phases of the urban water cycle are presented.

Water is first obtained from resources available on the environment. After being captured, the water is treated at a water treatment plant to achieve a quality level suitable for human consumption. The treated water is then transported from the collection and treatment area to the consumption areas, where it is stored in reservoirs that ensure the continuity of supply. In each consumption zone, water is distributed to the consumer's taps through a complex network of pipes and valves. Wastewater, resulting from the use of water by populations and productive activities, is collected and sent to a WWT plant, where it is treated so that it can be returned to nature in environmentally safe conditions. After being treated at the WWT plant, part of this water is reused for irrigation and washing, with the rest being returned to nature.

Considering the described cycle, the central focus of the present study is the wastewater treatment phase, as it is highlighted on figure 4.

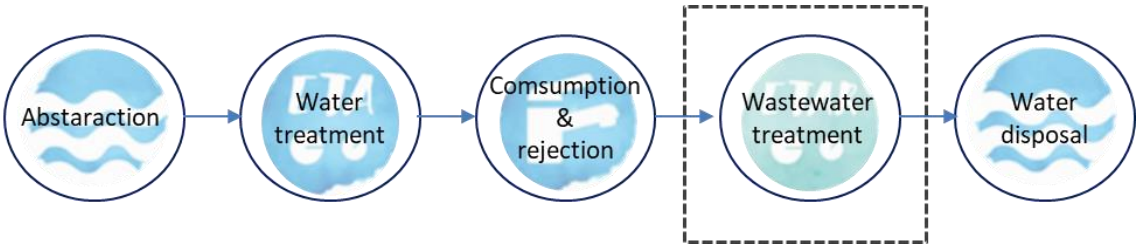

Figure 4. General overview of the life cycle stages involved in the urban water cycle. Adapted from Águas do Algarve (2022).

In this case, it was decided to follow the effect perspective (described in section 3.1.6) and focus on the organizations directly linked to the plant operator. In particular, the suppliers of consumables and services used during the wastewater treatment were considered to be within the system boundaries (figures 4 and 5). Such decision was based on a research from (Dreyer et al., 2006), who defends that the further upstream or downstream the activities are located, the weaker the influence of the manufacturer, in this case, the WWT plant operator. Furthermore, the author states that through the selection of suppliers, materials, and services, the product's manufacturer can have an impact on the life cycle's material stage. As a consumer, the product maker can affect how the suppliers behave. The Social LCA considers the first layer of suppliers as a minimum and includes all pertinent social implications at the material level.

From the analysis of both systems (figures 5 and 6), it is possible to understand that the two alternatives are quite similar in terms of engaged companies. Although some technical processes

to recover the Kaumera are added to the novel system, at the company level, the suppliers of materials and services remain the same. Main differences between the two alternatives regard the consumption amount of chemical substances and energy, besides the fact that in the novel system a waste is transformed into a good.

It is worth noticing that, while the recovery of Kaumera is the main focus of the WM case study, it is actually the treated water produced by Organization A that is taken as the main product of the system for which to conduct the S-LCA, in line with the definition of functional unit presented above. This is because Kaumera is a by-product and produced from a waste discharge of the water treatment process, which translates into Kaumera recovery not being the primary goal of the process. Concluding, the treatment of wastewater into environmentally safe water is the main goal of the WWT plant operator.

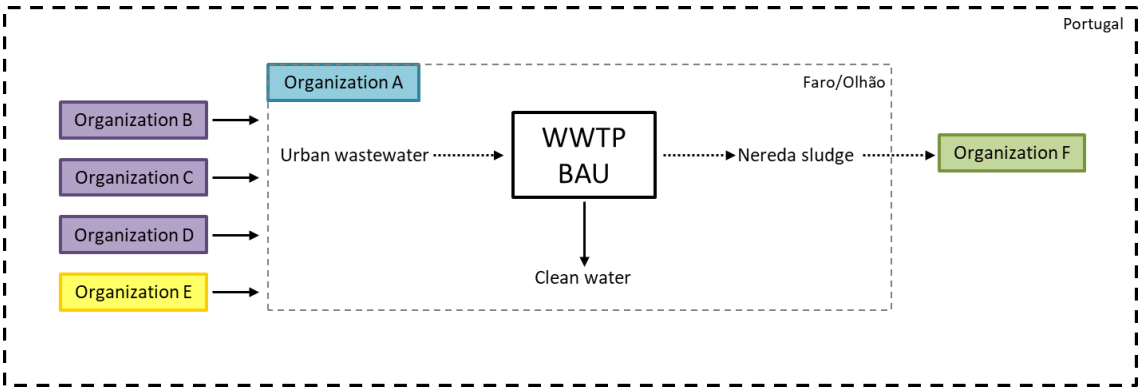

Figure 5. Reference System Boundaries

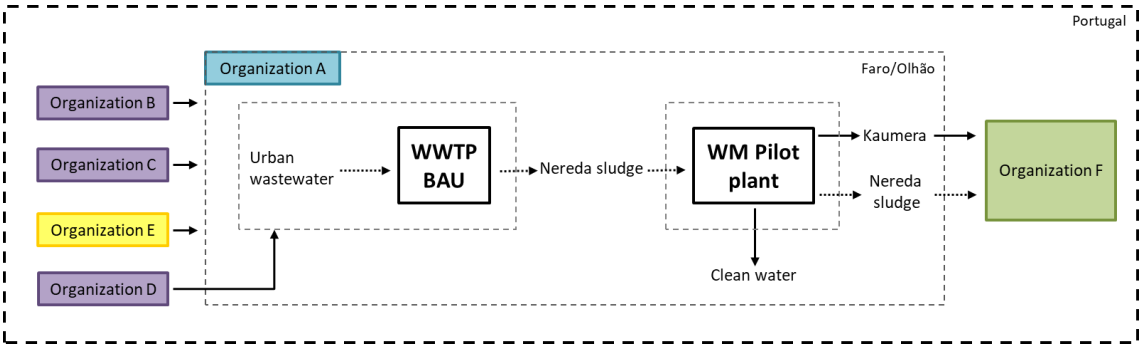

Figure 6. Novel System Boundaries.

Within the above-mentioned scope, six organizations were chosen for analysis, each with different functions in the system. Organization A is the focal company as it is directly involved in the operation of the WWT plant in which the Nereda technology is being implemented and where the WM pilot plant is being tested. Organizations B, C and D are suppliers of different materials used in the system: i) Organization B supplies sulfuric acid to the WWTP BAU and to the WM pilot plant; ii) Organization C supplies sodium hypochlorite and sodium hydroxide to the WWTP BAU, as well as potassium hydroxide to the WM pilot plant; and iii) Organization D supplies a dewatering polymer to the WWTP BAU. Organization E is the energy supplier of both systems and organization F provides the post processing service of Nereda sludge and Kaumera to both systems. An overview of the companies and its roles in the system is shown on table 2.

Table 2. Overview of the companies included in the S-LCA.

Organization	Role in Water Mining	Product
A	Operator of the WWTP where the Nereda technology is being implemented and the WM pilot plant will be implemented	Clean water
		Kaumera Gum
B	Supplier of chemical products to the WWTP BAU and WM pilot plant	Sulfuric acid
C	Supplier of chemical products to the WWTP BAU and WM pilot plant	Sodium hypochlorite
		Sodium hydroxide
		Potassium hydroxide
D	Supplier of substances to the WWTP BAU for sludge dewatering	Polymer
E	Energy supplier to the WWTP BAU and WM pilot plant	Electricity
F	Post processor of nereda sludge and potential post processor of kaumera gum	Sludge and Kaumera processed

It should be recalled from Chapter 3 that the ideal system boundary would be from cradle to grave, but this is not always possible due to goals, resources, or data availability. In this case, only the WWT part of the urban water cycle is deemed to be studied, thus limiting the scope of the study to an LCA gate-to-grave. The wastewater enters the system after the use phase (WWTP gate) and leaves the system after the treatment ready to be disposed on environment again (grave).

4.1.2.4 Selection of stakeholders' groups

The Current study followed the S-LCA methodology described in the Guidelines, resulting in the selection of all stakeholder categories listed in chapter 3, aside from children, for the purpose of the assessment.

Regarding the stakeholder category related to children, it can be assessed by three impact subcategories: (i) education provided in the local community, (ii) health issues for children as consumers and (iii) children concerns regarding marketing practices (UNEP, 2021). Reflecting on these three subcategories, it was decided to exclude the stakeholder based on the following assumptions:

- Education provided in the local community can also be addressed by assessing community engagement, which is addressed on the local community stakeholder. In this sense, educational programs for children can be perceived as a way of the company to engage with local communities.
- Health issues for children as consumers are comprised on the consumers stakeholder on the health and safety impact subcategory. The wastewater treatment service is provided to the entire population in the same way; therefore, it is assumed that the

health and safety of consumer covers everyone served by this operation, regardless of age.

- Children concerns regarding marketing strategies were considered as not relevant for the case study since marketing campaigns specifically targeted at children is not a practice among the companies being assessed.

All in all, a description of the chosen stakeholders can be seen on table 3. It is important to note that all organizations included within the system boundaries will be evaluated considering the perspective of the selected stakeholders applicable to each case.

Table 3. Description of Stakeholders groups addressed in S-LCA.

Stakeholders	Description
Workers	Category of stakeholders that comprise everyone employed by the companies under analysis.
Local community	Refers to the local communities located around the operations site of the organizations. This communities are perceived to be directly affected by the organization's activities (Goedkoop et al., 2018). Examples are neighbours, but also local and regional groups and surrounding populations of people.
Value chain actors (not including consumers)	Value chain actors are the entities present along the supply chain of the companies. In the present study, the first layer of suppliers are the main value chain actors considered.
Consumers	In the present study there are two types of consumers due to the nature of the products. The first type refers to the industry users, such as organization A, which is a consumer of products produced by organization B, C, D and E. The second type are the final consumers of the wastewater treated by organization A.
Society	With a broader spectrum than local communities, society stakeholder encompasses civil society in a regional and national level.

4.1.2.5 Selection of impact subcategories

Impact subcategories comprise socially relevant themes or attributes related to each stakeholder category. Impact indicators are used to evaluate these subcategories, and inventory indicators have a direct connection to the product life cycle inventory.

The UNE/SETAC Guidelines recommend a group of impact subcategories for each stakeholder. This list was adapted based on the following considerations:

First, a literature review on S-LCA studies, performed to the water sector in general, was conducted in order to understand what has been done in academia and to shed light on what are the most relevant and critical areas that deserve to be studied in the sector (as per Chapter 2).

It is important to note that the reviewed studies have diverse geographical, technological and social contexts and, therefore, a literature review by itself is not sufficient to support the choice of impact subcategories. The main conclusion taken from the literature review revealed that fair salary, hours of work, health and safety of workers and health and safety of consumers, were assessed in 69% of the studies. In 54% of the studies, one may also find subcategories related to local employment and freedom of association and collective bargaining. The rest of the subcategories addressed were present in less than 50% of the studies. Table 4 shows the percentage of the reviewed studies in which each impact subcategory was assessed.

Based on the results of the literature review, it was decided to perform a generic assessment to the social context of the WWT sector in Portugal. From the 20 subcategories addressed in the reviewed studies, the ones present in more than 20% of the studies were investigated in the generic assessment, with the exception of feedback mechanism because no public data was available.

The aim of the generic assessment is to identify the social hotspots of the country as well as the Portuguese water sector, in order to narrow down the scope of the site-specific assessment to the most relevant impacts. Data available on public sources was used to conduct the analysis.

Table 5 presents an explanation of the subcategories investigated in the generic assessment.

Table 4. Percentage of studies where each subcategory was assessed.

Impact Subcategories	Percentage
Freedom of association and collective bargaining	54%
Fair salary	69%
Hours of work	69%
Equal opportunities	46%
Health and safety	69%
Social benefits/social security	46%
Health and safety	69%
Feedback mechanism	38%
consumer privacy	8%
Transparency	8%
Access to material resources	23%
Safe and healthy living conditions	38%
Community engagement	46%
Local employment	54%
Public commitment to sustainability issues	31%
Contribution to the economic development	38%
Corruption	31%
Fair competition	23%
Supplier relationships	15%
Promoting social responsibility	38%

Table 5. Definition of subcategories addressed in the generic.

Stakeholder	Subcategories	Description
Workers	Freedom of association and collective bargaining	The subcategory addresses the right of workers and employers to freely join organizations of their choice without prior authorization, to promote and defend their respective interests, and to negotiate collectively with other parties. The right to join organizations encompasses: the right of workers to strike, the rights of organizations to elaborate their constitutions and rules, to elect their representatives in full freedom, to organize their activity without restraint, and to define their programs (UNEP, 2020).
	Fair salary	A fair salary is defined as a wage fairly and reasonably commensurate with the value of a specific service or class of service provided, considering a minimum fair wage for such service or class of service (UNEP, 2021).
	Working hours	The number of hours of work are an important indicator of decent working conditions and workers well-being. The assessment of this subcategory aims to verify if the number of hours effectively worked is in accordance with the ILO standards and when overtime occurs, compensation in terms of money or free time is planned and provided to the workers (UNEP, 2021).
	Equal opportunities /discrimination	Equal opportunity or the principle of non-discrimination emphasizes that opportunities in education, employment, advancement, benefits, resource distribution and other areas, should be freely available to all people regardless of their age, race, sex, religion, political association, ethnic origin, or any other individual or group characteristic unrelated to ability, performance, and qualification (UNEP,2021).
	Health and safety	Health at work implies the absence of disease or infirmity. Additionally, it also includes the physical and mental elements affecting health, which are directly related to safety and hygiene at work (UNEP,2021).
	Social benefits/ social security health	Social benefits refer to non-monetary employment compensation which are typically offered to full-time workers but may not be provided to other classes of workers (e.g., part-time, home workers, contractual) (UNEP,2021). The most common categories of social security benefits, that are usually paid based upon the record of worker's earnings, include: retirement, disability, dependents, and survivors' benefits. Other social benefits that may be provided comprise among others: medical insurance, dental insurance, paramedical insurance including preventive medicine, medicine insurance, wage insurance, paid parental leave, paid sick leave, education and training, meal voucher, agreements with gyms, kindergartens. The social benefits provided to the workers are often dependent on the social context, differing from country to country. As countries have different laws and policies regarding social security and social benefits, some benefits may already be covered by the national government. For example, some countries have a public medical system accessible to all citizen while other countries have a private medical system calling for citizen/workers to be covered by a medical insurance. Countries are free to decide who is to be insured under their legislation, which benefits are granted and under what conditions (UNE, 2021). This subcategory assesses whether and to what extent an organization provides social benefits and social security of workers.

Consumers	Health and safety	End users expect products/services to perform their intended functions satisfactorily, without posing a risk to their health and safety. According to ISO (2010), consumer health and safety implies the consumers' rights to be protected against products/service that may be harmful to health or life. This subcategory helps to identify the existence and scope of systematic efforts to address consumer health and safety across the organizations involved in the life cycle of a product and/or service.
Local community	Access to material resources	Communities and organizations often share the use of material resources (natural and man-made) and, consequently, the common interest in protecting and enhancing the quantity and quality of local resources and infrastructure. In order to protect the local population, organizations should conduct risk assessments with attention to potential conflict over material resources and engage with the local community over sustainable methods for sharing resources. Furthermore, organizations should elaborate risk management plans for preventing, mitigating, and controlling environmental damage. This includes management attention to the sustainable use of natural resources, pollution prevention, and waste recycling. (Maister et al., 2020) This subcategory assesses the extent to which organizations respect, work to protect, to provide or to improve community access to local material resources (i.e., water, land, mineral, and biological resources) and infrastructure (i.e., roads, sanitation facilities, schools, etc.).
	Safe and healthy living conditions	The present subcategory addresses the safe and healthy living condition of communities in regard to the impact that operations conducted by industries and organizations can cause on the living conditions of communities. Companies or whole industry sectors may threaten community safety through equipment accidents or structural failure. Additionally, among others, diseases may spread as result hazardous material releases, emissions or poor water drainage. It is of extreme importance that companies, and organizations commit to control health and safety impacts of their operation to surrounding communities. In case of negative health and safety effects, organizations should engage in remediation or compensation efforts (UNEP, 2021).
	Community engagement	Community stakeholders include individuals or groups that may be impacted by the actions or products of an organization. Organizations should involve these stakeholders during the development and implementation of business policies, particularly those that affect local environment, health, and well-being. In this sense, it is important that organizations enter communities with a willingness to engage with diverse community members that bring different interests and views. Community participation in decision-making processes is a fundamental aspect of sustainable development. Community representatives at the distinct level of an organization should engage in this continuous process (Maister et al., 2020). In this way, communities can voice their concerns and organization respond with a concrete strategic plan of action. A valuable way to strengthen this relationship is through the direct involvement in community initiatives and/or through financial support of community projects (e.g., Earth Day activities, recycling initiatives, and visits to local schools).
	Local employment	Local employment is an important factor to improve living conditions of communities, limit the risk of poverty and to prevent people from emigrating. In this sense, a close collaboration with local suppliers consolidates local economies, expands supply and promotes regional development (UNEP, 2021). Consequently, focusing on local hiring also contributes to the national development and country prosperity.

Society	Public commitments to sustainability issues	Public commitments to sustainable issues translate an organization promise or agreement regarding its contribution to sustainable development, including the reductions of impacts derived from its activities (UNEP, 2021). By making it public, a company is establishing a commitment to its customers, employees, shareholders, local community, or the general public. As such, performance improvement targets should be well defined and documented in a transparent and open way.
	Contribution to economic development	Organizations contribute to economic development in many ways. They generate revenue, create jobs, provide education and training, make investments, or forward research (Maister et al., 2020; UNEP, 2021). This subcategory evaluates to what extent the organization/product or service contributes to the economic development of the society.
	Corruption	Corruption consists of the misuse of power for personal advantages. According to Maister et al. (2020) bribery, embezzlement, theft and fraud, extortion, abuse of discretion, favouritism, nepotism and clientelism, conduct creating or exploiting interests, and improper political contributions, are all different types of corruption. This subcategory aims to assess the overall state of corruption of a country as well as the national effort to precent corruption.
Value chain actors	Fair competition	A fair competition among competitors is important to promote sustainable conditions along the life cycle of a product or service. In this sense, competition on the market should be kept fair and transparent in order to allow supply and demand to regulate freely. A fair competition can be defined as the absence of anti-competitive behaviour, anti-trust and monopoly practices. According to Methodological sheets, anti-competitive behaviour includes actions of the reporting organization and/or employees that may leave to collusion with potential competitors to fix prices, coordinate bids, create market or output restrictions, impose geographic quotas, or allocate customers, suppliers, geographic areas, and product lines with the purpose of limiting the effects of market competition (UNEP, 2021). Additionally, anti-trust and monopoly practices consist of actions that may result in collusion of organizations to erect barriers to entry to the sector, unfair business practices, abuse of market positions, cartels, anti-competitive mergers, price-fixing, and other collusive actions which prevent competition.
	Promoting social sustainability	Social responsibility (SR) is defined as organization's commitment to take into consideration the interests of all its stakeholders, such as customers, employees, shareholders, suppliers and communities (UNEP, 2021). By integrating SR into core business processes and stakeholder management, organizations can achieve the ultimate goal of creating both social and corporate value (shared value).

4.1.2.6 Selection of Indicators

The status of impact of subcategories is assessed by collecting data on one or several indicators, selected to cover the most relevant aspects of the category. In this sense, Tables 5 and 6 indicate the indicators used for the generic and site-specific assessments, respectively, as well as the adjustments based on literature.

The adjustments to the selected indicators were performed in accordance with both the scale of the assessment (generic or site-specific) and the availability of data. Since the present study follows the methodology proposed by the UNEP/SETAC Guidelines, both assessments resorted to suggestions included in the Methodological Sheets (UNEP, 2021) during the indicator's selection process.

The indicators proposed by the methodological sheets are mostly for specific level analysis. As such, whenever possible, for the generic assessment the suggested indicators were adapted for national or regional level. When necessary, adjustments were made based on literature as illustrated in the table 6.

The sources used to define site-specific reference scales and respective indicators can be consulted in appendix III.

Table 6. Subcategories and respective indicator used in Generic assessment as well as data sources.

Stakeholder	Subcategories	Indicators	Indicators definition source
Workers	Freedom of association	Level of compliance with FACB rights	UNEP (2021)
	Equal opportunities/ discrimination	Access to employment inequalities	UNEP (2021)
		Working hours inequalities	UNEP (2021)
		Salary inequalities	UNEP (2021)
	Health and safety	Rate of non-fatal accidents	UNEP (2021)
		Rate of fatal accidents	UNEP (2021)
	Social security / social benefits	Population in need covered by specific social protection systems	ILO (1952)
	Fair salary	Minimum wage required by law	Maister et al. (2020)
		Local industry wage	Maister et al. (2020)
		Living wage	Maister et al. (2020)
	Working hours	Number of working hours per week per sector	UNEP (2021)
Consumers	Health and safety	Presence of certified quality management systems	UNEP (2021)
Local community	Access to material resources	Presence of certified environment management systems	UNEP (2021)
		Level of water use, level of circular material use and quality of water infrastructures	Maister et al. (2020)
	Safe and healthy living conditions	Access to basic services: clean water and sanitation services	Maister et al. (2020)
		Pollution levels	Maister et al. (2020)
		Sector contribution to environmental load	Maister et al. (2020)
	Community engagement	Level of government transparency	World Economic Forum (2018)
		Level of public trust on government bodies	World Economic Forum (2018)
	Local employment	Unemployment rate	Maister et al. (2020)
Society	Public commitment to sustainability issues	Progress towards SDG	UNEP (2021)
	Corruption	Corruption perception index	Maister et al. (2020)
	Economic development	Public expenditure on education	Maister et al. (2020)
		Contribution of sector to economic development	Maister et al. (2020)
		Economic growth	World bank database
Value chain actors	Fair competition	Presence of policies to prevent anti-competitive behaviour	UNEP (2021)
	Promoting social responsibility	Presence of social responsibility certifications	UNEP (2021)
		Membership in initiatives to promote social responsibility in national organizations	UNEP (2021)

4.1.2.7 Scope definition: impact assessment approach

S-LCIA selection: reference scale or impact pathway?

Each approach presents distinct pros and cons that should be considered for the selection of the impact assessment method.

One can argue in favour of the IP approach as it is based on established impact pathways. Moreover, IPs help to understand how specific social impacts relate to one another and to anticipate future social impacts (Sureau et al., 2020). However, IPS characterization models tend to be case-specific and complex to model due to the qualitative nature of social mechanisms.

On the other hand, RS methods provide information regarding social performance of organizations, which can be extremely useful for decision-makers to learn about their companies and how to direct efforts towards a more sustainable future. RS methods are also perceived as less complex to apply, reason for most of the S-LCA studies until now have opt for this impact assessment method (UNEP, 2020).

The S-LCA Guidelines suggest the use of each IA approaches according to the practitioner goal. RS approach is advised to apply when evaluating the social performance or risk of a certain product system. Alternatively, the IP approach is suggested for predicting the consequences of the product system through the characterization of its social impacts.

Considering the characteristics of each IA approach described in section 3.3, the UNEP/SETAC Guidelines suggestions and the goal of the study, which aims to assess the social performance of the two systems under analysis, the RS approach will be applied in the current case study.

Selection of Reference Scale method

In terms of characterization method, the work from (Ramos Huarachi et al., 2020) identified fourteen frameworks for the characterization step with type I SLCA. The study concludes that it is important to apply existent frameworks to enhance the standardization of S-LCA methodology and that the subcategory assessment method (SAM) proposed by (Ramirez et al., 2014) is the most used.

The current study uses the SAM by Ramirez et al. (2014). Below, a description of the method and the reasons to choose it are provided.

The SAM technique allows to assess the social profile of organizations in a product life cycle, considering all the subcategories included in the UNEP/SETAC Guidelines, through the use of PRP called basic requirements (BR). The BR define a baseline that should be achieved by each organization in order to have a good performance. SAM is based on a four-level scale for each subcategory: A) organisation shows a pro-active attitude besides fulfilling BR; B) organization fulfils the BR; C) organisation do not comply with the BR in a negative context and D) organisation do not comply with the BR in a positive context. In turn, a scoring system to which each level is given a value is applied to allow a quantitative and uniform analysis.

When determining if an enterprise is above compliance (level A), it is taken into account whether it engages in proactive action to advance social responsibility throughout the value chain. When an organization is operating below compliance, the regional context in which it operates is considered to distinguish between two possible outcomes: either the organization does not meet the BR and is situated in a region where the overall performance for a given subcategory is considered positive (i.e., good), or it is situated in a region where the performance is perceived as negative (i.e., poor). Specific criteria, which are frequently based on national statistics, are used to identify the positive or negative settings.

It is worth to note that the levels should be clearly defined to ensure a standardization throughout all the evaluations.

There are three main reasons for choosing SAM as the assessment method within the RS approach. First, by defining a basic requirement it ensures objectivity during the assessment of subcategories and uniformity when different companies within a product value chain are being evaluated. Moreover, it is a flexible method able to be applied to different products and sectors (Ramos Huarachi et al., 2020), which is important given that companies working in distinct sectors are included in the system boundaries of the current study.

The second reason lies of the fact that SAM allows to perform a semi-qualitative assessment. In particular, by using SAM it is possible to transform qualitative data into quantitative data, and thus compare different types of information in a rather standardized way (Petti, Sanchez Ramirez, et al., 2018; Ramirez et al., 2014). A scoring scale is used, helping a decision maker to achieve a product overview.

Finally, the fact that SAM uses the subcategories according to the UNEP/SETAC Guidelines and that the basic requirements are based on indicators suggest by the Methodological Sheets (UNEP, 2021), is extremely useful since the current study follows the UNEP/SETAC Guidelines. As such, clear guidance regarding the data that must be gathered to accomplish the assessment is offered.

Adjustment to Subcategory Assessment Method

In order to overcome some limitations identified by different authors, and to achieve a better feat with the case study context and particularities, some adjustments to SAM were made.

The SAM introduced by Ramirez et al. (2014) has employed the BR in the different subcategories as a first level of assessment and the existence of a proactive behaviour in the value chain as a second level of assessment (Hannouf & Assefa, 2018). It is important to note that the choice of the BR is an important step that determines the path the assessment will take. In this sense, Hannouf & Assefa (2018) have recognized that in the SAM developed by Ramirez et al. (2014), a mix between the commitment to a social subcategory, whether through the company's policy, internal management or strategy, and the evidence of good practices within a subcategory occurs in the elaboration of the BRs. This means that some BRs are defined based on organization's internal efforts and intentions to performance well in a certain subcategory while other BRs are defined based on the actual performance. In fact, this might bring some inconsistency to the method since one doesn't mean necessarily the other. For example, an organization can commit to zero hazardous waste production through management systems or policies and, in reality, might not be able to achieve it.

The first adjustment to the SAM is based on the aspect mentioned above. To avoid mixing companies commitment and actual performance in the BRs, it was decided to separate the BRs requirement from the social indicators (de Santo, 2019). As such, for each subcategory there is at least one reference scale that comprises a normative BR. To assess the compliance with BRs, indicators regarding commitments in the form of policies or management systems, and indicators that address organization actions are employed. If an organization accomplishes the performance indicator that reflects the normative BR, meaning it achieves scale level B, then it is in compliance with the BR.

Compared to SAM, the BRs are established in this study considerably differently. The BR for each subcategory is taken directly from international standards or norms of conduct for organizations, as opposed to using a social indicator as the BR or developing a BR based on the indicators from the Methodological Sheets (UNEP, 2021). However, it is essential that the BR still reflect the definition of the subcategory as well as the indicators suggested by the Methodological Sheets.

The second adjustment to SAM is related to the fact that the method proposed by Ramirez et al. (2014), assumes the subcategory "promoting social responsibility" as present in the evaluation of all subcategories. Essentially, the level above compliance of the BR is achieved if in addition to the BR, the organization also promotes the subcategory among other supply chain actor, which reflects the definition of "promoting social responsibility". In the current study, "promoting social responsibility" is taken as an independent subcategory, therefore, to avoid double counting the level above compliance is assessed differently. In particular, actions that go beyond the compliance level are taken into account for the assignment of pro-active behaviour.

4.2 Life Cycle Inventory Data Collection

The Social Life Cycle Inventory (S-LCI) is about collecting data for all unit processes within the system boundaries. In this case, information regarding the organizations included in the system boundaries.

Depending on the goal and scope defined earlier, data collection has different requirements. According to the guidelines, two main sources of data can be used:

- Primary data describes information that a practitioner has personally gathered, such as through an interview, survey, or participant observation.
- Data that was initially gathered and modified by a person or organization other than the practitioner, collected for a different purpose than the one being considered at the time, or frequently a combination of the two is referred to as secondary data (e.g., a publication, external audit, or database).

In this section, a description of the data collection procedure and sources used for both assessments are provided.

4.2.1 Generic assessment

As mentioned in section 4.1.2.5, the aim of the generic assessment is to help identify the social hotspots in the Portuguese social context and of the Portuguese water sector, so the author can focus on the most relevant impact subcategories on the site-specific assessment. As such, data requirements for this phase of the study include:

- Data on the social flows of specific sectors at the national level
- Data on social flows of specific sectors at the European level

Secondary data sources were used to collect data for the generic assessment. Particularly, through a desktop search where online databases with free access (e.g., EUROSTAT, ILOSTAT, national institute of statistics), national government websites and platforms, European Union website, National legislation and international agreements were consulted. Table 5 presented in section 4.1.2.6, illustrates the social indicators used to assess each subcategory as well as the respective data sources.

The data collection procedure for the generic assessment is time demanding and requires multiple data sources. Furthermore, information for the scope under analysis is not always available or in the required units and, when that happens, alternative solutions need to be found. For instance, in the subcategory "social security / social benefits" one of the indicators reflects the percentage of the Population in need covered by specific social protection systems. The database used, didn't provide the aggregated percentage for the EU and, therefore, the average percentage for the EU constituent countries was calculated and used as the value for the European union region.

Another aspect that is relevant to mention is the time frame for which the data were collect. It was not possible to collect data from the same year for all the subcategories in question. In this case, most recent data was prioritized.

4.2.2 Site-specific assessment

4.2.2.1 Establishment of reference scales

The elaboration of the reference scales starts in the life cycle inventory phase since specific data is needed to define the BRs. In this section, a description of how the reference scales were elaborated and what they entail is provided.

As mentioned before, the levels are associated with a numerical scale to facilitate the presentation and aggregation of results.

The formulation of the reference scales begins with the definition of the BRs. In this respect, the BRs are based on international standards, norms of conduct for organizations or on the subcategory definition itself, to ensure that the organization commitment to the cause is being assessed. The second step entails the definition of the social indicators or PRPs, mainly based on the methodological sheets and on the suggestions from Ramirez et al, (2014). The author tried to mainly include action-oriented indicators to assess compliance with BR.

For each subcategory, one or more BRs can be specified according to the relevance for the assessment of the subcategory. In that case, the number of reference scales match the number of BRs. For example, for the subcategory "Health and Safety of Consumers" the Methodological Sheet's mention that consumers have the right to be protected against products and services that may be hazardous to health or life (ISO, 2010) as well as to express their displeasure regarding a product or service. In this sense, two BRs addressing these aspects were defined. This means that more than one reference scale was established to evaluate this subcategory. The reference values are defined individually according to the definition and goal of each subcategory. Instead of focusing on having a standard number of reference scales per subcategory, the author aims to perform the most complete possible assessment on each subcategory.

Additionally, it can also happen that for the same BR more than one social indicator is important to assess compliance. When this is case, again more than one reference scale is established in order to properly evaluate the subcategory. The example of the subcategory "Local employment" illustrates this exact situation. The BR refers to organization's efforts and initiatives to strengthen opportunities for local communities and suppliers to contribute to value chains (UNEP, 2020; OSHA, 2018). Nevertheless, two distinct reference scales with indicators designating local workforce and local suppliers separately were developed.

An important detail that emerges along with the elaboration of the reference scales is related to what happens when data is not available and compliance with BRs cannot be assessed. On these terms, the context of the sector is considered. If an organization operates in a context that is considered positive, it is assumed that it might be positively influenced by the positive performance of peers to also perform well, receiving a score of 3. In the same way, if the context is negative, it is assumed that the organizations will not feel compelled to perform better, attaining a score of 4. The rationale for this model choice is that organizations operating in unfavourable environments may find it more difficult to carry out socially responsible initiatives, whereas nations with favourable environments encourage businesses to abide by the terms of international agreements (Ramirez et al., 2014).

Finally, level 1 indicators reflect examples of actions that organizations can embark on to reach the proactive behaviour level. At least one reference scale per subcategory gives an example of such actions, the cases where no suggestions are offered are due to lack of information.

Table 7 provides an overview on the how a reference scale is formed.

Table 7 - Description of the performance levels. Adapted from (Hannouf & Assefa, 2018).

Level	Score	Description
Very good performance	1	Compliance with BR + proactive behaviour regarding the subcategory
Satisfactory performance	2	Compliance with BR
Inadequate performance	3	Non compliance with BR + negative contex OR No data and positive context
Bad performance	4	Non compliance with BR + positive context OR No data and negative context

4.2.2.2 Data requirements

Data collection for the site-specific assessment takes place with different actors and sources simultaneously. As such, different types of data are required: data on the physical flows of the product systems (quantities, costs, suppliers); data on the Basic Requirements (BRs); data on the social flows of each organization within the system boundaries; data for the assignment of a score if site-specific data is not available or if the BR is not met; and data for the sensitivity analysis.

The compilation of the required data demands the use of both primary and secondary data sources. To collect the data mentioned above, two main steps are executed:

1. A desktop search about social sustainability performance aspects for each organization in the system boundaries.
2. Interviews or questionnaires with employees of each organization within the system boundaries.

A desktop search is used with three purposes, as follows, resorting to secondary data sources.

First, to collect information about the stakeholders included in the system boundaries. More specifically, information available in organizations annual reports, websites, government documents as newspaper articles can be used as a complement to interviews or questionnaires.

For example, sustainability reports might contain useful information that can help the author to better prepare for the interviews and ask more detailed questions about precise topics found from the company website or reports. Moreover, it provides some background information about the company in question.

The second purpose of a desktop search is the elaboration of the reference scales and, in particular of the BRs. Although, the Methodological Sheets serve as a base for the BRs, international agreements, standards and policies are also used to define them. Such type of information is available on European Union websites, databases and also on governments websites and documents. In order to maintain consistency, all BRs are written in a way that includes an organization's commitment to social sustainability aspects through policies, management practices, or initiatives.

Finally, in case of not being able to collect detailed information about a specific organization, the assessment continues by studying the performance of peer companies. In this case, a desktop search is carried out to gather information on these organizations.

Interviews or questionnaires can be used to collect more specific and detailed data about organizations included in the system boundaries. In this case, primary data sources, directly contacted by the author are consulted.

To begin the data collection process, general information about the stakeholders involved needs to be gathered. For this part, data can be provided directly by the WWT plant through a list of the organizations included in the value chain of the wastewater treatment service supplemented by the details of contact persons in each organization. Note that chemical, energy and specialized services suppliers are subject to public concourse, meaning that these contracts are not fixed and might change. For the purpose of the study, the current suppliers are considered.

The physical flows of the product system are essential to calculate the weighting factors used during the impact assessment. Again, the WWT plant operator is able to share the costs of inputs, amounts used and operational data for the reference system. On the other hand, physical data for the novel system is more challenging to get since the operation of the pilot will start a few months after the current study. As an alternative, information from the description of the WM project and scientific literature can be used.

The first step of the construction of the reference scales is the definition of the BRs. The second step includes the assessment of organization’s performance through the use of indicators. For the fulfilment of the second step, specific data on each indicator is collected via semi-structured interviews or questionnaires. In this sense, it is essential to define the respondent’s sample and the type of interviews that will be performed.

Considering that the WM case study involves specific stakeholders, non-probability sampling is deemed to be the most adequate method to select the respondents (de Santo, 2019). Sampling involves choosing a subgroup of the population under study to observe and perform analysis, in order to infer conclusions about the entire population in question. Instead of using random selection, non-probability sampling techniques assume the selection of a sample based on the subjective judgment of the researcher (Berndt, 2020). In the current study, the organizations included in the system boundaries constitute the units of analysis. As a consequence, the employees, suppliers, final consumers and local communities of these organizations form the population of interest. However, due to time constraints and limited resources, it was decided

to focus on the employees to provide information about the social indicators, as it is assumed they hold a general view of how the organizations socially impact all its stakeholders. Although it is advised to interview or make questionnaires to more than one employee occupying different positions in the company to improve reliability (UNEP, 2020), this can be challenging due to time constraints of workers, willingness to participate in a non-mandatory research and reluctance to answer questions regarding sensitive social topics.

To select a sample from the population of interest, the subjective judgment of the researcher was applied. To facilitate the approach, the WWT plant operator provided a list of contact persons on each organization. After multiple contacts via online platforms (LinkedIn, email, mobile phone number), nominated people from each company were identified and invited to participate on the interviews, based on knowledge to answer questions regarding the company social performance in the addressed subcategories. Employees from the Human Resources and Sustainability departments, as well as Managers were some of the positions held by the participants.

As a survey research, semi-structured interviews and questionnaires are considered to be adequate methods to collect detailed information on a specific topic. Semi-structure interviews increase reciprocity between the interviewer and the participant, allows the interviewer to improvise follow-up questions based on participant responses, and leaves space for participants to elaborate on a certain topic or clarify any possible doubt, yet it can also be more time-consuming. On the other side, questionnaires can be less time consuming and present the opportunity to be completed at the convenience of the respondent. However, the level of detail of the answers is generally lower for questionnaires. The approach taken on the current study consisted of the elaboration of questionnaires that include open-ended questions, designed also to be used as an interview protocol. The questionnaire is organized as displayed: A summary of the WM project, the WM case study, and the research objectives are included in the opening sentences, followed by a brief description of the S-LCA approach. After that, the questions are presented in categories according to stakeholder groups and impact subcategories. The open-ended questions, which are based on the social indicators, give interviewers and participants the chance to freely comment on their questions/responses.

Given the low level of responses to the first contacts, when it was finally possible to approach the respondents, it was asked whether if they preferred to complete the questionnaire via an online interview or individually offline. All the respondents preferred to answer the questionnaire offline and send it via email to the author. It is the author's knowledge that an offline questionnaire might restrict the answers to yes/no, which limits the detail of the information collected and, consequently, the obtained results, mostly due to the unfeasibility to evaluate whether BRs are met, or proactive behaviour exists.

4.2.2.3 Activity Variables and Weighting Factors definition

An activity variable measures a process activity or scale in relation to the process output. Furthermore, it can be used to depict the product system in a way that conveys an understanding of the relative importance of each individual unit operation within the larger system (Zimdars et al., 2018). Meaning that processes that require a higher number of working hours or generate more added value, will have a greater importance on the product system and generate impacts with possibly more relevance. According to the UNEP/SETAC Guidelines, worker-hours is the most commonly used activity variable, consisting of the number of worker-hours necessary to complete a production activity/unit process. Additionally, added value is also

used by considering the total amount of added value created in each process. By calculating activity variables scaled to the functional unit of the study, the results obtained will similarly be calculated according to the FU.

In this study, activity variables will be used to understand the relevance of each stakeholder in the product system. Though, instead of using working hours or added value, the importance of each organization will be translated in terms of its share of the total revenues generated during the wastewater treatment process. This decision is based on the idea that the costs associated with the wastewater treatment (e.g., chemicals, energy, services) represent the revenues for the respective supplier company included in the system boundaries.

Furthermore, alternative data related to the number of working hours expensed by each organization or to the economic value that each organization produces could be either not available or considerably burdensome to collect.

The method being applied in the study - share of total revenues - doesn't meet the definition of activity variable as, in this case, the activity of the unit process is not being measured. Nonetheless, the obtained factor ends up serving the same purpose and being applied in the same way as an activity variable.

As such, from now on instead of activity variable the term weighting factor will be used (Herrera Almanza & Corona, 2020). Table 8 shows the weight factor of each organization in both the reference and novel systems.

Table 8. Weighting factor calculated for each organization within the system boundaries.

Company	Weigthing Factor [%]	
	Reference System	Novel System
B	0,019	0,083
C	3,176	3,781
D	0,588	0,389
E	6,299	5,499
F	0,003	0,002
WWTP operator - A	89,915	90,245
Total	**100**	**100**

As it is possible to observe, the difference between the weighting factors of both systems is relatively small. The reason for this is related to the fact that no major distinction exists between the two systems. In fact, the difference lies in the type and amount of materials used but the suppliers and services providers remain the same. Additionally, the extra amount of chemicals and energy used in the novel system is not enough to promote a change in the weighting factors greater than the one noted.

In both systems, the WWTP operator holds the largest share of total revenues, being slightly higher in the novel system. Such result was expected due to the fact that the company holds the final position in the supply chain under analysis and, consequently, the revenues obtained from upstream suppliers are embedded in the price of water treatment as a cost of the service. As for the remaining organizations, the relevance follows the same order in both systems. Organization E comes after the WWTP operator, followed by organization C. Next, comes organization B, and F showcasing a very small importance in the systems.

Comparing the two systems, one can see that while the weight factors of organizations B and C increase from the reference system to the novel system, the opposite happens for organization D, E and F.

4.2.2.4 Multifunctionality and Allocation

A product system is defined as multifunctional when generates more than on product or multiple co-products. When assessing the social and socio-economic impacts of only one of these products, it might be required to refine the system boundaries or assign only a share of social effects to this product.

(J. Guinée et al., 2021) suggests 3 steps that should be followed in order to identify multifunctional process. The first step consists of identifying each flow between two processes as either a product or a waste. To clarify, a product or good is a flow between two processes with an economic value higher than or equal to zero, whereas a waste presents an economic value smaller than zero. Note that any other criterion to distinguish between products and wastes could be applied as long as it can be consistently applied over different product systems. Next, identification of functional flows of the process needs to be done. This can be either products that are produced or wastes that are treated. Finally, it is possible to conclude if a process is multifunctional by analysing how many functional flows the unit process yields. By applying the three steps described it was possible to conclude that the WWT process in the novel system is multifunctional.

Based on the 3 steps method, it is possible to conclude that the novel system is multifunctional. While in the reference system a waste is treated but no products with economic value are generated, in the novel system product with economic value (kaumera) is produced from a waste.

In current study the allocation problem is solved through an allocating process impacts based on the share of revenue generated by the process for each of its product outputs, meaning economic allocation. The multifunctionality challenge has no commonly accepted answer. ISO 14044 (ISO, 2006) introduces a preference order of solutions to address the multifunctionality issue that will be further discussed in Section 7.2.

To calculate the allocation factors, it was necessary to quantify the functional flows in monetary terms. Data to execute the calculations was provided by the WWTP operator. The revenues obtained by the WWTP operator to treat the wastewater were normalized per functional unit and, thus ready to apply. As for the revenues derived from the selling of the Kaumera, these were computed from the Kaumera production and its selling price. In particular, to compute the Kaumera production, the Kaumera recovery rate was taken from literature (Amorim de Carvalho et al., 2021) and, the sludge production and wastewater flow rates were provided by the WWTP operator (personnel communication, March, 2022) (see appendix IV).

Table 9 summarizes the allocation factors obtained for the novel system.

Table 9. Economic allocation factor calculated for the WWT process of the novel system.

Goods from Multifunctional Process	Monetary Flow [EUR/m3 watewater]	Allocation Factor
Clean Water	7,02E-01	66%
Kaumera	3,62E-01	34%
Total	**1,06E+00**	**100%**

4.3 Life Cycle Impact Assessment

4.3.1 Generic Assessment

For the generic assessment, a simpler method was followed. In order to assess the Portuguese social risks, data for the European context was equally collected and compared to the Portuguese context. However, this comparison was based on the direct results obtained from the data collection via public databases and no further data treatment was performed.

The results of the generic assessment will be discussed in detail in Chapter 7.

After that, a critical analysis was done and conclusions on which subcategories are relevant to include in the site-specific assessment were drawn.

4.3.2 Site-specific Assessment

4.3.2.1 RS approach: step by step

Considering the adjustments to SAM presented above, the impact assessment used to assess an organization performance in each subcategory will be described. To begin with, there are four levels (table 9) that differentiate how well an organization is performing in a certain subcategory. Different indicators reflect the different levels that a company can achieve. Note that level two indicators represent the BR defined. In case of compliance with the BR, two things can occur: i) extra data demonstrates that the organization acts pro-actively regarding the subcategory and it receives a score of 1 or ii) no pro-active behaviour is shown and the organization gets a score of 2. When compliance with the BR is not met, depending on the context where the organization operates, a score of 3 or 4 is attributed. A score of 3 indicates a negative context, while a score of 4 implies a positive context. The context is investigated by analysing the performance of peers operating in the same region. Figure 6 depicts the approach taken step by step.

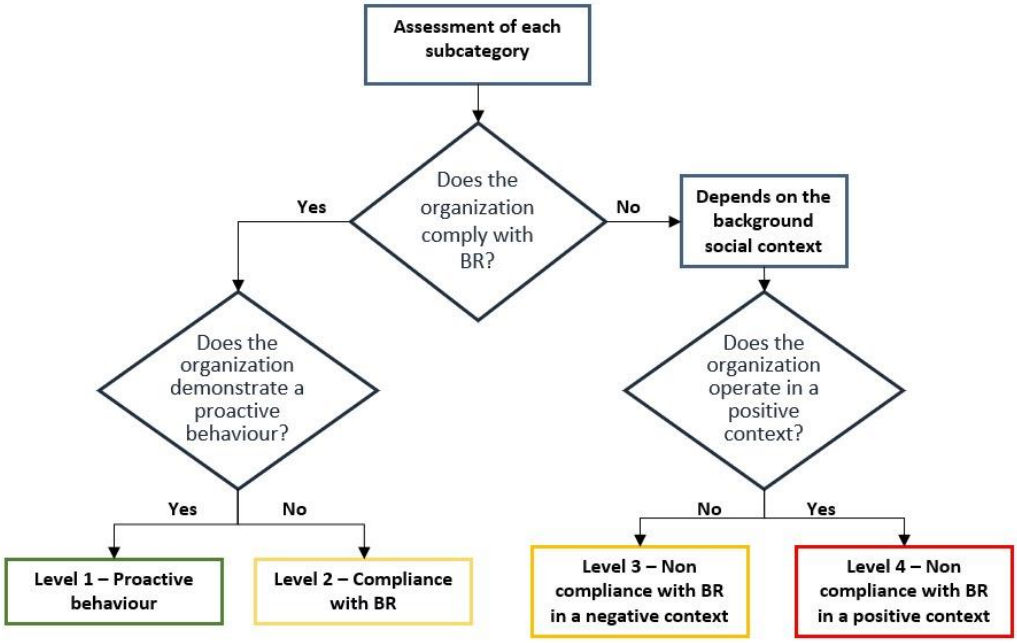

Figure 7. Impact assessment approach step-by-step. Adapted from Ramirez et al. (2014).

4.3.2.2 Aggregation and Weighting

The aggregation of semiquantitative and qualitative indicator via a scoring system (Table 7) and the subsequent step of weighting the contribution of each company to the overall system are essential to facilitate the interpretation of results, especially when assessing complex systems that combine different elements.

The aggregation process can occur at many points during the impact assessment phase and can be applied in different ways, such as i) aggregate indicators into social subcategories; ii) aggregate subcategories into stakeholders' groups, iii) aggregate subcategory results into impact categories or to a single overall score, among other possibilities. Moreover, aggregation implies the assignment of weights to each indicator, subcategory or stakeholders, in order to reflect their relative importance in the overall life cycle (Dreyer et al., 2006). Nonetheless, when weights are either not defined or attributed the same values, all indicators can be assumed to have equal relevance.

In the particular case of the current project, both aggregation and weighting steps are performed. The first one regards aggregation at the reference scale level, given that most of the subcategories present more than one reference scale. For each subcategory, a simple average of the scores obtained in each reference scale is calculated, meaning that an equal weight is applied to each reference scale. The second one involves the weighting factors displayed in Table 8, which are applied in order to reflect the importance of each organization in the system. Afterwards, a sensitivity is performed on the weighting factors considered for each organization, in order to assess the impact of such assumption in the overall results of the study.

5. Results and Analysis of Results

5.1 Generic Assessment results

This section presents the results of the generic assessment by stakeholder category and impact subcategory.

5.1.1 Stakeholder: Workers

5.1.1.1 Freedom of association and collective bargaining (FACB)

The subcategory addresses the right of workers and employers to freely join organizations of their choice without prior authorization, to promote and defend their respective interests, and to negotiate collectively with other parties (UNEP, 2021). To assess the subcategory the indicator level of compliance with FACB rights was assessed.

The level of compliance with FACB rights is evaluated in a scale from 0 to 10, with 0 indicating higher level of compliance and 10 indicating low levels of compliance with FACB rights (ILO, 2022a). Figure 8 depicts the results obtained for the level of compliance with FACB rights in Portugal and the average for European Union. Portugal presents a level of compliance of around 0.5 which in line with the average of the European Union countries.

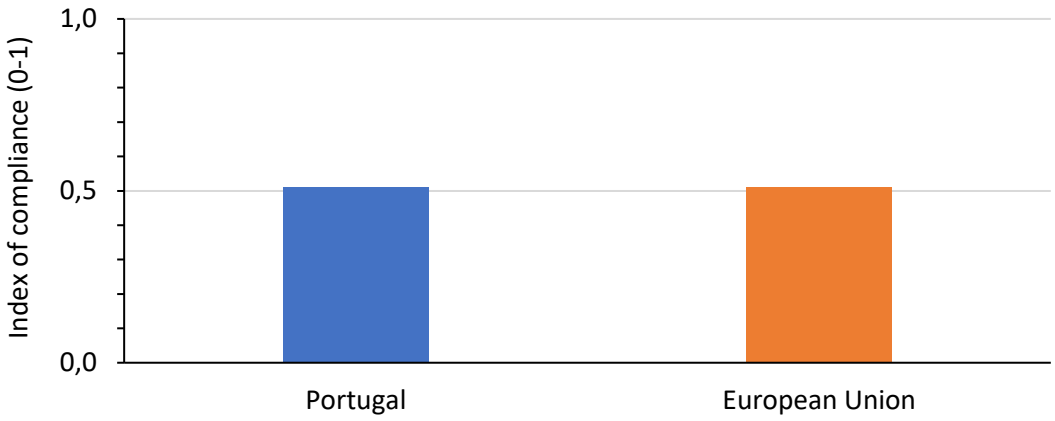

Figure 8. Level of compliance with FACB rights in Portugal, and in the EU-27 as an average of the represented countries. Data retrieved from ILO (2022a).

5.1.1.2 Fair salary

The present subcategory evaluates if practices concerning wages follow established standards and legal requirements (UNEP, 2021).
To assess the level of wages, three standards were considered: the minimum wage required by law, the local "prevailing industry wage" and the "living wage" (Maister et al., 2020).

Minimum wage required by law

In Portugal, the national minimum wage required by law is fixed at 705 €/month for 2022 (dgert, 2021).

Local Industry wage

According to data retrieved from the ILOSTAT database (ILO, 2022b), the average wage for the sector of water supply, sewerage, waste management and remediation activities was 974 €/month in 2020. Figure 9 shows that this value is slightly higher than the average wage for the

industry as a whole and provides a view on the positioning of the water sector in terms of salary among similar sectors of the industry.

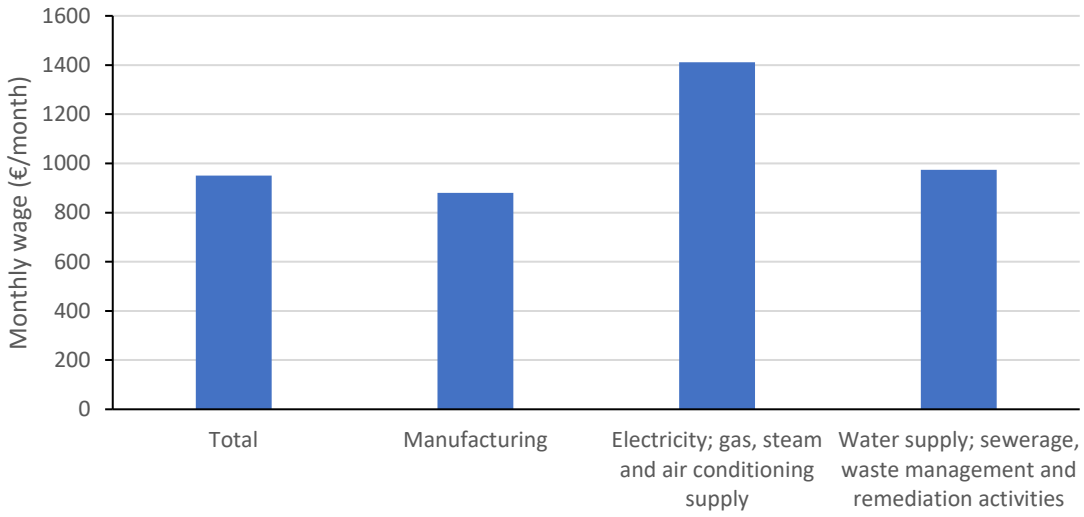

Figure 9. Average monthly wage paid in specific sectors in Portugal as well as the average wage in the industry as whole. Source: ILO (2022b).

Living wage

In terms of living wages, figure 10 shows that for a single adult in Portugal, the living wage ranges between 618 - 828 €/month, where the lower bound assumes a cost-optimizing household seeking cheaper than average housing, food and other indispensable goods or services, while the upper bound is measured using prices taken at the 50th percentile (median). As it is possible to observe, the gross income for a single adult, considering the minimum wage, is above the lower bound but below the upper bound for a single adult living in Portugal.

In addition, the full-time equivalent living wage in gross terms to cover a standard family (2 adults and 2 children) expenditure ranges between 908 – 1,330 €/month. Partner 1 is assumed to work full-time for the living wage. Partner 2 works with 80 % intensity (a four-day workweek) for an equivalent proportion of the living wage. Following this arrangement, the gross income, considering the national minimum wage, would be translated into 1,269 €/month*. This value is above the lower bound but below the upper bound of the living wage for a standard family living in Portugal (Guzi, 2021).

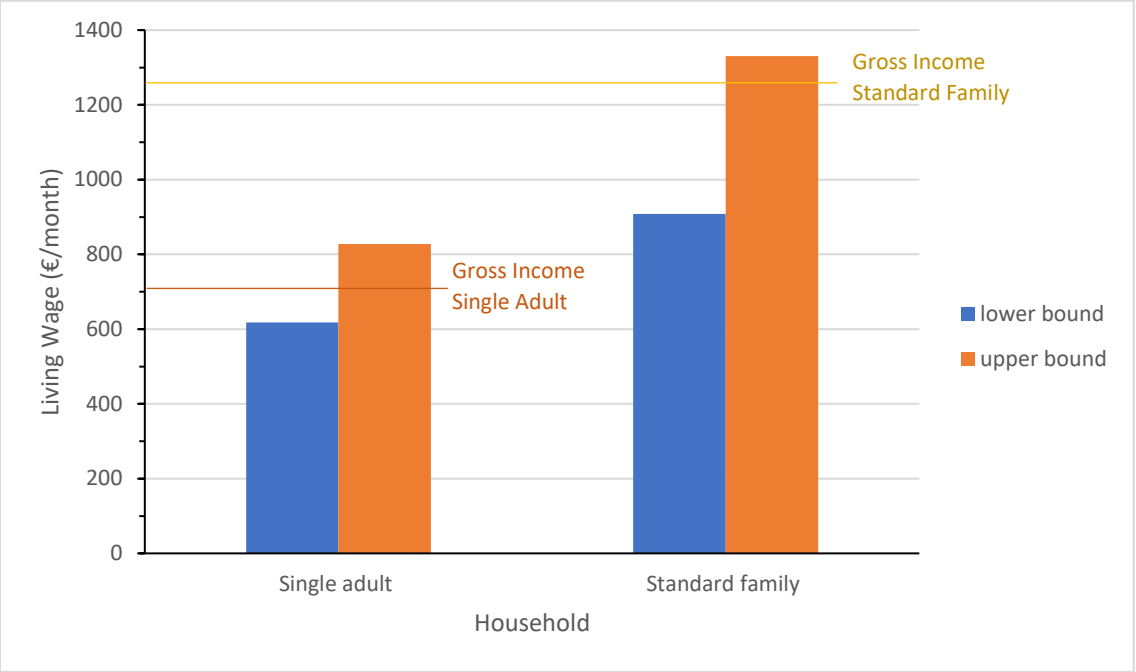

Figure 10. Monthly living wage in Portugal per type of family. For each type of family two distinct levels of expenditure are considered: lower bound and upper bound. The income per type of family considering the minimum wage as the salary, is represented by strait lines for both family typologies. Red line – single adult; yellow line – standard family.

$* (0.8 * 705 + 705 = 1{,}269\ €)$

5.1.1.3 Working hours

To verify the compliance of hours of work with legal requirements, the number of hours worked per week in distinct sectors of the industry were evaluated against standards legally defined.

As one can see in figure 11, data retrieved from ILOSTAT (ILO, 2022c) indicates that different industrial sectors, including water supply, sewerage, waste management and remediation activities, comply with the maximum of 48 hours/week defined in the ILO Hours of Work Convention 1919 (No. 1) (ILO, 2015). Additionally, in the three sectors the number of hours worked in Portugal follows the limit of 40 hours per week, established in the Portuguese labour law. Compared to the electricity and manufacturing sectors, the water sector presents less hours of work per week both in Portugal and EU average.

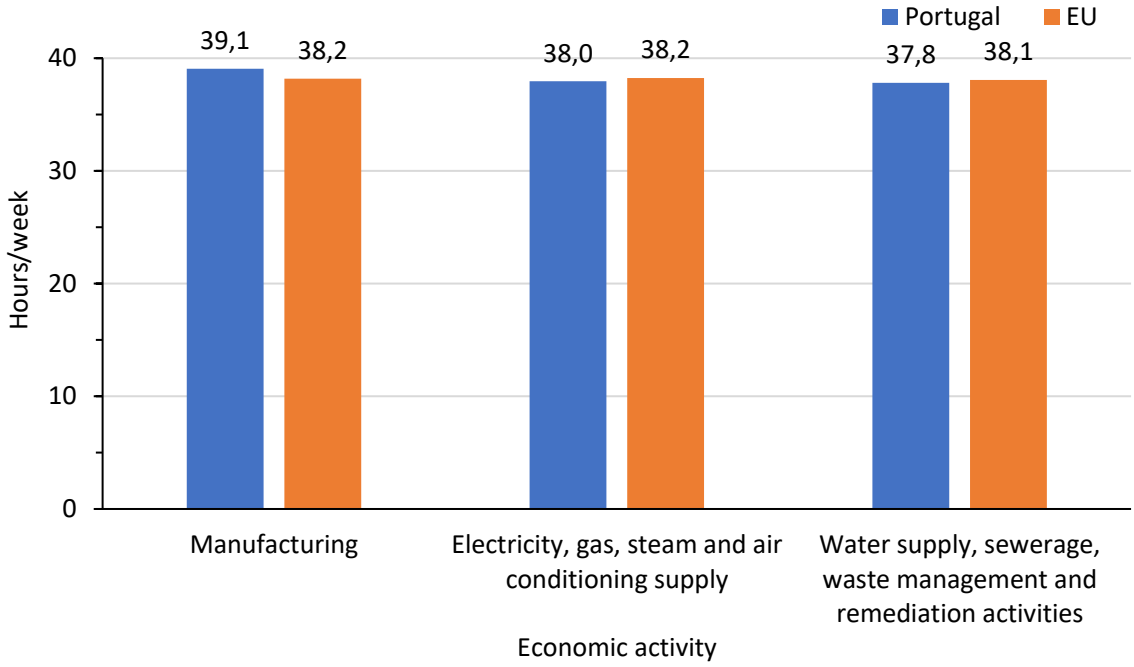

Figure 11. Hours worked per week in different industrial sectors. The figures are presented for both Portugal and the EU-27 average. Data retrieved from ILO (2022c).

5.1.1.4 Equal opportunities/discrimination

The subcategory aims to assess equal opportunity management practices and the presence of discrimination in the opportunities offered to workers by the organizations and in the working conditions (UNEP,2021). In order to assess the subcategory, indicators such as salary inequalities across the working force, as well as gender specific working hours inequalities and access to employment and particular occupations were analysed at the national level.

Salary inequalities

According to the Portuguese institute of statistics (INE, 2021), in 2020 salary inequality increased at the national level except for the Região Autónoma dos Açores. The Gini Coefficient (The World Bank, 2021) is a measure of statistical dispersion that represents income inequality or wealth inequality within a nation or a social group. It considers the entire distribution of income, reflecting income differences between all population groups. The coefficient assumes values between 0% (when all individuals have equal income) and 100% (when all income is concentrated on a single individual). In 2020, Portugal recorded a Gini coefficient of 33.0%, experiencing a 1.8% increase versus the previous year (31.2%) (The World Bank, 2021).

The S80/S20 ratio, which is the ratio between the net equivalent monetary income received by the 20% of the population with the highest income and net income received by the 20% of the population with the lowest income, increased 14%, from 5.0 in 2019 to 5.7 in 2020 (INE, 2021). Finally, the S90/S10 ratio, which is the ratio between the net equivalent monetary income received by the 10% of the population with the highest income and the income received by the 10% of the population with the lowest income, was 9.8, increasing 1% in relation to the previous year (INE, 2021).

Working hours inequalities

Figure 12 shows the distribution of working hours by sex and occupation. For both cases, Portugal and European average, it is possible to conclude that men work more hours per week when compared to women, independently of the occupation. Furthermore, people working in managerial positions work slightly more hours than in other occupations.

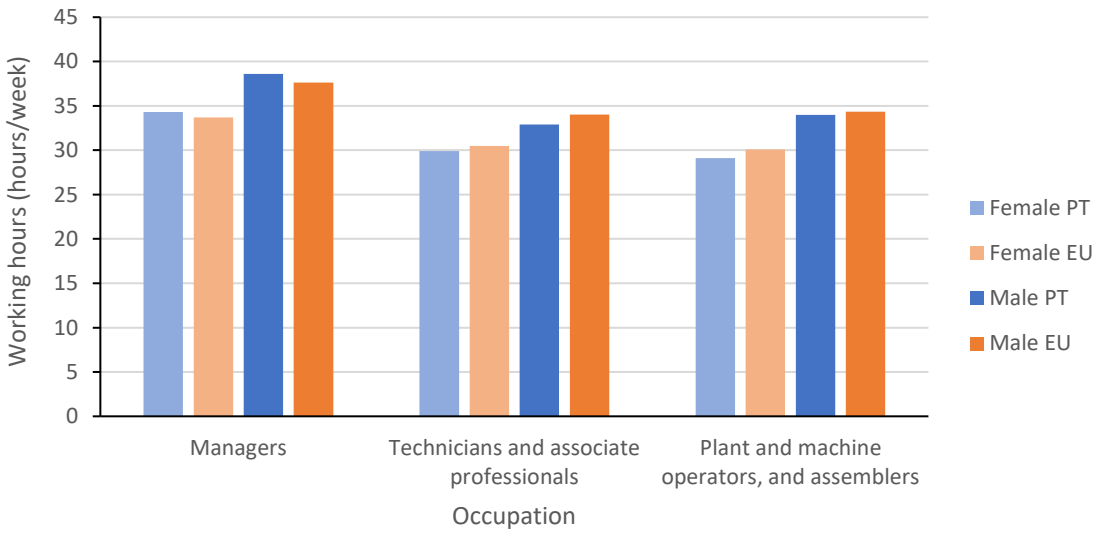

Figure 12. Mean weekly hours worked per employed person per occupation by sex and region. Data retrieved from ILO (2022c).

Access to employment inequalities

In terms of access to employment and particular occupations, figure 13 shows the share of female employees in managerial positions, in respect to the portion of the managerial sector in the workforce.

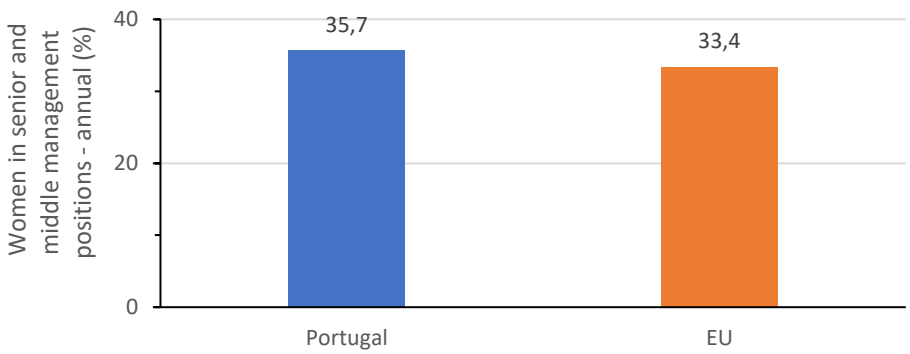

Figure 13. Female share of employment in managerial positions as a percentage of total managers in the workforce. Data retrieved from ILO (2020b).

In that respect, women employed in managerial positions in Portugal are 2.3% more than the average number of women in senior and middle management positions in the EU (figure 13). Portugal is the tenth country of Europe with more women in senior and middle management positions.

Additionally, figure 14 shows the percentage of male or female workforce that is working in each occupation both at Portugal and EU-27 levels.

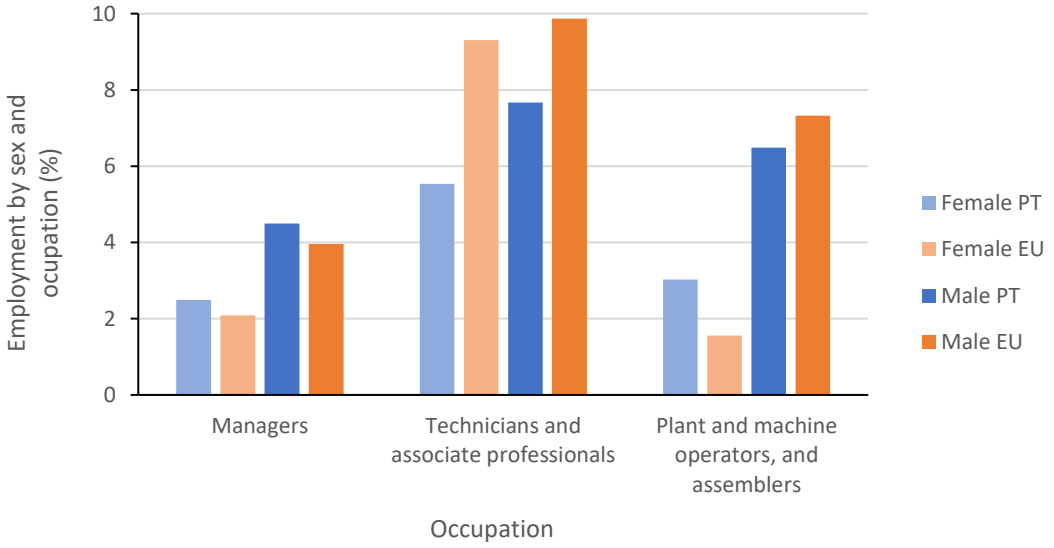

Figure 14. Workforce distribution by sex and occupation in Portugal and in the EU average. Data retrieved from ILO (2020a).

From the analysis of the data and considering the subset of occupations shown in figure 14, one highlight is that the percentage of men for the same occupation and geographical boundary is always higher than the percentage of women.

Regarding the comparison between the EU-27 and the specific case of Portugal, there is a higher percentage of female managers in Portugal when compared to EU-27. Specifically, 2.49% of female managers in Portugal and 2.09% of female managers in EU-27. The same trend is observed for female plant and machine operators, resulting in 3.02% for Portugal and 1.55% for EU-27. On the other hand, there are more female technicians and associate professional in EU-27 than in Portugal.

Performing the same comparison, but now in terms of male workforce, there is a higher percentage in EU-27 of men working as technicians and associate professionals as well as plant and machine operators. On the other side, Portugal has a higher percentage of male managers than EU-27.

5.1.1.5 Health and safety (of workers)

According to the International Labor Organization, all workers have the right to a safe and healthy workplace. In this sense, the definition of safe workplace consists of a workplace that is free of serious recognized hazards (ILO, 2022d).

This subcategory was assessed by using an indicator on the national rate of incidents.

National rate of incidents

According to Eurostat (2022b; 2022a), in 2019 Portugal experienced a total of 131,717 non-fatal accidents at work and a total of 104 fatal accidents at work. In particular, the sector of water supply, sewerage, waste management and remediation activities accounted with a total of 2,030 non-fatal accidents and 1 fatal accident.

In order to compare the non-fatal and fatal accidents at work occurred in Portugal and in Europe, the incidence rate per 100,000 persons employed was analysed in these two regions. Figure 15 indicates that when considering all economic activities, Portugal had an incidence rate of fatal accidents 22% higher than Europe. On the other hand, for the specific activity of water supply, sewerage, waste management and remediation activities, Europe presented an incidence rate 54% higher than Portugal.

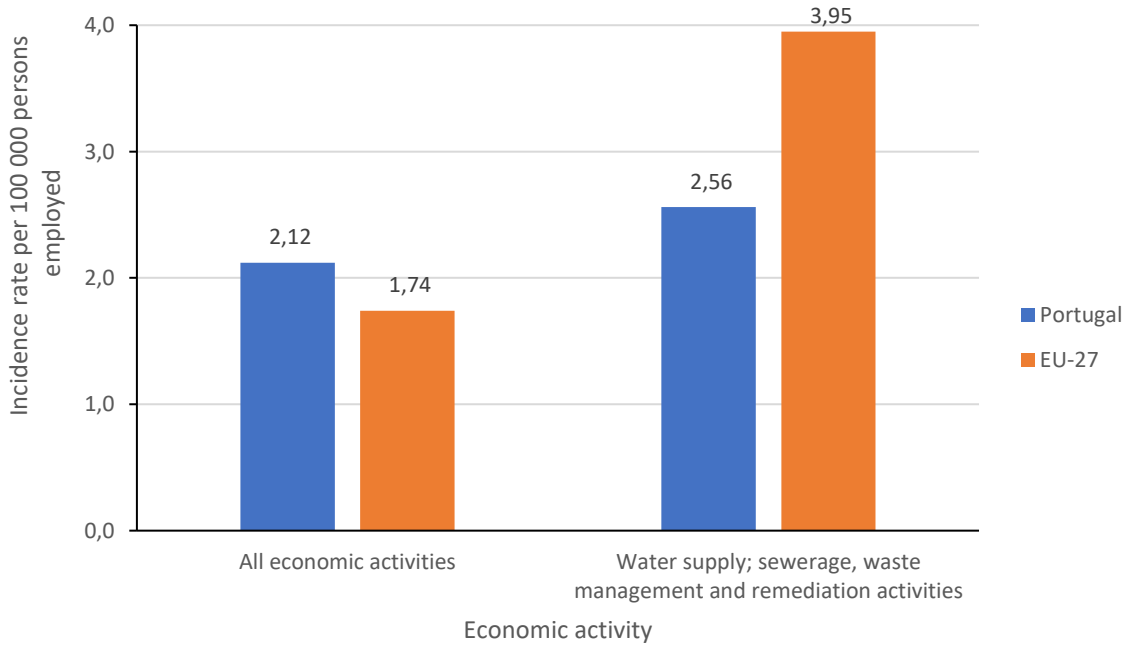

Figure 15. Rate of fatal incidents per 100 000 persons employed. The rates are projected for all economic activities and specifically to the water sector both in Portugal and the EU-27. Data retrieved from Eurostat (2022b).

In terms of non-fatal accidents, Portugal experienced an incidence rate higher than Europe both for the total of all economic activities and for water supply, sewerage, waste management

and remediation activities (Figure 16). Portugal has an incidence rate 74% higher on water supply, sewerage, waste management and remediation activities and 67% higher in on all economic activities.

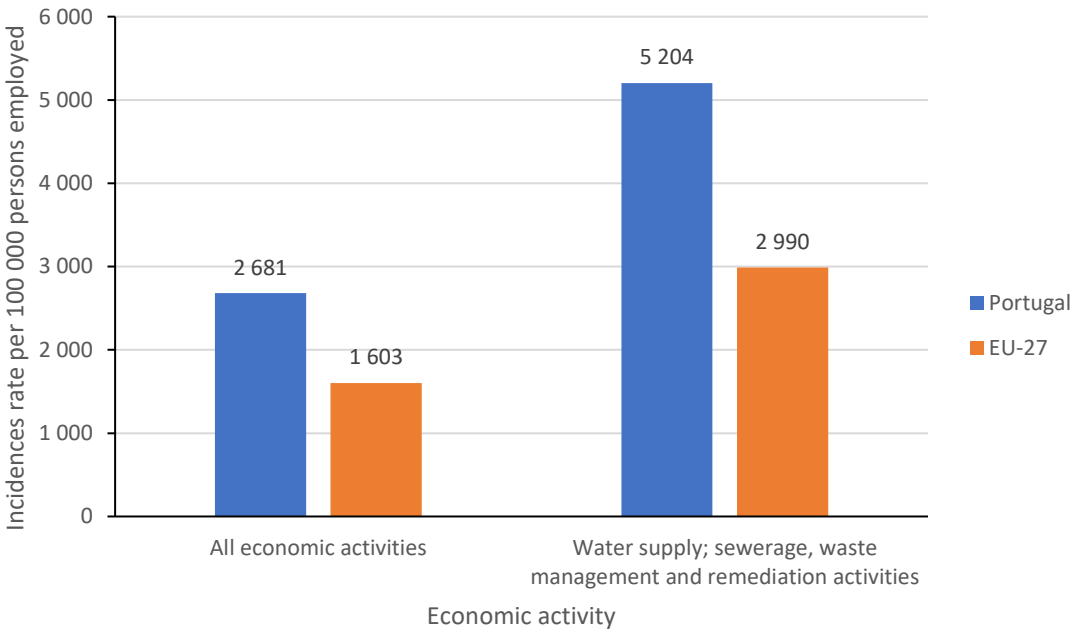

Figure 16. Rate of non-fatal incidents per 100,000 persons employed occurred in 2019 in Portugal and in EU-27. All economic activities and the water sector are represented. Data retrieved from Eurostat (2022a).

5.1.1.6 Social benefits/social security health

This subcategory assesses whether and to what extent an organization provides social benefits and social security to workers (UNEP, 2021). The indicator used to address the subcategory explores the presence of social benefits offered to workers.

Figure 17 shows some examples of specific social protection systems and the percentage of persons in need of the respective system that benefited from the same in 2020 (ILO, 2022e).

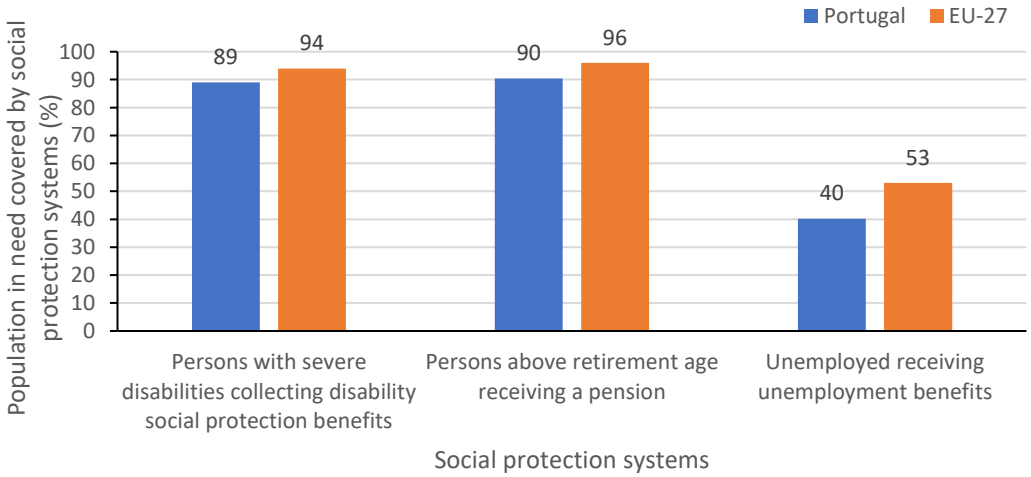

Figure 17. Percentage of the population in need of specific social protection systems covered by the same in 2020. Data retrieved from ILO (2022e).

Ideally, this proportion should be 100%. However, both in Portugal and in the EU as an average of the constituent countries, the value is below 100%. For disability social protection and retirement age pension benefits, 89% and 90% of the target population is covered, respectively. These values are slightly below than those for EU-27.

According to the European commission (2020) Portugal is a member of the international social security association, offering the following social security rights to its residents: family expenses relating to children and young people, maternity, paternity and adoption benefits, national public health care service, long-term care, sickness care, disability pension, occupational disease, old-age pension, survivor's benefits, social integration income, unemployment benefits, habitual residence. In order to be eligible for the different benefits mentioned above, specific conditions need to be met depending on the benefit in question. However, in Portugal only 40% of the eligible population is covered by unemployment benefits, which is one of the national social security rights of Portuguese citizens.
The same benefit was available for 53% of the eligible population in EU-27 countries.

5.1.2 Stakeholder: Consumers

5.1.2.1 Health and safety (of consumers)

End users expect products/services to perform their intended functions satisfactorily, without posing a risk to their health and safety (UNEP,2021).

This subcategory helps to identify the existence and scope of systematic efforts to address consumer health and safety across the organizations involved in the life cycle of a product and/or service. To evaluate this subcategory, the presence of certified quality management systems was analysed in detail.

Certified quality management systems

As it is possible to observe from figure 18, considering all economic sectors, Portugal has about 30 companies per 10,000 employees, certified with the ISO 9001:2015 - Quality Management System (ISO, 2020).

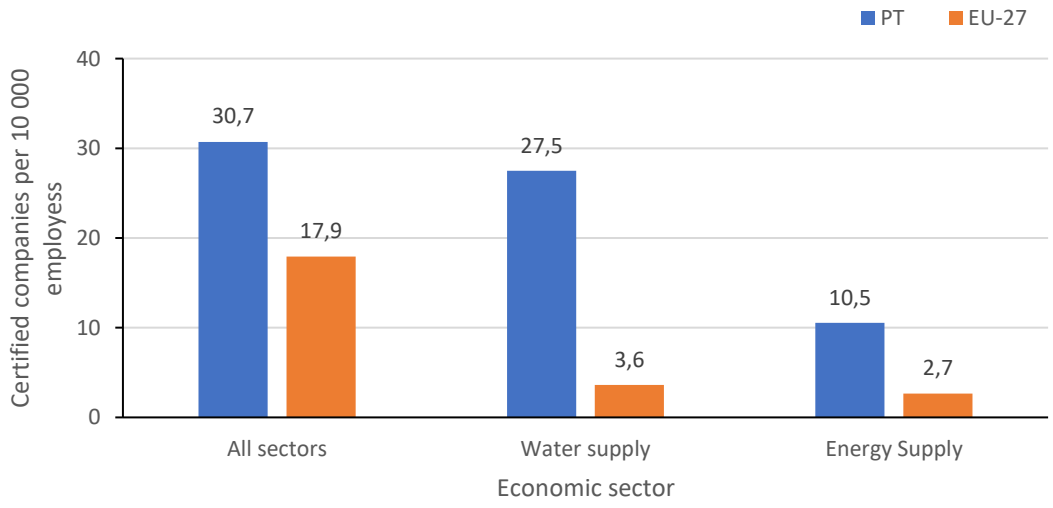

Figure 18. Number of companies per 10 000 employees certified with the ISO 9001:2015 standard in portugal and the average of an EU-27 country. Data retrieved from ISO (2020).

The EU-27 counts approximately less 40% certificates for the entire economical sector on relative terms.

Similarly, Portugal holds a certification rate at least four times higher than EU-27 for companies on the water supply and energy supply sectors.

5.1.3 Stakeholder: Local Community

5.1.3.1 Access to material resources

This subcategory assesses the extent to which organizations respect, work to protect, to provide or to improve community access to local material resources (i.e., water, land, mineral, and biological resources) and infrastructure (i.e., roads, sanitation facilities, schools, etc.) (UNEP, 2021).

To describe this subcategory the (i) level of water use, (ii) level of circular material use, (iii) quality of water infrastructure and (iv) presence of certified environmental management systems, were assessed at the national level.

Water Use

The pressure on water resources can be measured through distinct indicators. Figure 19 shows both the freshwater withdrawal as a % of total renewable water resources and the level of water stress both in Portugal and in EU-27 region.

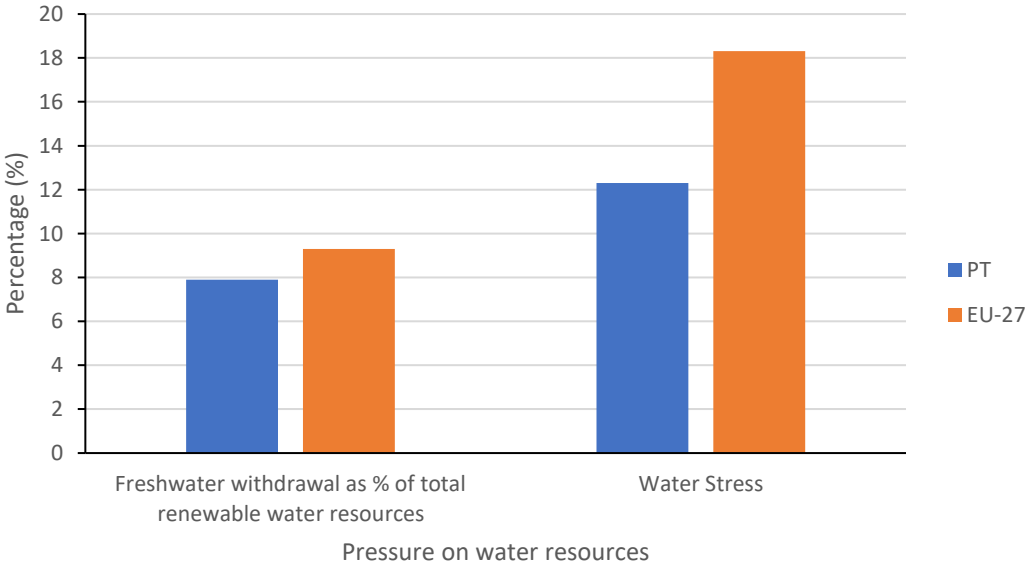

Figure 19. Freshwater withdrawal as a percentage of total renewable water resources and level of water stress in Portugal and in EU-27. Data retrieved from FAO (2020b).

The annual freshwater withdrawal indicates the pressure on the renewable water resources, which correspond to the maximum theoretical yearly amount of water available for a country at a given moment. Portugal withdraws 7.9 % of the total amount of water available in 2018. For the same year, in EU-27 about 9.3% of total freshwater available was extracted.

It can be assumed that high levels of water withdrawal are accompanied by high levels of water depletion. Withdrawing water faster than it can be replenished may result in an inability to meet

both current and future requirements. Environments that depend on shallow ground water or long-lasting streams can be particularly harmed by misuse of water. Moreover, conflicts between customers, between communities upstream and downstream, and between withdrawal demands and recreational and environmental interests can result from demand exceeding supply (Senthil Kumar & Yaashikaa, 2019).

Portugal faces 12,1% of water stress, while the region constituted by the EU-27 faces 18,3% of water stress (FAO, 2020b). This percentage represents the ratio between total freshwater withdrawn by all major sectors and total renewable freshwater resources, after considering environmental flow requirements. Environmental flow requirements characterize the quantity and timing of freshwater flows required to sustain freshwater ecosystems & the human livelihoods (food, water, shelter and clothing) and well-being that depend on them (FAO, 2020a).

Water Infrastructure

In terms of water infrastructure, according to The World Bank (2020a), 99% of the Portuguese population has access to at least basic sanitation services safely managed. Likewise, 98% of the EU-27 benefits from the same service (figure 20).

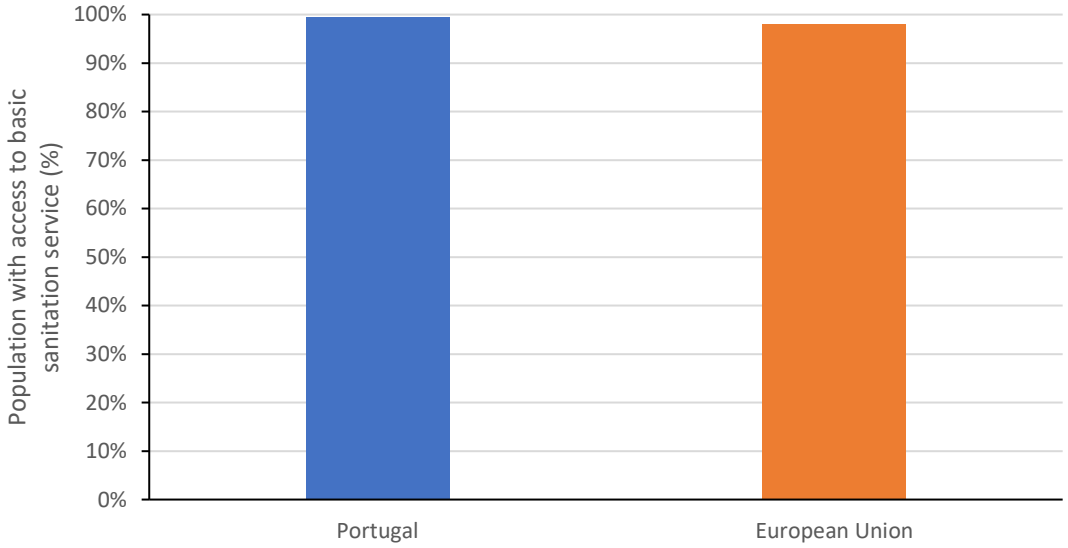

Figure 20. Percentage of the population with access to basic sanitation services both in Portugal and in the European Union. Data retrieved from The World Bank (2020a).

Circular material rate

The circular material rate or circularity rate, measures the share of material that is recycled and fed back into the economy. Consequently, the extraction of primary raw material decreases. The indicator is defined as the ratio between the circular use of materials and the overall material use. A higher circularity rate value means that more secondary materials substitute primary raw materials thus reducing the environmental impacts of extracting primary material (Eurostat, 2022c). Considering the subcategory “access to material resources”, one could say that the circular material use rate translates the effort of a country to reduce potential burdens on natural material resources (Maister et al., 2020). In that sense, figure 20 shows that Portugal has a low circular material use rate. The country accounts for a circularity rate of 2.2%, while the same value for the region of EU-27 is of about 12.8%. This means that in 2020, 2.2% of the total

materials used were recycled before. This percentage includes the circularity of metals, non-metallic minerals, biomass and fossil fuels.

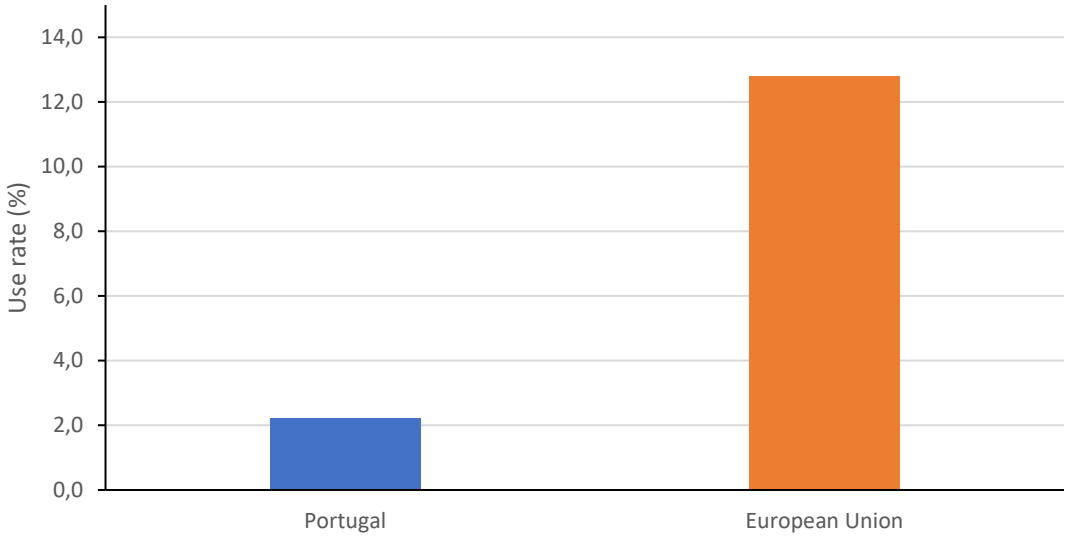

Figure 21. Circular material use rate in Portugal and in EU-27. The rate translates the share of materials that are recycled and fed back into the economy. Data retrieved from Eurostat (2022c).

The Netherlands (31%), Belgium (23%), and France (22%) had the greatest circularity rates in 2020. Romania reported the lowest percentage (1%), followed by Portugal (both 2%) and Ireland (both 1%) (Eurostat, 202c).

Certified environmental management system

This indicator assesses the number of certified environmental management systems (EMS) per country, in relation to the number of employees (figure 22). It is assumed that the more certified EMS exist in companies of a specific country, the bigger the commitment of the country to incentivize environmental protection. The number of companies with an ISO 14001:2015 certifications per 10,000 employees was analyzed.

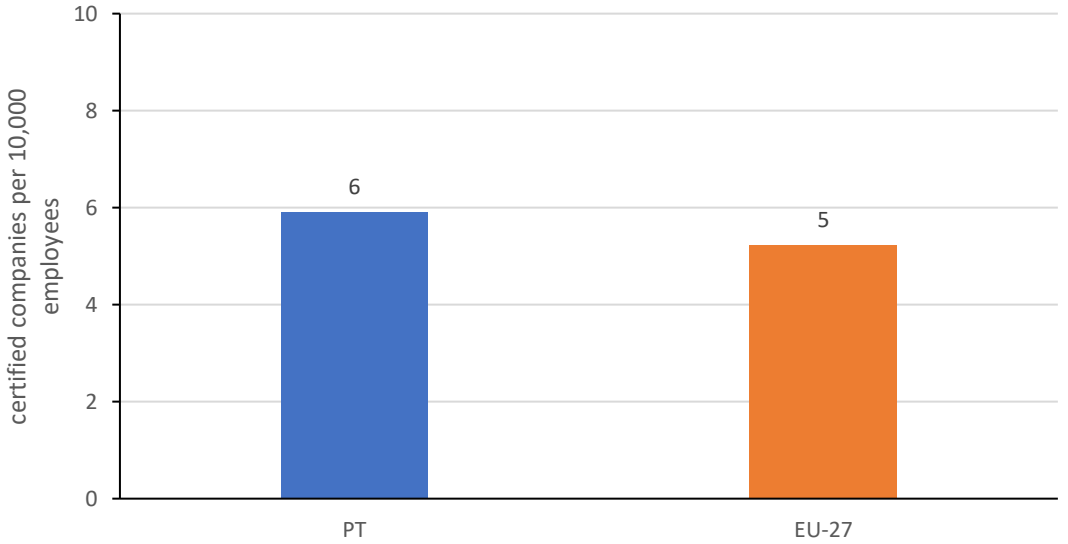

Figure 22. Number of companies per 10,000 employees certified with the ISO 14001:2015 standard in Portugal and the average of an EU-27 country. Data retrieved from ISO (2020).

ISO 14001 establishes the criteria for an environmental management system, mapping a framework that a company or organization can follow in order to build an effective EMS. This certification is intended for any type of organization, regardless of its activity or sector, assuring the company management, employees and external stakeholders, that environmental impacts are being measured and improved.

In Portugal there are approximately 6 certified companies with the ISO 14001:2015 per 10 000 employees. Similarly, in EU-27 about 5 companies present the same certificate (figure 22).

5.1.3.2 Safe and healthy living conditions

The present subcategory addresses the safe and healthy living conditions of communities regarding the impact that operations conducted by industries and organizations can cause on the living conditions of communities (UNEP,2021).
Different indicators were used to reflect on the living conditions of communities. In particular, (i) the contribution to environmental load, (ii) pollution level and (iii) access to basic services were considered to reflect countries efforts to regulate economic activities in terms of risks of negative health effects by specific industries due to emission of different components (Maister et al., 2020).

Contribution of the sector to environmental load

This indicator measures the emissions of gases into air per sector and, therefore, a sector's contribution to environmental pollution, global warming and health risks. For this purpose, data for the GHG emissions by sector was used. These emissions contribute to climate change and air pollution as well as to negative health effects, such as respiratory diseases and lung cancer (Maister et al., 2020).

Figure 23 illustrates the contributions of three economic sectors to environmental load, in terms of GHG emissions. The values are presented in kg/capita for the year 2020.

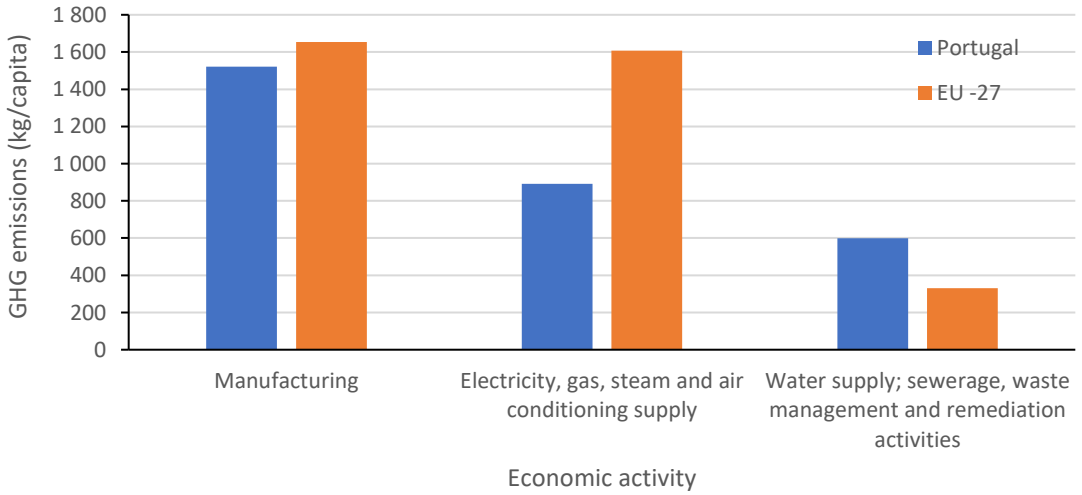

Figure 23. GHG emissions per economic activity measured in kg per capita in Portugal and the EU-27. Data retrieved from Eurostat (2022d).

The manufacturing sector has the biggest contribution of emissions both in EU-27 average and in Portugal. In the EU-27 the value rounds 1650 kg/capita of GHG, being a slightly smaller in Portugal, 1520 kg/capita.

In terms of emissions from the electricity sector, the values are considerably higher in EU-27 than in Portugal. For the same year, the sector released about 1,600 kg/capita of GHG emissions in the EU-27 and 890 kg/capita in Portugal. Finally, the water sector has the fewest contribution of emissions in both locations. However, while for the other sectors the GHG emissions for the European average were higher than in Portugal, the case is not the same for the water sector. In Portugal, the water sector was responsible for 600 kg/capita of GHG emissions. As for the EU-27, the sector counted with 330 kg/capita of GHG emissions.

Pollution level of the country

This indicator measures the overall level of pollution in a country in order to describe the situation in that a company or industry is operating. Consequently, it provides information about the importance of clean economic activities and compensation efforts that countries and organizations should do.
Data is based on the pollution index by Numbeo (2022). The index refers to different types of contamination in countries. The index reflects an estimation of the overall pollution in the country. The biggest weight is given to air pollution and to water pollution/accessibility. Other types of pollution are described with a smaller weight. The results are given in a scale from 0 to 100, with 0 representing the minimum level of pollution and 100 the maximum.
In 2022, Portugal exhibited a pollution index of 30.48. Based on each country pollution index, the averaged pollution index was calculated for EU-27, resulting in an index of 37.9.

Access to basic services

The indicator assesses the availability and accessibility of populations to water for domestic use and to sanitation services. The "Proportion of population using safely managed drinking water services" was used to evaluate the availability and accessibility to water for domestic use.
Drinking water services refers to the accessibility, availability and quality of the main source used by households for drinking, cooking, personal hygiene and other domestic uses. The definition of safely managed indicates drinking water from an improved water source which is located on premises, available when needed and free from faecal and priority chemical contamination (UN – Water, 2022). Improved drinking water sources are those that have the potential to deliver safe water by nature of their design and construction, and include piped water, boreholes or tube wells, protected dug wells, protected springs, rainwater, and packaged or delivered water. As the indicator also indirectly shows the share of the population without access to an improved drinking water source, it serves to assess the vulnerability of populations and local communities to water pollution and water shortages. Hence, people's exposure to diseases can be derived. Vice versa, the indicator provides information about the potential for countries and organizations to engage in improving water treatment and water supply.

To measure the level of sanitation coverage, the indicator "Proportion of population using safely managed sanitation services" was analysed. Sanitation services consist of the management of excreta from the facilities used by people, through emptying and transport of excreta for treatment and possible discharge or reuse. The safely management of sanitation services implies the use of improved facilities which are not shared with other households and where excreta are safely disposed in situ or transported and treated off-site. Improved sanitation facilities are those designed to hygienically separate excreta from human contact and include flush/pour flush to piped sewer system, septic tanks or pit latrines; ventilated improved pit latrines, composting toilets or pit latrines with slabs (UN – Water, 2021). Populations with lower sanitation coverage are exposed to a higher risk of infectious diseases and epidemics. Assuming

that low access to improved and safely managed sanitation facilities is accompanied by lower water treatment rates, the indicator also provides information about general water quality (e.g., because wastewater might be piped directly into rivers). Once more, this should motivate countries and companies to improve sanitation facilities.

Data retrieved from the UN – Water (2021; 2022) shows that 95% of both the Portuguese and Europe population have access to drinking water services safely managed. In terms of access to sanitation service safely managed, 85% of the Portuguese and 77% of Europe population, benefit from this service (figure 24).
In this case, given that no data related exclusively to Europe was available, values for both Europe and Northern America were used.

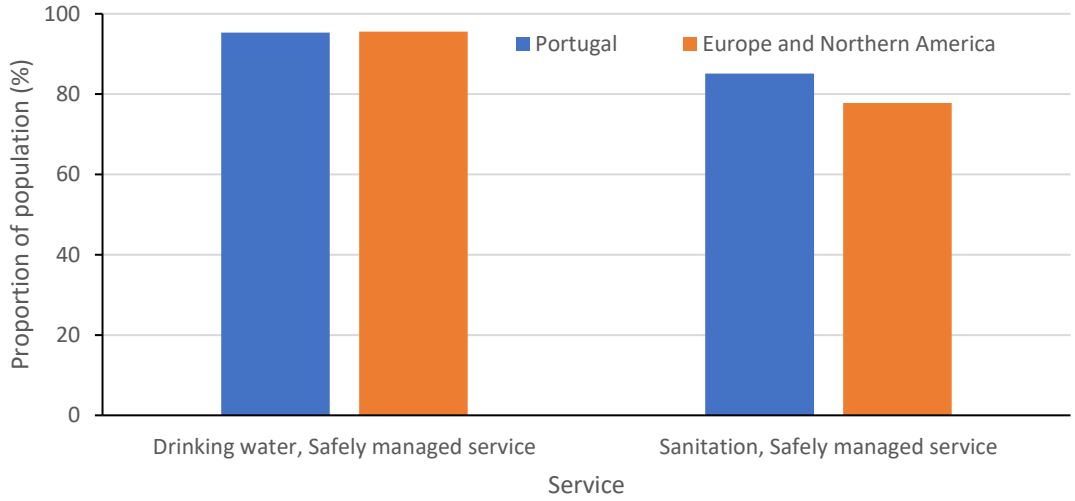

Figure 24. Share of the Portuguese and European population with access to drinking water and sanitation services. Data retrieved from UN – Water (2021; 2022).

5.1.3.3 Community engagement

The aim of this subcategory is to assess whether organizations include community stakeholders in relevant decision-making processes (UNEP, 2021). At the national level, the annual country rankings on transparency of government policymaking and public trust in politicians will be analysed. The mentioned indicators were assumed to reflect the level of engagement of populations with national governments. The transparency of governments can be perceived as the willingness to share and engage the population in national affairs, while the public trust might reflect if such actions are being conducted in a correct way.

These rankings are obtained through the executive opinion survey. The executive opinion survey integrates the global competitiveness report (World Economic Forum, 2018). The aim of the survey is to describe reality through the opinion of business leaders. Through this survey, respondents are asked to evaluate the situation for specific domains at the country level. The lowest score that a country can obtain is 1 while 7 corresponds to the highest score.
The global competitiveness report published by the world economic forum, shows the ranking and scores achieved for the above-mentioned indicators. In terms of transparency of government policymaking, Portugal scores 3.9/7, occupying the position 10/27. Regarding public trust in politicians, Portugal performs slightly worst with a score of 3.2, translating into the position 16/27 of the ranking (World Economic Forum, 2018).

5.1.3.4 *Local employment*

The present subcategory evaluates the role of organizations in directly or indirectly affecting local employment (UNEP,2021). At the national level, the unemployment rate of Portugal was taken as a basis for the evaluation of the share of workforce hired nationally.

Unemployment rate

In order to understand the current indicator, some definitions need to be introduced. An employed person is an individual aged 15 and over who worked, for one hour a week or more, for pay, profit or family gain. Additionally, people that were not working during the reference week due to illness, holiday, industrial dispute or education and training, were also considered as employed. In turn, an unemployed person consists of a person aged 15 to 74 years old who are not employed according to the definition of employment presented above, that are currently available for work and actively seeking work (Eurostat 2022e).

The unemployment rate reflects the number of people unemployed as a percentage of the labor force. In this sense, the labor force is constituted by population employed and unemployed.

For the three years presented in figure 25, the unemployment rate in Portugal is slightly lower than in EU-27. More specifically, about 6,6% of the Portuguese labor force was unemployed in 2021. Furthermore, it is possible to observe a similar trend for both geopolitical entities.

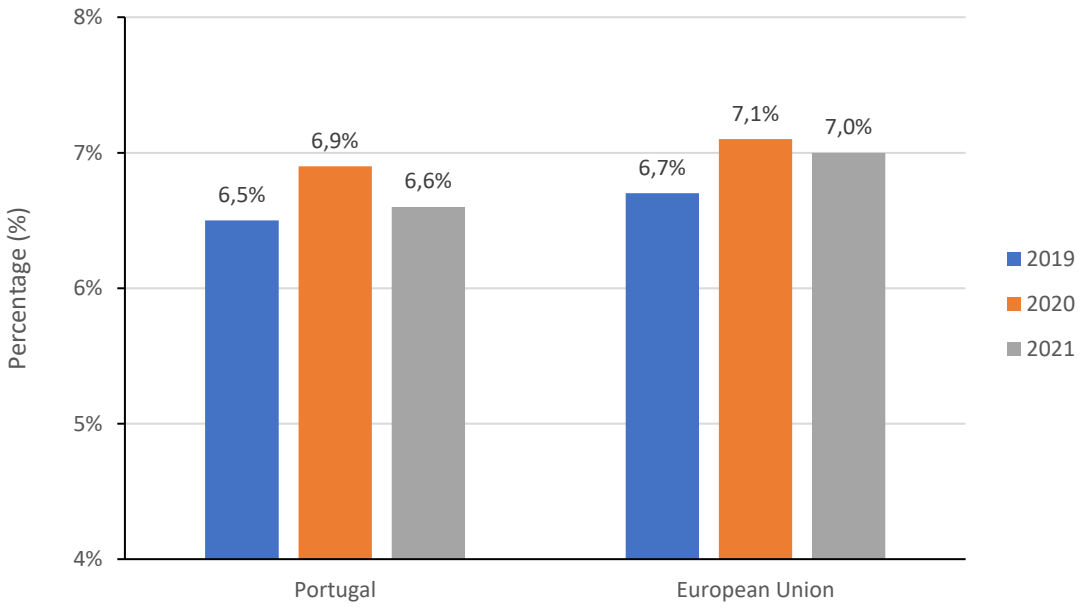

Figure 25. Unemployment rate by year in Portugal and Europe. Data retrieved from Eurostat (2022e).

5.1.4 Stakeholder: Society

5.1.4.1 *Public commitments to sustainability issues*

This subcategory seeks to assess to what extent an organization is willing to reduce its sustainability impacts. To evaluate the subcategory at the national level, the progress towards SDGs will be analysed.

Progress towards SDGs

Portugal holds an overall score of 79.23, which can be interpreted as 79.23% of SDG achievement. A score of 100 indicates that all SDGs have been achieved. In terms of European ranking, Portugal is in the second half of the table, occupying the place 16/27 (Sustainable Development Report, 2022). The previous numbers allow us to conclude that in the European context there are 15 countries performing better than Portugal regarding the public commitment to the SDGs.

5.1.4.2 Contribution to economic development

Organizations contribute to economic development in many ways. This subcategory evaluates to what extent the organization/product or service contributes to the economic development of the society. In other to analyze the economic development at the national level and how the country is working to further improve it, the subcategory aims to draw a picture of the overall economic situation in a country. In this sense, the following indicators were addressed: (i) national economic growth, (ii) contribution of a sector to economic development and (iii) public expenditure on education.

National economic growth

The national economic growth can be measured through the annual GDP growth rate. According to the World Bank (2020b), this rate translates the annual average rate of change of the GDP at market prices on constant local currency, for a given national economy, during a specified period.

GDP measure the monetary value of final good and services bought by the final consumer, produced in a country in a given period of time.

Figure 26 illustrates the annual GDP growth rate of Portugal and the aggregated values for EU-26. As it is possible to observe, Portugal follows a similar trend to EU-27 in terms of the annual changes of the GDP. However, the variations are relatively more accentuated in Portugal. It is important to note that from 2019 to 2020, a negative variation on the GDP growth of -8,4% and -6% is observed for both Portugal and EU-27, respectively. This change is due to the COVID-19 pandemic.

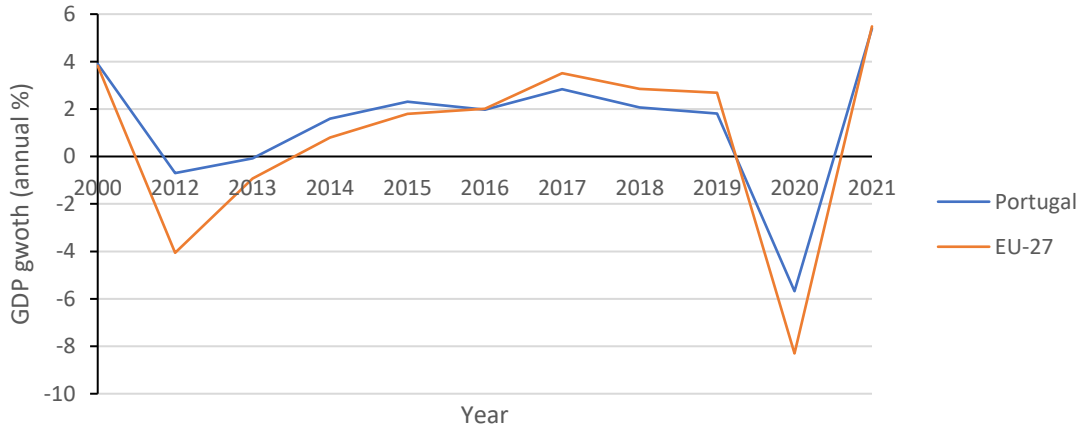

Figure 26. Annual GDP growth rate for Portugal and the EU-27. Data retrieved from The World Bank (2020b).

Contribution of sector to economic development

The current indicator considers the sectors contribution to the economic development of the country, being measured as the monetary contribution to a country's GDP. According to Maister

et al. (2020), this metric can be perceived as an indication for other types of contributions to economic development, such as the creation of jobs, specific education and training, investments in businesses/ infrastructure etc. Values are expressed as a sector´s share of the GDP. From figure 27 it is possible to conclude that the services sector is the that contributes the most to GDP, followed by the industry sector and agriculture The same trend is observed in Portugal and in EU-27.

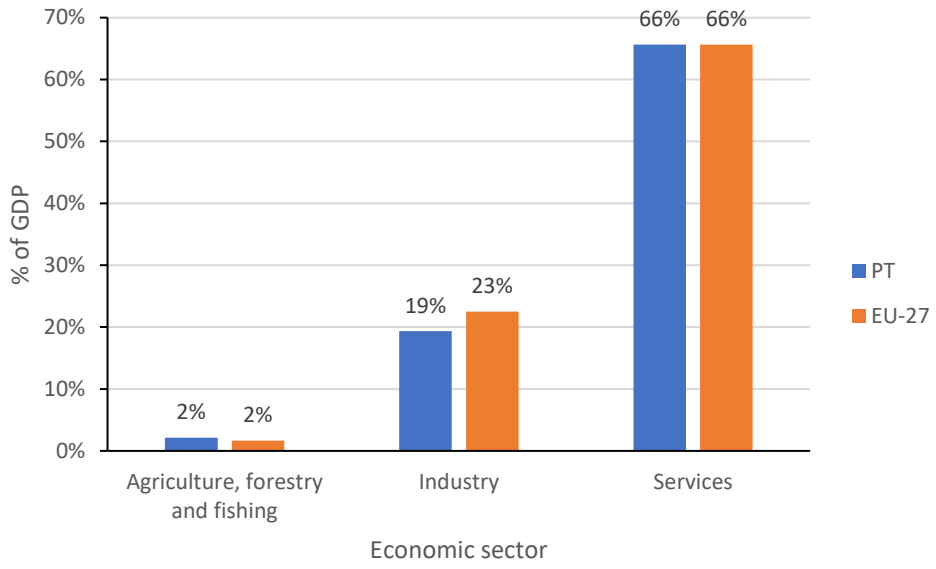

Figure 27. Contribution of specific sector to the GDP. Data retrieved from Statista (2020).

Public expenditure on education

The public expenditure on education reflects the priority that the government gives to education. Maister et al. (2020), considers that if public expenditure is low, good and higher education might heavily relate on private institutions, that are mainly availably for wealthier groups of the society. As such, government expenditure on education can be perceived as an indication for the overall educational level of societies. This in turn might prevent companies to settle or invest because of a possible lack of qualified and skilled labour force. To help the countries out of this vicious circle and foster economic development, governments and organizations already established in these regions should invest and promote education.

The indicator is defined by the World Bank as the "Total general (local, regional and central) government expenditure on education (current, capital, and transfers), expressed as a percentage of GDP. It includes expenditure funded by transfers from international sources to government."

In 2018, an equivalent to 4,7 % of the GDP in Portugal was invested in education. In the same year, the aggregated value for EU-27 was 4,6% of the GDP (figure 28).

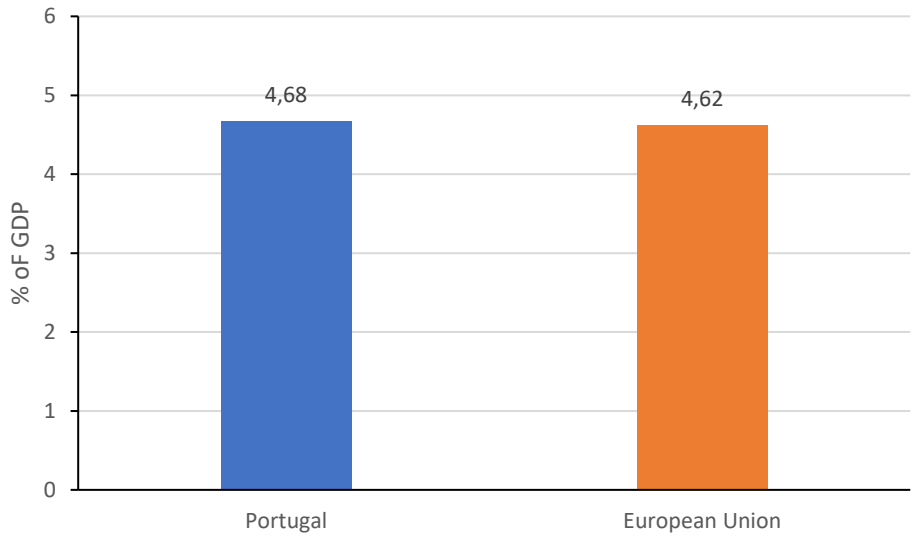

Figure 28. Public expenditure on education. The values are given in terms of percentage of the total GDP. Data retrieved from UIS (2022).

5.1.4.3 Corruption

This subcategory aims to assess the overall state of corruption of a country as well as the national effort to prevent corruption. For this purpose, the corruption perception index and national policies were analyzed.

Corruption perception index

The international non-governmental organization Transparency International, publishes the corruption perception index per country at the annual basis (Transparency International Organization, 2019). The index aggregates data from distinct sources that provide the perception of businesspeople and country experts of the level of corruption in the public sector. The results are given on a scale of 0 (highly corrupt) to 100 (very clean).

Since 2012 that Portuguese corruption perception index has oscillated between 61 and 64. In 2022, Portugal achieved a score of 62/100, occupying the place 12/27 in the EU-27 ranking.

5.1.5 Stakeholder: Value chain actors (excluding consumers)

5.1.5.1 Fair competition

The present subcategory evaluates if the competitive activities followed by organizations are conducted in a fair way and in accordance with legislations preventing anti-competitive behaviour, anti-trust, or monopoly practices (UNEP,2021).
For this purpose, the presence of policies and/or strategies to prevent anti-competitive behaviour was evaluated at the national level. Unfortunately, it wasn't possible to find data regarding this indicator at the European level. In that sense, the author analysed the Portuguese context and based on the available information, decide whether or not to include the "Fair competition" subcategory in the site-specific assessment.

Policies/strategies to prevent anti-competitive behaviour

As a member state of the European Union, Portugal follows the EU competition rules announced on the Treaty on the Functioning of the European Union (Official Journal of the European Union, 2012), that aim to prevent restrictions on and distortions of competition in the internal market.

In Portugal, the Competition Authority acts as an independent regulator across all sectors of the economy. Its main mission is to ensure compliance with the national competition defence legislation (Autoridade da Concorrência, 2022), encourage the adoption of practices to promote competition and contribute to the dissemination of culture and competition policy. The results achieved by the Portuguese competition authority in 2021 reveal a total of nine convictions and six illegality notes issued, in sectors such as health, telecommunications, large distribution and environment.

At the international level, Portugal is member of both the International Competition Network and the OECD Competition Bureau.

5.1.5.2 Promoting social responsibility

The subcategory aims to assess if an enterprise promotes social responsibility among its suppliers and through its own actions. For the purpose of the assessment of this subcategory, the memberships in initiatives and foundations with a related focus was used as an indicator and analysed at the national and European levels.

The indicator investigates, to what extent social responsibility is taken seriously and assured by companies both within a country and specific sector. The approach follows the idea mentioned above to recur to initiatives and agreements with a focus on social sustainability (Maister et al., 2020). The UN Global Compact Initiative is deemed to be an adequate association. It supports and binds participating companies to align their strategies with the initiative´s Ten Principles referring to human rights, labour, environment and anti-corruption. Seven of these principles directly address workers, local communities or value chain actors, hence, the initiative has a strong social focus.
The total number of participants on the UN Global Compact in Portugal and in the European Union was normalized with the number of employees (United Nations Global Compact, 2022). Figure 29 shows that the number of participants on the UN global compact per 10000 employees is about 0,27 in Portugal while the total number of participants per 10 000 employees in the EU is 0,41.

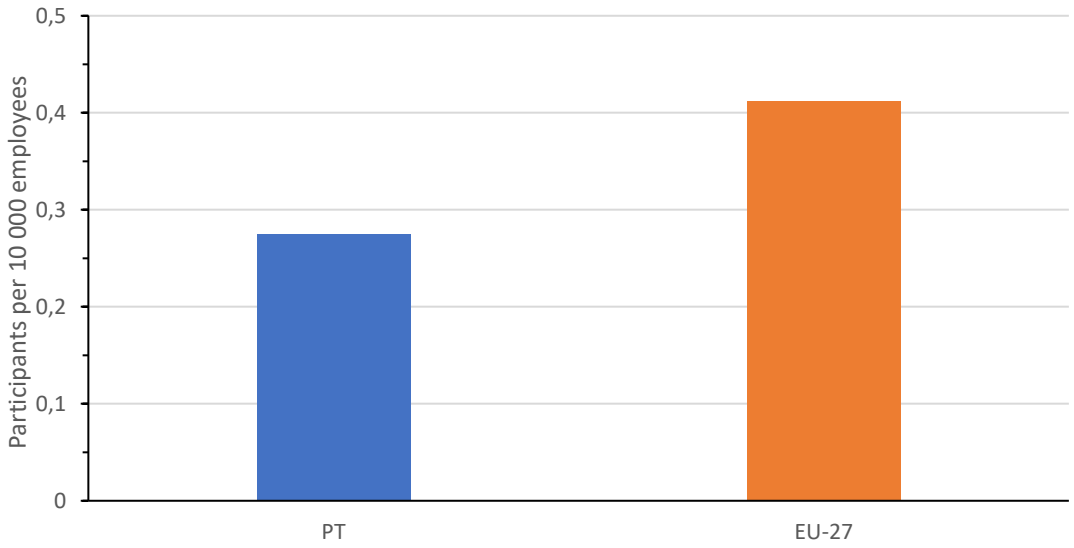

Figure 29. Number of companies per 10 000 employees, participating on the UN Global Compact. Data adapted from the United Nations Global Compact (2022).

5.2 Relevant findings from the generic assessment results

The results revealed some hotspots areas, indicating the subcategories at risk of negative social impacts generated by the WWT sector in Portugal. The collected data were filtered and the subcategories in which the respective indicators present a worse result for Portugal when compared to Europe, were considered as areas of risk.

Bearing in mind that the impact subcategories are grouped by stakeholder, the results identified workers, local community and society as the stakeholders most at risk of negative social impacts. For workers the impact subcategories signaled were fair salary, equal opportunities/discrimination, health and safety of workers and social benefits/social security. Regarding local community the subcategories access to material resources, safe and healthy living conditions and community engagement were identified. As for the society stakeholder, the subcategories public commitments to sustainability issues, contribution to economic development, corruption and promoting social responsibility were identified as potential social hotspots.

As an example of the how the filtering method was applied, the subcategory health and safety pertaining to workers stakeholder, will be described. The results for this subcategory show that Portugal has a smaller rate of fatal accidents in the water supply, sewerage and waste management sector, when compared to EU-27. However, the rate of non-fatal accidents is considerably higher in Portugal, both in the water sector and in the total of all economic activities. In that sense, health and safety of workers is considered a hotspot area that need extra attention in the site-specific assessment to ensure that organizations provide safe and healthy working conditions to employees.

Considering the results of the generic assessment presented above, the impact subcategories to be analysed in the site-specific assessment were selected. Nevertheless, adjustments had to be made. In particular, from the subcategories identified as hotspots in the generic assessment, fair salary and corruption were decided to be excluded from the site-specific assessment. Such decision was based on the sensitive nature of data related to these impact subcategories. In general, organizations are not willing to share information regarding salary distribution and corruption actions. In addition, these type of data are not publicly available to assess neither organizations performance nor the context if needed.

Moreover, the subcategories local employment and consumer health were included regardless of the results in the generic assessment, once these are relevant subcategories for the WWT service under analysis. In particular, local employment is deemed to be a relevant topic to be addressed in more detail at the site-specific level mainly due to the importance of the organizations on the specific communities where they are inserted, while consumer health is a key subcategory for a service related to a basic needs such as water and sanitation, which directly affect population health.

5.3 Site-specific Assessment results

5.3.1 Organization's scores

In this section the results obtained for each subcategory by organization are described. To better understand the results, it is important to remind the reader that when no data is available to attribute a value, the score is exclusively based in the performance of peer companies. In this

case, a negative performance from peer's side represents a score of 4 to the organization under assessment and a positive performance means a score of 3.

In the cases where an organization doesn't meet the BR, after analysing the collected data, the context of peer companies will also be analysed. Here, a negative context means a score of 3 and a positive context a score of 4. This assumes that when operating in a positive context companies should have a higher incentive to perform well, being further penalized in the score if BR are not met, while the opposite happens in case of companies inserted in a negative context.

Compliance with the BRs is assessed via the indicators corresponding to level 2 (score of 2) and proactive behaviour that goes beyond the BRs is translated by indicator from level 1.

Table 10 shows the scores of each individual organization obtained per subcategory per reference scale.

The presentation of the individual results before aggregation aims to provide a clear view of how each company is performing. As the Guidelines remind, aggregation steps taken along the way might hide details. Furthermore, by increasing transparency of the results, misinterpretation of the results can be avoided. This stage can be seen as a mapping of the scores and performance of each individual stakeholder.

Table 10. Assessment scores obtained for each reference scale per subcategory.

Stakeholders	Subcategory	Reference Scale	Assessment Scores					
			Organization A	Organization B	Organization C	Organization D	Organization E	Organization F
Workers	Equal opportunities/Descrimination	EOD1	1	3	4	2	2	2
		EOD2	1	1	3	3	3	3
	Health and safety	HSW1	2	2	2	2	2	2
		HSW2	2	2	2	2	2	2
	Social Benefits/social security health	SB1	1	1	1	3	1	2
Consumers	Health and safety	HSC1	2	NA	NA	NA	NA	4
		HSC2	2	NA	NA	NA	NA	2
Local Community	Access to material resources	AMR1	2	2	2	2	2	2
		AMR2	2	2	2	2	2	2
	Safe and healthy living conditions	SHLC1	2	2	2	2	2	2
		SHLC2	2	2	2	2	2	3
		SHLC2	2	2	2	2	2	2
	Community engagement	CE1	2	2	2	2	2	4
		CE2	1	2	1	2	2	2
		CE3	2	2	2	4	4	2
	Local employment	LE1	2	2	2	2	2	2
		LE2	2	2	2	3	2	2
Society	Public commitments to sustainability issues	PCSI1	2	2	2	2	2	2
		PCSI2	2	2	2	2	2	4
	Contribution to economic development	CED1	1	2	1	2	1	2
Value chain actors	Promoting social responsability	PSR1	1	4	4	2	2	2
		PSR2	2	2	4	2	2	2

Stakeholder: Workers

1. Equal opportunities/discrimination

In equal opportunities/discrimination two reference scales (EOD1 and EOD2) were defined in order to provide a complete assessment of each organization regarding this subcategory (see section 4.3.2.4).

Organization A performed extremely well in EOD1, achieving a score of 1 due to the pro-active behaviour regarding equal opportunities. The company has an extensive gender equality plan with clear goals as well as the social accountability certification SA8000. SA 8000 certification addresses issues such as forced and child labour, occupational health and safety, freedom of association and collective bargaining, discrimination, disciplinary actions, working hours, remuneration and management systems (SAI, 2022). In addition, regular monitorization of the gender equality plan and the SA8000 are conducted.

As for EOD2, where the share of women and men in the company is evaluated and compared with that of the sector, organization A performs better than the respective sector, which is 70% constituted by men. Organization A takes efforts to increase the share of women in the company, contributing to balance the trend of the sector with 40% women and 60% men. d

As for organization B, no data that prove the existence of formal documents addressing the topic were found and the participant did not reply to the question in the questionnaire. Consequently, after evaluation of the context a score of 3 in EOD1 was obtained. Since it is a chemical supplier, major competitors operating in the area were studied. On the other hand, the respondent of the questionnaire confirmed a gender composition of 50/50, giving the company a result of 1 in EOD2 with a better gender distribution than the one observed in the respective sector – 60% men and 40% women.

Organization F presents clear goals about equal opportunities and rules of conduct regarding the topic, obtaining a score of 2 in EDO1. However, the composition of employees by gender was not possible to assess as no public information about the breakdown of employees by gender was available and the answer to the questionnaire was considered invalid. The respondent provided the gender distribution in its unit, which given the size of the group is not considered a representative sample. Thus, organization F received a score of 3, solely based on the negative context investigated at the level of peer companies.

Organizations D and E follow with a final score of 2.5. Both companies are committed to diversity and inclusion policies, having obtained a score of 2 in EOD1. Organization E published an action plan in gender, age, nationality and disability. Unfortunately, neither organizations D and E met the BR for EOD2, and both companies present a gender distribution worse than the one of the sectors. The context was analysed, and concluded to be negative, meaning a score of 3 for both companies in EOD2.

Finally, organization C present the worst performance in “Equal opportunities/discrimination” as for both EOD1 and EOD2 the BRs aren’t met. The participant of the questionnaire has highlighted that “There is no specific policies regarding equal opportunities/discrimination” (participant of organization C, June 21, 2022). After analysing the context of peer companies, Organization C was scored with a 4 in EOD1. Regarding EOD2, the participant answered that “the management team has 3 women and only one man”. However, in a company with between 50 and 200 employees, a sample of one department with 3 people doesn’t necessarily describe the working force of the company. The answer was considered invalid, and the case was handled as

a no information situation. Again, the context was studied and determined to be positive, meaning a score of 3 in EOD2.

2. *Health and safety (Workers)*

For this subcategory two reference scales were defined (HSW1; HSW2). To comply with the BR of HSW1 organizations should present policy/guidelines or a program related to the health and safety of employees as well as preventative measures and emergency protocols exist regarding accidents & injuries. As for compliance with the BR of HSW2, the annual reports should include health and safety performance of the company, including records of occupational injuries or fatal accidents. The reported number of fatal accidents should be similar to that of the sector.

All the companies present a clear health and safety policy and/or a health and safety certified system (ISO 45001:2019 or OHSAS 18001) with preventive measures and emergency systems. Consequently, a score of 2 was attributed to each organization in HSW1.

According to the questionnaires, all companies keep record of occupational injuries and fatal accidents. Furthermore, no fatal accidents were reported for any of the companies in the last three years. Having this in mind, all the organizations received a score of 2 in HSW2.

3. *Social benefits/Social security health*

In "Social benefits/social security health" one reference scale (SB1) was defined to assess organizations performance regarding the topic. To meet the BR defined for SB1, organizations must provide its workers with at least two of the social benefits stipulated by the ILO social security convention, 1952 (No.102) (ILO, 1952).

Organization A, organization B, organization C and organization E were attributed with a score of 1. In this sense, the results of the questionnaires inform that these organizations provide their workers with more than two social benefits enunciated in the ILO convention mentioned above. More specifically, organization A offers personnel health insurance with an extension to direct family and life insurance. Organization B provides personnel health insurance, paid maternity and paternity leave, social security and retirement benefits. In addition to health insurance, organization C created an education program - "Our company built an education program for dependents of the direct household, paying nursery monthly fees from 4 months until entering the 1st cycle, university fees, subsidy for food, schoolbooks up to the 12th grade, compulsory school material, passing school year award and school transport subsidy" (participant organization C, May 5, 2022).

A score of 2 was attributed to organization F in SB1 for the existence of scholarships. As the respondent was too vague, it was not possible to identify other benefits.

There was no data available to assess organization D in SB1, so the context of peer companies was analysed. As all the companies evaluated presented social benefits to their workers, therefore the context was considered positive. Thus, organization D was received a score of 4 in SB1.

Stakeholder: Consumers

1. *Health and safety (Consumers)*

The health and safety of consumers was evaluated for organizations A and F - the WWTP operator and waste management company, respectively. The rest of the companies - chemical

and energy suppliers - stated in the questionnaire that this subcategory was not applicable to their business.

Organization A received a score of 2 for both HSC1 and HSC2. The company fulfils the basic requirements by showing internal management measures to assess consumer health and safety (HSC1). In particular, the company holds an ISO 22000 food security certification and a product certification for waster for human consumption. In terms of health or safety incidents regarding the consumer (HSC2), no cases were reported.

Finally, organization F has no internal management measures to assess consumer health and safety. The context was evaluated and concluded to be positive, which enhanced a score of 4 in HSC1. The company did not report any incident regarding consumers health and safety, meaning a score of 2 in HSC2.

Stakeholder: Local Community

1. Access to material resources

All the organizations met the BRs defined for "Access to material resources".

Considering the reference scale AMR1, all the organizations achieved a score of 2 due the existence of environmental management system or certifications that ensure the sustainable use of natural resources, the prevention of pollution and the recycling of wastes. Organizations A, B, C and D hold the ISO 14001:2015 certification and while organization F has an internal quality and environmental system.

Similarly, all organizations comply with the BR defined for AMR2 as they all showed proofs of the involvement in projects/initiatives to improve local natural resources and/or infrastructures. For instance, optimization of products transportation and reutilization of raw materials when possible are some of the actions performed by the companies. Again, a score of 2 was attributed to all companies in AMR2.

2. Safe and Healthy Living conditions

Three reference scales (SHLC1; SHLC2; SHLC3) were defined to assess the performance of each organization in "Safe and healthy living conditions".

Organizations A, B, C, D and E met the BRS of the three reference scales.

Regarding SHLC1, all organizations are certified with at least one of the following systems: i) environmental management system ISO 14001:2015quality; ii) management system ISO 9001:2015. Organizations D and F present a clear environmental policy as well as an action plan to reduce atmospheric emissions. A score of 2 in SHLC1 was attributed to all companies.

For SHLC2, evidence that the organization participates with local stakeholders in communicating the potential health and safety impacts of their operations on surrounding communities was investigated. Organizations A, B, C, D and E showed evidence on their websites, sustainability reports and other documents of the risks that their activity can pose to employees, environment and community. Organization C possesses a document called Information to be communicated to the public regarding the use of harmful substances. As mentioned before, organization B, C and D are chemical producers and suppliers and given the danger inherent to the production of chemicals, it is even more essential to be public.

As no information was available to assess organization F in SHLC2, the score was ascribed based on the performance of peer companies, which was concluded to be positive. This means a score of 3 for organization F in SHLC2.

To assess if the BR for SHLC3 was met, the presence of incidents on community health and safety was investigated. All the participants answered that there were no evidence affecting the community. As such, a score of 2 was assigned to all organizations in SHLC3.

3. *Community Engagement*

The assessment of each organization regarding "community engagement" was performed based on the three reference scales (CE1, CE2, CE3).

Organizations A, B, C and E met the BR for CE1 as written policies regarding community engagement were verified to exist, which allow these companies to reach a score of 2 in CE1. Organization F received a score of 4 in CE1 since no data was available to verify the compliance with the BR for CE1. A score of 4 was attributed to organization f in CE1 given the positive context of peer companies.

Regarding the reference scale CE2, organizations B, D, E and F received a score of 2 due to the engagement in activities with the general public. Annual open days, educational programs for children, online activities and public contests for schools, are some of initiatives organized by these organizations. As organization A and C organize these types of activities in a regular basis, a score of 1 was attributed to both companies.

Finally, organizations A, B, C and F indicate on their strategy the importance of including local communities in the decision-making process, highlighting the stakeholder as one of the relevant actors in the company business structure. This allowed organizations A, B, C and F to receive a score of 2 in CE3.

No evidence of the involvement of local communities in the decision-making process were found for organizations D and E and their score was solely based on the performance of peers. A score of 4 was attributed to both companies in CE3 as the context was assessed as negative.

4. *Local employment*

Regarding local employment, it is possible to observe that all the companies under analysis expect organization D, comply with the basic requirements for the subcategory, and thus present a score of 2. The companies present local hiring policies and goals as well as a percentage of local employees of more than 50%. On the case of organization D, the company has goals for local hiring in its management policy, which corresponds to BR of reference scale LE1 (Appendix II). However, there was no data for the indicator percentage of local employees in the Portuguese facility (LE2). As such, the context of the chemical sector in this subject was assessed and concluded to be positive, allowing the company to receive a final score of 2.5.

Stakeholder: Society

1. *Public commitment to sustainability issues*

"Public commitment to sustainability issues" was assessed via two reference scales – PCSI1 and PCSI2. In PCSI1, managing sustainability issues as part of the company's policy, strategy and goals is investigated. Next, PCSI2 evaluates the presence of publicly available documents or standards as promises or agreements on sustainability issues.

A score of 2 was attributed to all companies in PCSI1 since sustainability issues like reduction of emissions, sustainable use of resources, equal opportunities and diversity, are included in their policy, strategy or goals. For instance, all companies hold at least one of the following: certified environmental system, quality management system, sustainability strategy, social responsibility policy, UN global compact standards.

Organizations A, B, C, D and E have publicly available documents or standards that prove the engagement in sustainability issues, receiving a score of 2 in PCSI2. In particular, organizations A, D and E publish an annual sustainability report where their sustainability performance and goals are clearly stated. Likewise, organization B and C have public certification and standards concerning their commitments to environmental and quality systems.

For organization F there are no public documents or standards to confirm its promises or agreements on sustainability issues (PCSI2). As the context for this indicator was positive, a score of 4 in PCSI2 was given to organization F.

2. *Contribution to economic development*

Regarding *"contribution to economic development"*, all the organizations met the BR stipulated for the reference scale CED1. In the questionnaire, the respondents of all companies mentioned the generation profits and the creation of jobs. As such, organizations B, D and F accomplished a score of 2.

Extra information demonstrated that organizations A, C and E also contribute by fostering and supporting extra education for their employees and respective families. Reflecting a score of 1 for these companies.

Stakeholder: Value chain actors

1. *Promoting social responsibility*

Two reference scales (PSR1, PSR2) were elaborated to assess the performance of each company regarding the promotion of social responsibility among value chain actors.

Considering PSR1 the evidence of audits by the organizations with regard to social responsibility of value chain actors was examined. Organizations D, E and F obtained a score of 2 as audits to suppliers are performed by these companies. Organization A, in addition to audits, engages in consciousness-raising programs and training to promote social responsibility among suppliers and the value chain, deserving a score of 1 in PSR1.

According to the questionnaire respondents, Organization B and C do not comply with the BR for PSR1. In this case, the context of the sector regarding this subject was evaluated and used to provide a score to both companies. The context was perceived to be positive since most of the companies addressed have a social responsibility certification/ethic code of conduct, a code of conduct for suppliers and also conduct annual audits to suppliers. Thus, organizations B and C were scored with 4 for PSR1.

All organizations, except organization C, present a code of conduct for suppliers or a responsible purchasing policy, finishing with a score of 2 for PSR2.

Respondent from company C confirmed the non-existence of a code of conduct for suppliers. The organization received a score of 4 for PSR2.

Figure 30 illustrates the results obtained when reference scales are aggregated assuming equal weights, per subcategory (see section 4.3.4).

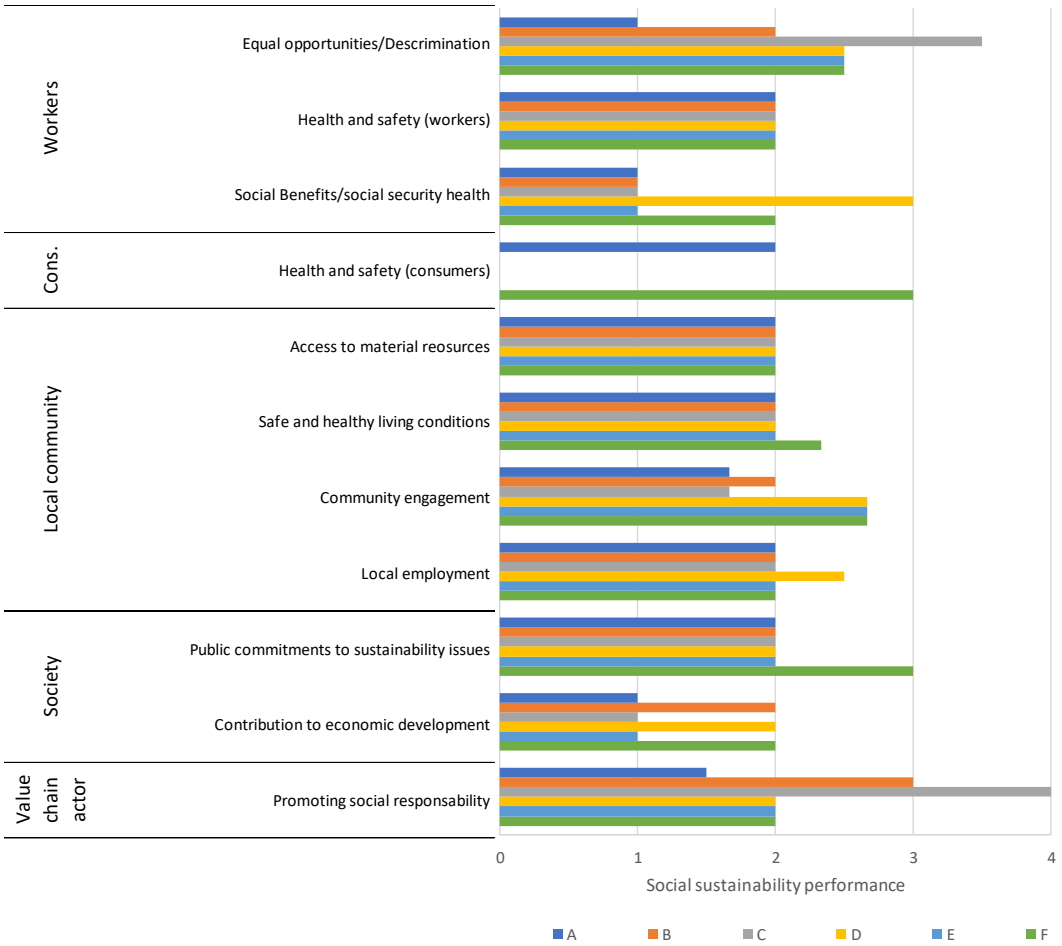

Figure 30. Site specific results obtained for the reference and novel system, per organization, per subcategory.

As mentioned before, besides the recovery of a product in the novel system, the difference between the two systems regards the amount of chemicals used, the energy consumed, and the post processing service used. Consequently, when assessing the social performance at the organizational level, the companies involved remain the same. As a result, there is no differentiation between reference and novel systems when assessing the individual stakeholder score, prior to the assessment of the companies as part of a system.

Looking at figure 30, it is possible to observe that Organization A holds the best performance, meeting the BRs in all the subcategories. Organizations B comes next, failing to meet BRs in only one category, followed by Organizations C and E that show compliance with BRs in 8 out of 10 subcategories. Note that, organizations B, C, D and E are not assessed in "Health and safety of consumers" since they operate in a business-to-business segment. Organization D meets the BRs in 7 out of 10 subcategories, representing the second worst performance after organization F, that performed well in only 6 categories.

Moreover, "equal opportunities/discrimination" is the subcategory where more organizations didn't meet the BRs. More specifically, the chemical (organizations C and D) and energy suppliers (organization E) as well as the Kaumera post-processer company (Organization F). Other subcategories where organizations performed poorly are "community engagement" and "promoting social responsibility".

The worst score was obtained by company C in “promoting social sustainability”, while all the companies meet the BRs for “Health and safety of workers”, “Access to material resources” and “contribution to economic development”.

5.3.2 Comparison of Reference and Novel systems by subcategory

In this section, the global social performance of each system per subcategory (figure 31) is determined. The performance in each subcategory is analysed considering the weighting factors attributed to each organization in each system.

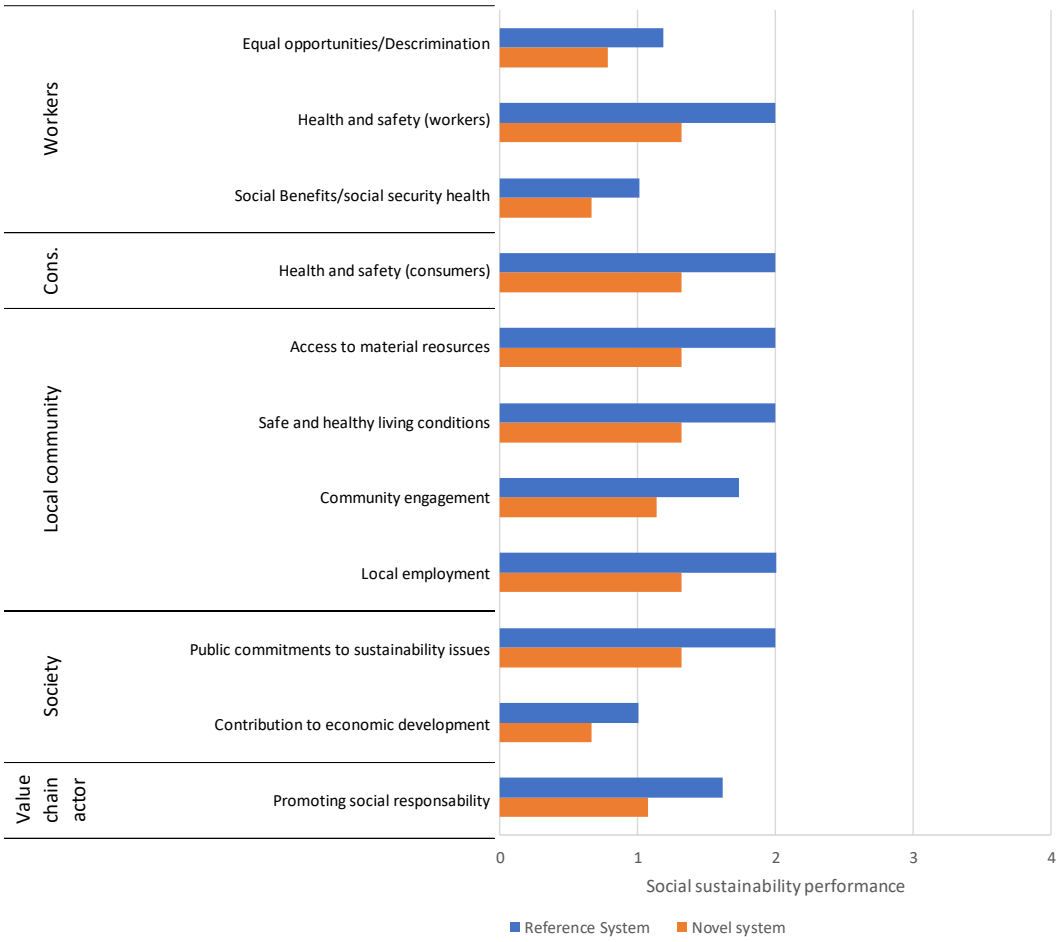

Figure 31. Results obtained for both systems after applying the weighting factors respective to each system and the allocation factor to the novel system.

The results show that both systems have satisfactory or very good performances in all the subcategories.

Recall that from an organization involvement perspective there are no differences between the reference and the novel systems. For the rest, theoretically, the main differences experienced by the two systems are changes in quantities of supply or consumption of materials. While essentially the recovery of kaumera in the novel systems would increase the consumption of chemical substances and electricity, such increase is considered minor when compared to the

consumption patterns of the reference system. This results in a very small variation of the weighting factors of each company, from one system to the other.

Considering that each organization's weight indicates the degree to which the organization is accountable for the social performance of the overall system, a connection is established between the product system and each organization's behavior. In this sense, the global positive performance of both systems is related to the good individual performance of Organization A. As the organization has a dominant weight in the two systems, it dictates the global performance of both.

Additionally, the order in terms of performance of each subcategory remains the same in both systems. The subcategories “Social benefits/Social security health” and “Contribution to economic development” present a very good performance in both systems, while”, “health and safety of workers”, “Access to material resources”, “safe and healthy living conditions”, “local employment” and “Public commitment to sustainability issues” hold a satisfactory performance.

From figure 30, it can also be observed that the novel system has a better performance than the reference system in all the subcategories. Moreover, some scores are smaller than one for the novel system. In particular, the scores for “Equal opportunities/Discrimination”, “Social Benefits/social security health” and “Contribution to economic development”.

At this stage, one should note that while the consumption patterns of the two systems are very similar, the production patterns suffer a considerable change, as in the novel system an additional product is generated. In fact, as the values obtained for the novel system go through an allocation process to solve multifunctionality, the results do not fit within the same scale as the one of the reference system. Consequently, it is possible to find results for the novel system between 0.66 and 2.64, which corresponds to the limits of the scoring scale used (1-4) multiplied by the allocation factor. On one hand, as pointed above, there is limited readability of the novel system scores under the scale initially defined (1-4). On the other hand, it must be noted that this derives from the allocation process, meaning that the fact of having a multifunctional system dilutes the social impacts generated by the treatment of 1m3 of wastewater. One can think as if the remaining impacts are retained by the novel system co-product, in this case the kaumera.

Finally, if a different proxy for each organization's weight and kaumera's selling price is chosen, different results might be obtained, which will be tested in the sensitivity analysis.

5.4 Organizations’ social hotspots and recommendations for improvement

The UNEP/SETAC Guidelines define a social hotspot as a unit process, location or activity in a product life cycle, where a social issue (impact or risk) or an opportunity is likely to occur. In this S-LCA, as an organizational approach was followed, the unit processes are represented by the activities of the organizations involved in the value chain of the WWT service. Consequently, the hotspots identified are associated with the negative performance of the companies in question.

The aim of this section is to identify the hotspots present along the value chain of the two systems under study and suggest measures to improve the social performance of each organization.

As most of the subcategories are assessed with more than one reference scale, looking solely to the aggregated results on figure 29 might hide the negative performance of a certain reference scale. To identify the organizations that need to improve its social performance and the areas

where this should happen, the individual performance of each organization per subcategory per reference scale was considered (table 10). In this way, each organization is then made aware of how their social sustainability performance may be enhanced in a manner that is specific to their circumstances.

From table 10, with the exception of organization A, all companies contribute negatively to the performance of the reference and novel systems with a non-compliance result in at least one reference scale.

Once more, it is important to note that the hotspots identified are common to the reference and novel systems as they integrate the same organizations.

Organization A

No hotspots were identified in organization A. The company complies with all the basic requirements stipulated for the subcategories under assessment. In general, organization A can continue to implement the best practices available and ensure that their suppliers operate at the same standard. Organization A is the company provider of the WWT service, which means that the other organizations are located upstream in the value chain under study. That said, organization A holds the power to choose the companies with which to work. Thus, it is imperative to pay close attention to the sustainability aspects of suppliers, provide guidance and encourage them to improve their operations and relations, both with their workers and the surrounding community, should remain a priority.

Organization B

1. **Recommendations for "Equal opportunities/discrimination":**

   Since organization B integrates a business group that is considered a large enterprise, it is recommended to elaborate an equal opportunities and nondiscrimination plan. Assuming a proper disclosure of the plan, this can be either made at the company level or at the group level. The European Union proposes a general framework for equal treatment in employment and occupation that can be adjusted according to the country and company characteristics. In this sense, the directive 2000/78/EC (European Commission, 2000) lays down general minimum rules to be applied that can be consulted to help elaborating the equal opportunities and nondiscrimination plan. In addition, the company could implement initiatives to promote these principles across the organization. For instance, by supporting awareness raising initiatives and offering training to employees. Leaders and recruiters could also receive training on unconscious biases and inclusive leaderships.
   Note that the elaboration of an equal opportunities and non-discrimination plan is only mandatory for corporate public sector entities and companies listed on the stock exchange, which is not the case of organization B. However, in addition to promoting non-discrimination, a plan of this nature also encourages a healthy reconciliation between personal, family and professional life.

2. **Recommendations for "Promoting social responsibility":**

   Regarding "Promoting social responsibility", organization B is advised to establish a closer relationship with its suppliers and audit their actions on environmental and social topics to ensure they meet sector standards and organization B specific standards. Such monitorization would help to identify potential problems and risks across the supply chain as well as to incentivise companies to improve their social performance. Once this

relationship is built, the exchange of feedback and knowledge can help organization B improving its social performance and ensure that suppliers meet their clients' standards and requirements. Furthermore, by doing this, organization B is enhancing transparency in the supply chain, which increases the confidence that clients have in the company.

Organization C

1. **Recommendation for "Equal opportunities/discrimination":**

Organization C, despite being considered a small enterprise, with few employees, should demonstrate its commitment to equal opportunities and non-discrimination principles by explicitly mentioning them in its hiring policies and code of conduct. In addition, like suggested to organization B, initiatives to raise awareness about the topic could also implemented as well as offering training to employees on the matter (e.g., lectures and team workshops).

2. **Recommendation for "Promoting social responsibility":**

The first suggestion to organization C improves in "Promoting social responsibility" along the value chain actors is the creation of a code of conduct or policy for suppliers. This will force suppliers to pay attention to the topic and encourage them to invest in strategies and initiatives to achieve social responsibility standards ad requirements.
Following the elaboration of a code of conduct for suppliers, organization B should establish an auditing system for its suppliers. Ideally, the audits should be carried at a regular basis (e.g., yearly) to ensure compliance with social responsibility rules and standards.
Finally, organization B is advised to create a close communication with its first line suppliers so both companies can learn about the social responsibility of their stakeholders. The exchange of information and feedback can help in the implementation of eventual improvements needed.

Organization D

All the subcategories identified as hotspots in organization D are due to lack of data. Unfortunately, the author didn't obtain any response from organization D, which means that the data collected through the questionnaire couldn't be considered. Consequently, the assessment of organization D was solely based on the information available on the website of the business group to which organization D belongs to. When information regarding a subcategory couldn't be found, the case was handled as a no data situation.
In any case, it was decided to offer recommendations for the areas identified as hotspots. However, the reader should be aware that these suggestions may not be entirely necessary. In case of information regarding the subcategories identified as hotspots exists but is not publicly available for consultation, the company is advised to include it in its reports, websites or newsletters.

1. **Equal Opportunities/discrimination EOD2 NO BR**

The recommendations suggested to organization B and C to improve their performance in "Equal opportunities/discrimination" also apply to organization D.

2. **Social benefit/social security**

According to the Portuguese labor code, all companies, regardless of the sector and size, are required to pay the minimum wage and provide rest days or vacations, work accident insurance and 40 hours of annual training to their employees. Any other extra benefits offered to workers are considered good practices that contribute to employee satisfaction and talent retention. Examples of these benefits are food subsidy, health insurance, travel subsidy and support in children's educations.

3. Community engagement

To improve this subcategory, the management may include the community in the decision-making process. While the company organizes and engages in activities with and to the community, it should also consider the opinion of the local communities' representatives. To prevent this relationship from being seen as a burden for both parties, an efficient communication method should be created. For example, an online form available on the organization D website that can be filled by the different stakeholders.

4. Local employment

Although organization D seeks to promote the proportion of local labor in its teams and management, there was no information available that could confirm this goal. In that sense, the company is advised to be more specific in its local hiring policy, including a specific percentage for local employees and a strategy to achieve the goals. For example, the definition of the adequate job divulgation among local communities could be contemplated in the strategy. Additionally, an annual internal audit can be used to ensure the achievement of the goals and to define future actions regarding the topic.

Organization E

1. Equal opportunities/discrimination EOD2

The recommendations suggested to organization B and C to improve their performance in "Equal opportunities/discrimination" also apply to organization E.

2. Community engagement

The recommendations suggested to organization C to improve its performance in "Community engagement" also apply to organization E.

Organization F

1. Equal opportunities/discrimination EOD2

The recommendations suggested to organization B and C to improve their performance in "Equal opportunities/discrimination" also apply to organization F.

2. Health and safety of consumers

Organization F should consider the health risks associated with consumption/use of its products in order to ensure the safety of the consumers. In that sense, the organization is advised to create management measure to assess its products. Additionally, regular discussions with consumers and customer surveys are encouraged as an opportunity to learn about the health and safety aspects important for its clients and improve according to that.

3. Safe and healthy living conditions

To improve in this subcategory, organization F is encouraged to actively participate with local stakeholders in communicating the potential health and safety impacts of their operations on surrounding communities. This can be done through the divulgation (e.g., via website, newsletter, LinkedIn) of a document specifying the risk that the organization operations can pose for its employees, for the environment and for surrounding communities. Furthermore, the organization can make use of its small dimension and less corporative environment and organize activities together with local community actor regarding public health issues or support local initiatives that promote public health and safety.

4. Community engagement

Although organization F engages on initiatives with the local community and involves community stakeholders (parish council, city council and residents' association) in the organizational decision-making process, there isn't a written policy on community engagement at the organizational level. In that regard, organization F should elaborate a specific policy to maintain the between the organization and the community.

5. Public commitment to sustainability issues

To improve in this subcategory organization F is advised to make commitments regarding sustainability issues, establish specific targets, and communicate its progress regarding those targets on the company website or newsletter. Initiatives like these will drive Organization's F to be more visible and attractive to potential new clients.
After establishing sustainability related targets and the strategies to achieve them, the organization could use adequate standards and guidelines to assess sustainability and later apply to certifications on sustainability topics (e.g., ISO certifications).

6. Interpretation

6.1 Consistency check

In this section, the consistency of the methods applied is assessed in a narrative way, as guided by the UNEP/SETAC Guidelines.

Regarding the terminology, an effort was made to use the concepts like risk, performance and impact consistently. In terms of Goal and Scope, the author considers that the methodology is applied according to the goals of the study and consistently adjusted to the specific case study when necessary. A clear explanation of the modelling decisions is provided on chapter 4.

In terms of life cycle inventory, several aspects can be mentioned in regard to consistency. Depending on scale of the assessment, data was collected at the national and regional levels or at site-specific level.

Data collected for the generic assessment is mainly obtained from online public databases and, ideally, all indicators resort to data corresponding to the same reference year. Yet, it was not possible to collect data for the same year for all indicators. In addition, differences in geographical coverage do not contribute for the consistency of the study. As for the site-specific, the type of data collected is coherent with the goal and scope of the study.

For both levels of assessments, qualitative and quantitative, primary and secondary, site-specific and generic data have been used.

Although the same type of impact assessment has not been used in the generic and site-specific assessments, it is considered that the methods used allowed the study's goals to be achieved.

The impact assessment method, weighting, aggregation and allocation performed in the site-specific assessment for the reference and novel systems, are consistent with the study's goals. In particular, the reference scales are consistently defined based on international agreements (BRs) and on the methodological sheets (indicators).

Finally, the generic assessment provided a vision of the socio-economic context of the wastewater treatment sector in Portugal. Thus, the results of the site-specific assessment consider the context of the case study.

6.2 Completeness check

As suggested in the UNEP/SETAC Guidelines, the completeness check is conducted in a narrative way, following the guiding questions (UNEP, 2020, p.110).

The Goal and Scope of the study are clearly defined on section 4.1. All the relevant stakeholders are considered in the study and, from those suggested by the Guidelines, only the Children stakeholder was excluded. As mentioned on Chapter 4, the exclusion of Children as a stakeholder is based on the fact that the impacts addressed in this stakeholder's category can be included in the "Society" and "Local community" stakeholder categories. Besides, most of the organizations included in the study operate in a business-to-business context, and the impacts on children can be deemed as indirect. In terms of processes, the most relevant organizations for the product system have been included in the study, mainly supplies. Nevertheless, technology suppliers, distributors and final consumers of kaumera were not considered in the novel system. Ideally, these types of entities should be included in order to achieve higher levels of completeness. Unfortunately, the uncertainty related to the kaumera value chain and data availability constraints didn't allow the inclusion of these entities.

Regardless of potential improvements (discussed on Chapter 7), the inventory data collected is considered sufficient to evaluate the relevant social aspects and achieve the study's goals. The impact subcategories and indicators are based on the methodological sheets (UNEP, 2021) and when necessary other S-LCA studies were consulted. For both the generic and site-specific assessment, it is important to note that these choices are not exhaustive and necessarily complete. In the site-specific assessment, data was only gathered from one stakeholder. Considering that five stakeholders are addressed, the study could be more complete with data from all the stakeholders included. However, the data collected proved to be adequate and sufficient to identify social hotspots in Portuguese wastewater treatment sector as well as to calculate the social performance of different organizations. Moreover, the reference scales used in the impact assessment method of the site-specific assessment are able to accommodate the lack of data about a certain organization, granting the continuation of the assessment in cases where no data is available.

6.3 Sensitivity analysis

Figure 32 illustrates the results of the two sensitivity analysis performed to the novel system.

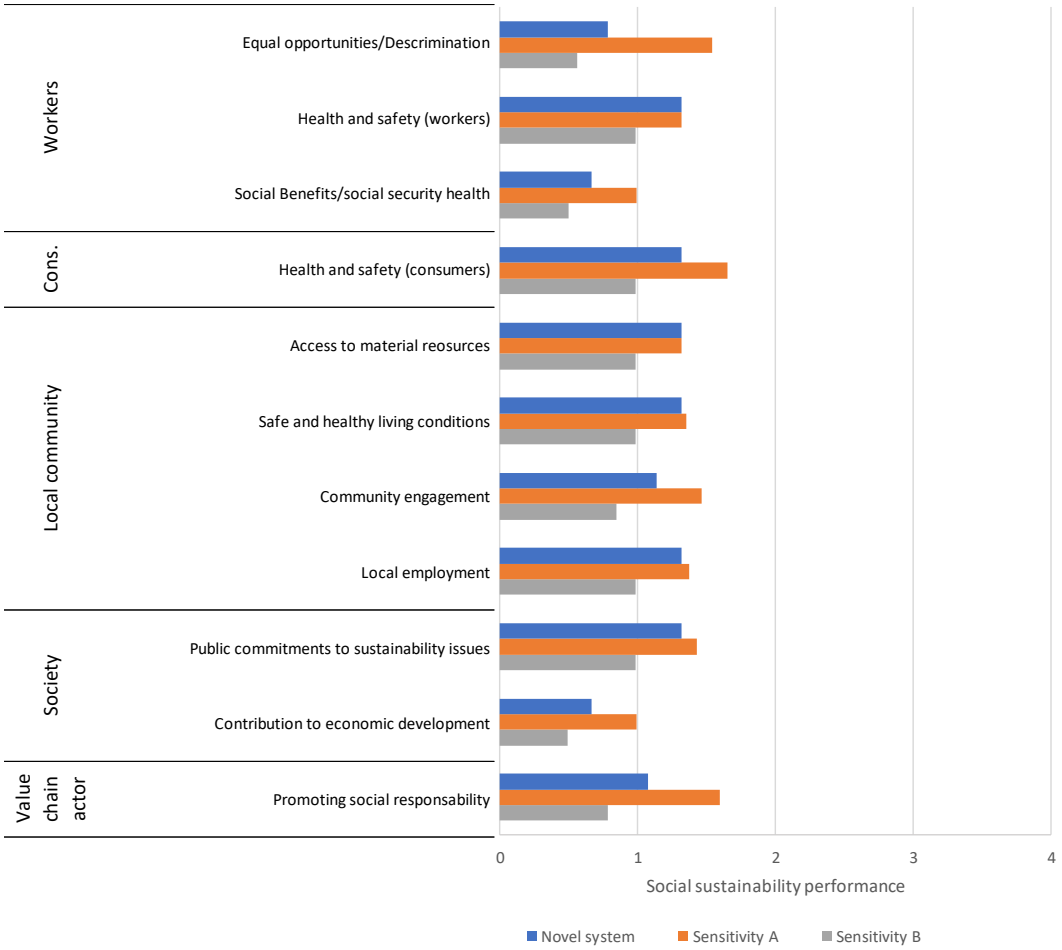

Figure 32. Sensitivity analysis performed to the novel system.

Sensitivity A assumes that all organizations bear the same importance in the social assessment of the system, which is translated into the same weighting factors for all companies (equivalent to considering an arithmetic average). Main impact of the sensitivity is related to the disconnect of the results from the scores of Organization A, as its overall weight has decreased significantly.

Given that Organization A scores are always best-in-class when compared to the remaining companies included in the study, Sensitivity A presents a worse performance across all subcategories. The highest differences occur in “Equal opportunities/Discrimination” and “Promoting social responsibility” as these were the subcategories where other organizations have shown the poorest performances, which now provide a higher contribution to the final result.

Sensitivity B main assumption is related to Kaumera, whose selling price is multiplied by a factor of 2. The sensitivity implies a modification in the allocation factor as, from an economic point of view, Kaumera will gain relevance in the multifunctional process. As such, Kaumera can be considered as holding a higher share of social impacts, hence improving the overall performance of the novel system under this sensitivity. More specifically, it can be observed that the results

of sensitivity B are better than those of the novel system for all subcategories, with proportional differences in each of them, which are attributed to impact of the change in allocation factor.

7. Discussion

The goal of this chapter is to discuss the application of the UNEP/SETAC Guidelines at the generic and site-specific levels as well as the modelling decisions applied in this case study.

7.1 Generic assessment

The main goal of the generic assessment is the identification of the social hotspots present in the wastewater treatment sector at the national level. In general, the methodology applied to the generic assessment follows the UNEP/SETAC Guidelines. However, in order to make the assessment feasible, many simplifications had to be made. In particular, instead of following one of the social impact assessment methods suggested in the guidelines, data regarding the Portuguese context was assessed against data collected for Europe. Afterwards, the data was filtered and the subcategories where Portugal holds results worse than Europe were identified as social hotspots. Despite the problems in finding data, it was possible to identify the subcategories that are considered weaknesses in the wastewater treatment sector and, therefore, important to be investigated at the site-specific level in Portugal.

Considering the method used in the generic assessment, there are three points that deserve to be discussed.

First, it is interesting to reflect on the impact assessment method chosen and why the same method has not been applied in the generic and site-specific assessment. The SAM method itself is data intensive, being necessary to collect data not only for the different reference scales but also to analyse the context in cases of non-compliance with the BR. While in the site-specific assessment the context is analysed by peer companies, at the generic level this would have to be investigated relative to peer countries. In addition, the generic assessment includes many more subcategories than the site-specific. All this would have result in a highly data intensive and time-consuming process.

A filtering system where a screening of the impacts is performed is considered more time and data efficient. It is important to mention that since the method used is based on the comparison of data for two locations, the results obtained are relative and only have meaning when analyzed together. Although it is true that using Europe as a comparison term provides a perspective about the importance and dimension of the impacts observed, it also limits the conclusions to the terms of the analysis. In fact, an impact subcategory is considered a hotspot if it has poorer results when compared to Europe. Likewise, a subcategory with better results than those observed for Europe is not considered of concern. However, it might occur that Portugal presents better results than Europe in a certain subcategory and yet still be an issue of concern for the country. In order to avoid a misinterpretation of the results, the actual socio-economic context of the country should be contemplated.

The second point comes with the fact that data was mainly collected from data sources suggested in the methodological sheets (UNEP, 2021), mostly online sources from the government and international organizations like ILO and NGOs. Unfortunately, multiple sources were needed, and it was not possible to collect information for the same year for all subcategories. In some cases, data at the regional level was not available and approximations had to be done. For example, in “health and safety living conditions” information regarding the

access to basic services was not available exclusively for European and data for Europe and Northern America was used. Furthermore, not all indicators could be analysed per sector. The author recognizes that more sector and uniform data would increase the credibility of the results. In fact, social impacts can be originated by one or a few sectors, and the sector under assessment might actually not contribute to that specific impact. Additionally, as the socio-economic context of a country is constantly changing it is very important to collect the most recent data possible.

The third point, as mentioned in the assessment by (Ekener-Petersen & Moberg, 2013), questions whether the inventory indicators suggested provide relevant and sufficient information on the social impacts on a specific subcategory and, eventually, a relevant description of social hotspots. Note that the indicators offered in the methodological sheets (UNEP, 2021) serve as examples and are not claimed to be exhaustive or complete. In any case, having a set of suggested indicators is still useful to guide the study and saves time during data collection.

A proper link between the subcategories and the indicators is considered essential to ensure that the indicators represent the total performance of a subcategory. Otherwise, when indicators look less significant or are challenging to interpret, the respective subcategories and stakeholders might be disregarded to facilitate the assessment (Ekener-Petersen & Moberg, 2013).

Finally, other studies question the usefulness of generic assessments (Dreyer et al., 2006; Jørgensen et al., 2009). According to Dreyer et al. (2006), social performance is strongly correlated with the actions of specific enterprises in the supply chain rather than with the production processes, which emphasizes the significance of conducting site-specific assessments. On the other hand, (Ekener-Petersen & Moberg, 2013) argue that regardless of the fact that there might be minor differences in companies conduct, the national context has a strong impact on the performance at the company level. The organizational practices are influenced by the legislation, culture and normative values of a country. The vision adopted in the current study resembles to the one from Ekener-Petersen & Moberg (2013), who explains that a generic hotspot analysis can be perceived as a first step to facilitate the decision on where to focus on a following site-specific assessment.

7.2 Site-Specific assessment

Selection of Impact subcategories and indicators

As explained in section 4.1.2.5, the selection of the impact subcategories analyzed in the site-specific assessment was based on the results of the generic assessment. This modelling decision assumed that the results of the generic assessment translate the current state of the wastewater treatment sector in Portugal. In that sense, the most significant issues of concern, also known as hotspots, in a products/service life cycle were identified. In this case, the social impact subcategories deemed to be hotspots in the Portuguese wastewater sector were selected. It is important to feature that the choice of impact subcategories for the site-specific assessment is then highly dependent on the results of the generic assessment. As such, one can conclude that the limitations encountered during the generic assessment (section 6.1) as well as the possible uncertainty of the results, might affect the site-specific assessment.

Due to time and resources constraints, different methods were used to assess the social impacts at both level of analysis. As mentioned before (section 6.1), in the generic assessment data

regarding the Portuguese context was assessed against data collected for Europe. As opposed to this, a scoring system was used in the site-specific assessment.

An alternative method to select the subcategories for the site-specific assessment include the cooperation of the case study stakeholders. As a matter of fact, in order to keep efficiency, the first round of questionnaires included a question regarding the importance and relevancy of each of the 16 subcategories assessed in the generic assessment. However, most of the respondents answered "very important" or “important” for all the subcategories with no further elaboration on it. These types of answers consist of the most logical response for a representative of a company, but it does not provide clear insides on whether a subcategory should be disregarded from the assessment or not. Instead, it gives the impression that all the subcategories are equally relevant and should be included in the assessment. The reason to this is mainly attributed to the fact that the questionnaire has been conducted online. As social topics are deemed sensitive for organizations, a questionnaire where a social topic might be prioritized in relation to other can be easily misinterpreted, holding back the respondent to be more assertive and detailed about the importance of each one of the subcategories for his/her organization.

The selection process might have been enhanced if in-person interviews or focus groups with relevant stakeholders, S-LCA specialists, CSR experts, and/or other industry or national experts had been held. A general understanding of the subcategories to include in the study, including those from the Guidelines but also new ones, may have been defined through these.

The selection of the social indicators included in the site-specific assessment was mainly based on the ones suggested in the methodological sheets. Yet, the indicators suggestions provided by the methodological sheets are not exhaustive nor sector specific. A such, based on the S-LCIA characterization method requirements, data availability and other studies (Ramirez et al., 2014; Life Cycle Initiative, & Social Life Cycle Alliance, 2022), some indicators were adopted, disregarded, and created.

The selection and definition of indicators is a challenging process due to the subjective nature of social subjects. In the current study, the indicator selection method utilized relies mostly on the methodological sheets and data availability, with no stakeholder’s consultation. It can be argued that the chosen indicators are not representative of social sustainability performance for the impact subcategories assessed. Another critique that can be made to the indicator selection method is related to the non-inclusion of wastewater treatment sector specific indicators. As the systems under analysis include companies with distinct activities, indicators defined for the WWT sector would only be applicable to the WWTP operator. Furthermore, since the companies represented in both the reference and novel systems are the same, the results would be similar unless indicators specific to the type of activity of each company or to each product system are included.

In this sense, as mentioned earlier, the involvement of stakeholders and/or experts (e.g., through focus groups) could have been important to define indicators relevant for the case study.

Finally, authors like Hannouf & Assefa (2018) highlighted the importance of not mixing organization’s commitment and actual performance when applying the SAM method. Considering that organization ‘s commitment to a social issue doesn’t necessarily translate its actual performance, and that the present study aims to assess the social performance of the systems under study, some indicators were adjusted to address actual performance. It is

important to note that the indicators added are mainly based on the description of the subcategories in the methodological sheets.

The adjustment made to the SAM method allow for the separation between organizations commitment, represented in the BR, and actual performance, embodied in the respective social indicators. Thus, both the commitment and performance of a company are evaluated in a way that reveals the reality of the company.

Inventory data collection

The data collection phase is one of the most important and time-consuming phases of an S-LCA, where information for the inventory analysis is gathered. In this section, the main challenges and limitations encountered during the data collection process will be discussed. First, one should recall that in order to compile the inventory data needed, the framework provided by the Guidelines and the Methodological Sheets was followed. In the current case study, both primary and secondary data sources were used. The study allowed to understand how thorough data gathering can be and how it can improve comprehension and interpretation of the processes' real social status. In this sense, (Petti, Sanchez Ramirez, et al., 2018)) explains that in S-LCA studies primary data is typically qualitative, highlighting that the more data collected, the more accurate the representation of reality is. The first point of discussion is precisely related to the amount of information collected. Ideally, data should be collected from more than one employee and from different working in each company, for example a representative of the management board and an operation representative. This could offer a more complete and realistic vision of an organization as workers might have different views of a company and be exposed to different experiences within it, depending on his/her role. For example, the perception of the company actions and the access to resources might vary according to the role performed within the company. Besides, information might not flow equally within a company, usually management positions have a more general and complete overview of what is happening in the company when compared with technical operators.

Unfortunately, it was not possible to interview more than one worker in each organization and, most of the respondents occupy a management position or are part of the sustainability department. Considering that it was only possible to interview one worker of each company, it was decided to interview employees from management positions to guarantee uniformity and be fair to all companies present in the assessment. In any case, even interviewing only workers with management positions, there should be more than one management viewpoint, and group research would be preferable. It might be beneficial to consider the size of the institution and advise, for example, one manager opinion in short supply chains and for medium-sized or big supply chains three or five workers should be interviewed (de santo, 2019).

In order to overcome this limitation, one should bear in mind that S-LCA relies on a broad collection of qualitative and quantitative data from multiple sources (Tokede & Traverso, 2020). Numerous S-LCA studies involve time and efforts, yet data needed is not always easily accessible. Communication with stakeholders is often challenging and difficult to establish in specific contexts, especially when sensitive topics are in stake. More efficient data collection methods are necessary to ensure high quality results. Direct interviews or questionnaires, for example, allow the interviewer to better understand an organization real situation and to easily link the data to the assessment, which according to (Petti, Sanchez Ramirez, et al., 2018) is an important type of sensitivity when performing an S-LCA. Moreover, direct interviews might enable the interviewer to reach more people in one company and to further develop some of the topics

and/or reformulate questions in case of doubt. As opposed to this, offline questionnaires, applied in the current study, are entirely dependent of the respondent understanding, knowledge and willingness to answer in a detail way. For example, respondent of organization F, answered “In my unit we are three people. Two women and one men.” to the question “Can you please indicate the total number of employees and gender composition?”. This response does not allow for any conclusion regarding the actions of the company as a whole regarding “Equal opportunities/discrimination” due to the reduced sample. Although it is not possible to identify exactly how the results are influenced by the collection of little primary data, it is considered that the results are conditioned by the experience and knowledge provided by the interviewee.

Following the same reasoning, one could bring the same discussion about the integration of the stakeholders’ viewpoints (workers, local community, society, consumers and value chain actors). In the current study it was only gathered data from the workers stakeholder. Ideally, members from each stakeholder group should be approached so that different viewpoints can be incorporated (de santo, 2019) and possible bias avoided. This could be done by selecting samples of each stakeholder.

De santo (2019) stresses to the fact that even though a management perspective may provide a preliminary idea of social sustainability within an organization, the incorporation of other stakeholder’s perspective offers a more complete and realistic vision of social performance. In this way, studies can benefit from insights provided by external members, such as local communities’ members, society members, consumers and value chain actors.

For example, a company manager may claim that the organization promotes community engagement, but an interview with a local community member may reveal more details on what kind of actions reach the community and how community members perceive it. In an extreme situation, an interview with a community members can also have an outcome opposite to the interview with the company manager. The integration of different point of views can be considered important in terms of research validity as it contributes for a more complete and detailed analysis (Bonilla-Alicea & Fu, 2021).

The feasibility of collecting data from different stakeholders is an interesting topic to reflect upon, as it might present some challenges. In the current study, this would imply collecting data via questionnaires from five stakeholder groups (workers, consumers, local community, society and value chain actors) of the WWT plant operator and its suppliers. As it can be expected, this would require considerable resources and it may need to take place in difference locations. Limit the scope of the study and focus only on specific stakeholders can be an option to reduce intensive data collection processes. Yet, it can also cause a loss of life cycle perspective.

According to the UNEP/SETAC Guidelines, in cases where more than one stakeholder is covered, it is important to keep in mind that double counting among stakeholders’ groups can occur (e.g., a worker can also be a member of the local community). In the case of society and local community stakeholders, for example, it can be even harder to define to which the two stakeholders an individual belongs.

Finally, during the data collection process the author verified that larger companies, in addition to having more data available online, were more detailed in their answers to the questionnaire. For instance, the WWTP operator integrates a company with more than 3000 employees distributed by different locations and geographies. The information available on the WWTP operator includes annual company results, sustainability reports, financial reports, statutes and

regulations, gender equality plan, company code of conduct, among others. On the other hand, organization C has less than 50 employees and has less information available.

According to D'Eusanio et al. (2018), due to a lack of financial resources and time, smaller businesses do not fully engage in the study and analysis of social data. The author also asserts that the absence of a corporate culture causes companies to view social issues as a burden rather than an opportunity. This might also be the reason to the difference in the amount and quality of data collected from each organization.

Impact Assessment method

In this section both the aspects in which the S-LCIA method succeeded and those in which it didn't will be discussed.

The adjustments made to the SAM method enabled the creation of a link between organization commitment and actual performance. The BRs were designed in order to reflect each subcategory description and goal, being mainly based on international agreements and on the subcategory's descriptions in the UNEP/SETAC Guidelines. In turn, the social indicators reflect the BRs, measuring actual performance. It was up to the author's discretion to make sure the BRs covered the subcategories and that they were accurately reflected by the social indicators. As the subcategories differ in terms of purposes, the reference scales are defined based on subcategory-specific BRs, which means that there isn't a standard reference scale for all subcategories. Instead, each RS must be built separately according to the needs of the subcategory. Furthermore, as the social indicators do not define the subcategories, gaps between subcategories definition and social indicators can be more easily identified. In that case, more social indicator can be added. The author considers that the two levels of assessment applied in the definition of the reference scales, have offered a more objective mean to assess each subcategory while maintaining a distinction between organizations commitment to a cause and the evidence of good/bad practices regarding the same.

Other researchers based the social indicators on international agreements and used them directly as BRs (García-Sánchez & Güereca, 2019; Hannouf & Assefa, 2018; Padilla-Rivera et al., 2016; Ramirez et al., 2014). In these cases, one can argue that the construction of the reference scales can be more straightforward and that it relies less on the researcher judgment. Nevertheless, disadvantages of such approach include (i) the non-existence of a clear distinction between organizations commitment and actual performance, (ii) indicators that are not referring to national legislation or international agreements cannot be used and (iii) one reference scale for each indicator needs to be established (García-Sánchez & Güereca, 2019).

In the reference scale method applied, the first aggregation step implies that an equal weight is given to all impact subcategories and social indicators. Yet, it is not certain that all impact categories and social indicators are equally important. For example, the same importance is attributed to the evidence of occupational accidents and to presence of written policies on community engagement at organizational level. The author acknowledges that this assumption might be too simplistic. Ultimately, it can be argued that a company might be benefiting from having a very good result in an indicator that in another situation could be considered less important, leading to an unrealistic result. An alternative can be to establish a hierarchical structure based on SLCA expert judgement (do Carmo et al., 2017). Even that, would have to be

case-specific due to the complex nature of social issues and considering the different goals of each case study.

Another aspect worth to discussing is related to scoring system used to convert the qualitative social levels (very good, satisfactory, inadequate and bad performance) into a cardinal performance (1, 2, 3 or 4). The SAM method introduced by Ramirez et al (2014) is not explicit about the intervals between classification levels. Thus, it is assumed that the scores of the performance levels increase linearly. A consequence of this is the impossibility to make a distinction between companies that take one proactive action beyond the BR and companies that carry several proactive actions. Moreover, finding indicators to assess the existence of proactive behaviour (level 1) was not always possible and, in those cases, it is assumed that for some subcategories organizations can't go further the BR.

To assign a non-compliance score of 3 or 4, the context where an organization operates needed to be investigated. In this instance, the performance of peer companies in Portugal was assed. One should note that for this purpose data was collected purely from documents publicly available on organization's websites. A critique to this approach is related to the fact that the geographical context is limited to the assignment of scores 3 and 4. (Hannouf & Assefa, 2018) suggest to analyse the social background context in a broader sense for all subcategories. By doing this, the attribution of any of the 4 available scores would be based not only on the BRs and social indicators but it would also consider the organization's position in relation to the respective sector (Hannouf & Assefa, 2018).

The analysis performed to the WM case study is based on the theory that social impacts are mostly induced by companies' behavior and less dependent on the technical nature of the processes (Parent et al., 2010). In addition, the SAM method applied is a characterization model that enables the assessment of the social profile of the organizations involved in the product life cycle (Ramirez et al., 2014). Consequently, the comparative analysis of the reference and novel systems is highly dependent on the companies involved in the value chain of the wastewater treatment service. Unfortunately, the study revealed that the characteristic of the WM case study in Faro/Olhão are not ideal to apply the method selected. First, as mentioned before, it is worth highlighting that the stakeholders involved in both systems are the same, which at a first glance could promote a significant similarity in the results. Additionally, the difference in chemical and energy consumption is marginal, not being enough to introduce a relevant variability in the weighting factors of the stakeholders, hence maintaining the order of magnitude of each contributor in both systems. The most relevant characteristic is the multifunctionality of the novel system, which is captured in the allocation procedure. The results showed that the allocation process introduces the most relevant variability factor between the two systems. Otherwise, the results obtained for the two systems would be very similar. On the other hand, the use of economic allocation to solve multifunctionality brought complexity to the system. The results of the novel system were adjusted by the allocation factor, consequently falling within a different scale (0.66-2.64) than the one of the reference system (1-4). The main limitation of the method is the distortion of the scale that happens when the allocation factor is applied. However, it is assumed that the remaining percentage of social impacts is carried by the co-product. Meaning that the novel system performance benefits from a dilution of the social impacts by the two products generated (clean water and kaumera).

Notwithstanding the constraints described in the previous paragraphs, specifically concerning the effect of the allocation on the novel system scores, the author considers that the performance of the two systems can be compared as they all represent the social impacts generated by the involved organizations during the treatment of 1m3 of wastewater.

Weighting factor

In this section the approach used to link the social impacts to the product system will be discussed.

According to the UNEP/SETAC Guidelines, there are two ways to connect social impacts and the product system. First, the use of quantitative causal-effect chain (IP approach), which enables the carrying of the quantitative link between the inventory data to the functional unit across the impact pathway (Parent et al., 2010). Second, by using a weighting factor to attribute an importance to each unit context relatively to the product system.

In E-LCA, the elementary flows are proportional to the functional unit and are directly used in this proportionate form. Therefore, the characterization model leads to indicator values proportional to the functional unit.

In this case, the social indicators give a relative position compared to the basic requirements but are not expressed in the form of "unit per output". Also, as a scoring system is used to establish a quantitative link with the social indicators, without carrying a quantitative link with the functional unit. Hence, the link with the functional unit is lost and the indicator result does not represent the functional unit's burden per se (Parent et al., 2010). The indicator results that are not expressed per functional unit were weighted by the relative importance of each organization in the system. This relative importance was assigned according to a weighting factor based on the monetary value added by each company. The weighting factor allocates a share factor to the performance results of each organization, reflecting each company's importance in wastewater treatment service life cycle.

The use of a weighting factor as explained above, carries some limitations. First, it is questionable if it provides relevant information about the importance of unit processes in a system. For example, organizations whose product is used in higher quantities, or it is sold at a higher price hold a bigger importance and are, consequently, determinants for the results. In contrast, organizations with a smaller weight will be less relevant for the calculation of the results. However, this might not be completely accurate in terms of social impacts as the amount of products used and the price paid, doesn't necessarily reflect the severity of the social impacts generated by an organization. Second, it is not usually possible to isolate social inventory data regarding a specific organizations' product and, the performance of an organization isn't necessarily the performance associated to the production of a specific product.

Considering the points mentioned above, the use of a weighting factor to link the results to the product system can be considered an artificial solution that introduces bias in the analysis, serving only for methodological purposes.

Multifunctionality

In this section the issues of multifunctionality are discussed. As explained by J. B. Guinée et al. (2004), the multifunctionality problem is an artifact that aims to isolate a specific function of a

system with multiple ones. The author adds that as artifacts can only be solved in an artificial way, there is no correct form to solve it, not even in theory. However, the efforts done until now lead to a better comprehension of the advantages and disadvantages of the existent solutions for multifunctionality (J. Guinée et al., 2021). In particular, the ISO hierarchy indicates the methods that should be primarily applied to solve multifunctionality (UNEP, 2020). The UNEP/SETAC Guidelines specify this hierarchy in the context of S-LCA:

At first, allocation should be avoided through the subdivision of activities and collection of data respective to the production of each co-product separately. If subdivision is not feasible, the expansion of the system in order to include the additional functions can be a viable option. In the case of combined products, where the relative amount produced vary independently, social risk and impacts can be allocated to the process outputs based on the underlying physical relationships. This relationship might be established trough an activity variable. For instance, one may contend that in an agricultural system, an asparagus cultivation requires more labor time than a carrots cultivation, hence a larger proportion of overtime or number foreign can be allocated to the asparagus cultivation. Finally, when all the other option are not viable, process impacts can be allocated based on the share of revenues entering the system for each product outputs.

In the current case study, economic allocation was used to solve the multifunctionality problem. Subdivision and expansion of the system were not an option. First, due to lack of data regarding the operation of the WM pilot. Second, as this is an exploratory study, some aspects are yet to be defined. For example, when the data for this analysis was collected, it was not entirely clear what would happen to kaumera nor which entities would be involved in its processing, distribution and final consumption.

By applying economic allocation, the inputs of the novel system were allocated to the different functional flows of the process (clean water and kaumera) according to their chares in the total proceeds. Afterwards, the weight of each organization was multiplied by the allocation factor calculated for 1 m3 of wastewater treated. Meaning that the results exclusively translate the social performance associated with the treatment of 1m3 of wastewater.

As proceeds are based on prices, it is important to have correct information on the relative prices of the functional flows at stake (J. B. Guinée et al., 2004). Moreover, literature shows that the allocation factor is highly influenced by the price of the functional flows (J. B. Guinée et al., 2004). One should keep in mind that, as the Portuguese market is not yet established for kaumera, a proxy for its price was adopted, which might not reflect reality.

Solving multifunctionality is of extreme relevance in a resource recovery system that produces more than one product with economic value. Particularly, when comparing two systems, a resource efficient with a non-resource efficient, the recovered resources should be considered. Otherwise, the eventual benefits or drawbacks of recovering a resource will not be included.

Notwithstanding, like environmental impacts cannot be split among co-products as if they exist in separate, social impacts are not solely restricted to a defined product. As such, independently on the method applied, it can be said that solving multifunctionality will lead to a distortion of reality.

For the present study, it can be argued that the use of an allocation factor will always benefit the novel system, independently on how it is calculated. As it is true that the social impacts of the novel system are diluted by the two products, in this specific case there are no major

technical and stakeholders related changes between the two systems to balance the use of an allocation factor. For instance, if there was a big change in the stakeholders involved or in the system inputs, the comparison of the two systems would not be solely dependent on the multifunctionality issue. Nevertheless, this is a characteristic intrinsic to the case study that should be noted but cannot be altered.

8. Self-reflection on the application of S-LCA to the WM case study

- The S-LCA framework as applied in this case study is not able to accommodate all the aspects that an organizational approach might require. In particular, the assessment is performed regardless of the characteristics of each organization. Listed or state-owned companies are subject to comply with certain requirements and legislations. On the other hand, small and medium – sized enterprises (SMEs) are not obliged to comply with so many requirements. For instance, SMEs are not required to have an equality plan neither to publish financial or sustainability reports.
- In spite of public and listed companies having a greater incentive to comply with certain standards of good social performance, it does not necessarily mean that these companies perform better than SMEs. Furthermore, the sample investigated in this case study shows that there is more information available about larger companies. Note that most of the non-compliance results obtained by the SMEs present in this study are due to a lack of information.
- The socio-economic context in which a product or service is found is an important factor to consider when assessing its social performance of a product or service. This can be even more relevant when conducting an organizational approach as the social needs of the different stakeholders might vary according to the economic, socio, cultural or technological dynamic of a country. In this sense, the results of the S-LCA should be interpreted considering the surrounding socio-economic context, knowing that this can easily change. Moreover, the results should not be seen as fixed and eternal but as screenshot of a situation in a certain time frame.
- Even though the UNEP/SETAC Guidelines provide a solid base on how to conduct a S-LCA study, the application of the S-LCA framework is subject to the characteristic of the system under analysis. As each case study is unique, some of the modelling decisions are left to the authors judgement and research. This being said, the comparison of site-specific assessments should be done carefully. Even in the case of studies with similar goals and performed to products/services from the same sector, the impact assessment method is built adjusted to the case study. Since the reference scales are defined individually for each study, two organizations evaluated in the same subcategory could achieve different results.
- The assessment of two similar systems (e.g., reference and novel systems of the present case study) at the organization level through the application of the S-LCA framework can be challenging. The organizational approach is based on the companies present in each system. For each system the performance of each of the constituent companies is assessed. From a S-LCA point of view, the obvious difference between two systems, derived from a technological or process alteration for example, consists of a change on the organizations operating in the system, which will directly affect its global performance. When such difference doesn't exist, the need to apply a weighting step, optional according to the UNEP/SETAC Guidelines, becomes more urgent. In this case study, neither the organizations nor the weighting factors vary significantly, which makes the comparison of the reference and novel systems even more challenging.
- An interesting reflection concerns the extension of the social impacts captured by the S-LCA framework. At a conceptual level, considering that the social performance of an

innovative wastewater treatment method is being studied, there might be unknown social impacts that are not addressed by the impact assessment method used.

- The RS impact assessment method can be complex and time consuming since many decisions need to be made. The choice of which RS method to apply and the elaboration of the reference scales, including the definition of basic requirements and indicators can be a challenging task. Thus, it is essential to choose the RS method at an early stage of the study and start building the reference scales. In this way, the researcher can incorporate adjustments in accordance with the case study characteristic (e.g., companies' economic sector) and focus on the necessary indicators. A solid definition of the reference scales is essential for an efficient data collection.

9. Conclusions

The final chapter of this thesis research project aims to answer the research questions and sub-questions previously introduced in section 1.5. In addition, the validity and reliability of the study will be addressed as well as its contribution to literature. In the final section of the present chapter, recommendations for future research are drawn.

9.1 Research question and sub-questions

1. **Based on a generic assessment at the national level, what are the social hotspots areas in the WWT sector that should be prioritized in a site-specific assessment to WM case study?**

   This study shows that it is possible to conduct a simplified S-LCA, using the Guidelines for social LCA, on a generic product. A detailed study of the wastewater treatment sector in Portugal and by comparing it to the context of the same in Europe, allowed the identification of the impact subcategories that should be prioritized in the site-specific assessment performed to in the WM case study.

   While there were some challenges, for example in data collection, it was possible to obtain results which revealed some hotspots areas, indicating a risk of negative social impacts in the product system of wastewater treatment service. The study identified local community, workers as the stakeholders most at risk of negative social impacts.

   Local community was mainly affected by" Access to material resources", "Safe and healthy living conditions", "Community engagement" and "Local employment". Within the workers stakeholder, the impact subcategories that were considered as hotspot areas were: "Equal opportunities/discrimination"; "Health and safety of workers" and "Social benefits/social security".

   Other Stakeholders that present a smaller risk of negative social impacts were Society with two hotspot areas and Consumer and value chain actor with one hotspot area each.

   To sum up, a total of eleven impact subcategories were listed as critical areas regarding the operation of companies in wastewater treatment sector.

2. **What is the social performance of the Water Mining urban WWT system and how does it compare with the performance of the current WWT system applied in Faro-Olhão, Portugal?**

   Recall that reference system applies for the current WWT system operating in Faro/Olhão and novel system for the Water Mining urban WWT system under study. The performance of the two systems was calculated in two steps. In the first step the individual performance of each organization within the systems was evaluated and aggregated assuming an equal weight per reference scale. As the two systems are constituted by the same organizations, the results obtained in this step are the same for the reference and novel systems.

   From the aggregated results the performance each organization per subcategory was obtained. Organizations F and D had the (relative) poorest performance since they failed to meet the BRs in five and four impact subcategories, respectively. On the other hand, organization A holds the best performance by meeting the BRs in all subcategories.

These results allowed to conclude that organization F needs to improve in the subcategories “Equal opportunities/discrimination”, “Healthy and safety of consumers”, “Safe and healthy living conditions”, “Community engagement” and “Public commitments to sustainability issues”. In turn, organization C should improve in the subcategories “Equal opportunities/discrimination”, “Social benefits/social security”, “Community engagement” and “Local employment”.

In the second step of the analysis, the performance of each system per subcategory was calculated based on the aggregated performances (mentioned above) and on the different shares of organizations and in relation to the functional unit. The novel systems performance was better than the reference system in all subcategories. Yet, the reference system also achieved a score of at least 2 in all the subcategories. The calculation of the results considering the weight of each organization in the system resulted in a better performance for both systems. It is important to mention that in both systems organizations A keeps a very high weight, shaping the performance of the two systems.

In addition, the novel system is multifunctional and required allocation to solve the multifunctionality problem. The very good performance of the novel system is attributed to the fact that the social impacts generated by the novel system is shared by the two products obtained. More specifically, an allocation factor of 66% was calculated, meaning that 66% of the impacts are attributed to the clean water obtained and the others 34% to the production of kaumera.

3. **How can negative social performances of the Water Mining urban WWT system and current WWT system applied in Faro/Olhão be improved?**

   Recommendations were offered per organization for social areas in which they received an individual score of “3” for inadequate performance or “4” for poor performance (section 5.5). In this way, the advice offered can be valuable for members of management of the organizations wishing to increase the social sustainability of the business.

   Recommendations were drawn for organizations B, C, D, E and F. As organization A complies with all the BRs defined, only general recommendations to further enhance social performance among the value chain.

   Most of the recommendations consist of the elaboration of company policies, action plans, improved communication and involvement in public initiatives.

The three sub-questions specified above paved the path to answer the main research question: **How can the social sustainability performance of the WM system in Portugal be assessed through S-LCA?**

Through the performance of a generic assessment to first identify the impact subcategories that should be prioritized in a study in wastewater sector field followed by a site-specific assessment, it was possible to assess the performance of the WM system in Portugal. Given the exploratory nature of the WWT technology under study and the methodological challenges derived from the relatively young age of the S-LCA methodology, many modelling decisions had to be done based on literature and the author judgement and reasoning. In particular, the choice of the most

adequate impact assessment method, the use and calculation of weighting factors and the solution to solve multifunctionality. In terms of the S-LCA method used, although there is space for improvement, the method allowed to understand what are the S-LCA decisions that affect the calculation of the performance of each system and how they influence it.

9.2 Recommendations for future research

The present chapter provides recommendations for future research regarding the case study conducted in this master thesis research project.

Future research regarding the WM case study in Faro/Olhão includes alterations to the S-LCA application as there are multiple ways to conduct a S-LCA that can be more adequate to the case study. In this sense, the first recommendation draws attention for the participation of the stakeholders involved in the system (i.e., workers, local community, society, consumers and value chain actor) to better understand their perspectives on the implementation of the new technology and what social areas are perceived as more critical. Stakeholders' participation would make the S-LCA study more locally relevant, it can help validating the list of indicators, improves democratic representation, and promotes empowerment and learning opportunities for communities while encouraging partnerships (UNEP, 2020). Further research regarding the WM case study in Faro/Olhão include the selection of new social indicators. Especially, indicators addressing the recovery of a product from a waste treatment process can be highly relevant in the assessment of the novel system. This could help to highlight the potential positive impacts associated with the use of innovative resource recovery wastewater treatment technologies and, consequently, contribute to public acceptance and market penetration of the recovered product.

Another recommendation is to perform a sensitivity analysis to the multifunctionality problem seen in the novel system. There are multiple solutions to solve multifunctionality. As mentioned in Chapter 7, allocation is not necessarily the most indicated one. In fact, when no direct physical causation between flows can be established, such as with social flows, a solution different from allocation should be applied (J. Guinée et al., 2021). For example, system expansion refers to expand the system for including the additional functions. In this case, expansion of the system at an organizational level can result in a more complete picture of the involved organizations in the novel system.

Finally, another interesting thing to study is the use of the Impact Pathway or type II impact assessment method instead of the reference scale method. Type II aims at including cause-effect chains or impact pathways in the analysis. The application of type II might lead to interesting results about interdependencies between social impacts (e.g., the use of an input or the exposure to certain working conditions in a production process and health impacts on workers), since the link between two or more phenomena or events in the assessment is considered in this approach (Sureau et al., 2020). This would also help to identify social impacts that might not be expected.

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Appendices

Appendix I

Online interview protocol for Case Study 3: Faro-Olhão

First of all, I would like to thank you for your participation in this study. As I explained in my presentation, 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 3 of the Water Mining project, and you have a position in the company to provide a managerial perspective about certain social issues.

The objective of this session is 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 Mª do Carmo Vasconcelos at M.D.C.ManteroMoraisVieiraVasconcelos@student.tudelft.nl for any clarification regarding the objective of Task 8.2, the impact subcategories meaning, or any other question.

Thank you for your participation! Please send this questionnaire with your answers to Mª do Carmo Vasconcelos at M.D.C.ManteroMoraisVieiraVasconcelos@student.tudelft.nl .

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.

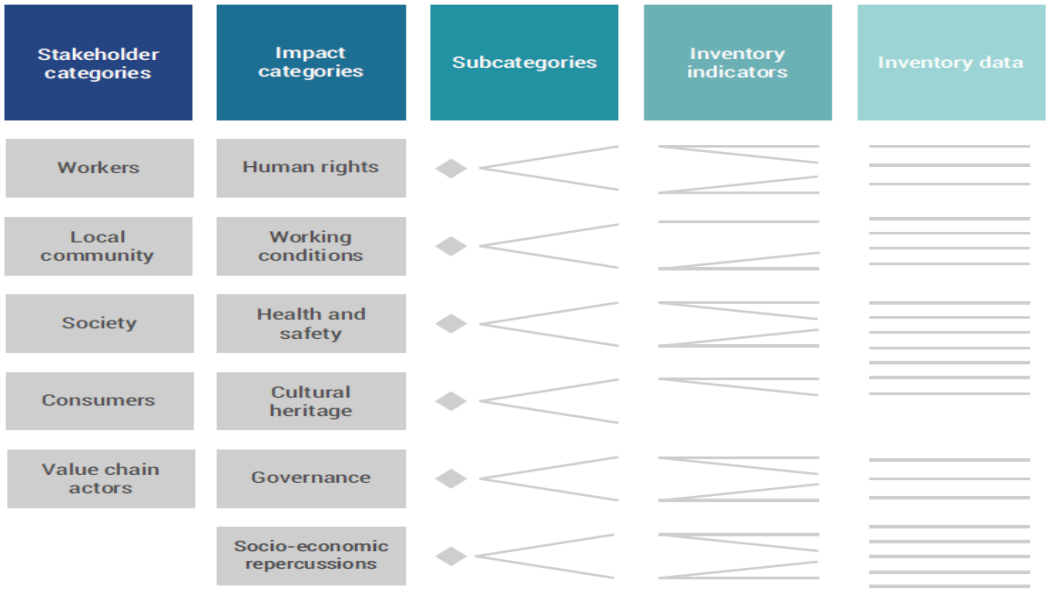

Figure 1. Structure of Social Life Cycle Assessment impacts

2. Social sustainability performance

The second section consists of a questionnaire for data collection. Data collection regards a limited list of impact subcategories, previously defined based on literature research and the national context regarding social aspects. Please use a different font color for your answers.

1. Stakeholder: Workers

1.1. Equal opportunities/discrimination

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

1.1.2. 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 presence of unequal opportunities at the organization?

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. Health and safety (of workers)

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

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

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

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

1.3. Social benefits/social security health

1.3.1. To what extent do you think social benefits for the workers are important to your organization?

1.3.2. Are social benefits part of the organization's policy?

1.3.3. What social benefits does the organization offer its employees (e.g., Social Security benefits, Retirement, Disability, Dependents, Survivors benefits, paid maternity and paternity leave (parental leave), Paid sick leave, Education and training, for all countries and additionally, medical insurance, Dental insurance, Paramedical insurance, including preventive medicine, Medication insurance, Wage insurance)

1.3.4. Do you know if there have ever been any issues regarding social benefits for employees?

2. Stakeholder: Consumers

2.1. Health and safety (of consumers)

2.1.1. To what extent do you think consumer health and safety is important to your organization?

2.1.2. Does the organization have a procedure regarding consumer product health and safety standards? If so, please elaborate.

2.1.3. Are there any complaints regarding health or safety that have been received by a consumer that you can elaborate on?

3. Stakeholder: Local Community

3.1. Access to material* resources

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.

* Material resources include natural and man-made resources such as water, land, mineral, and biological resources, roads, sanitation facilities, schools, etc

3.2. Safe and healthy living conditions

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 any instances where the health and safety of a community has been at risk due to the to the organization's activities?

3.3. Community engagement

3.3.1. To what extent do you think community engagement is important to your organization?

3.3.2. Are there any written policies on community engagement at the organizational level? If

so, please elaborate.

3.3.3. Which community stakeholder groups engage with the organization?

3.3.4. Does the company involve community stakeholders in decision-making processes?

3.3.5. Does the organization offer support (volunteer-hours or financial) for community initiatives?

3.4. Local employment

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

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

3.4.3. Approximately what percentage of workers do you think 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 regards to social responsibility of value chain actors?

5.1.4. Does the organization participate in any initiatives that promotes social responsibility in the value chain (e.g., consciousness-raising programs or counselling)?

Thank you for your participation!

Appendix II

Reference scales for site-specific assessment are presented below. Recall that level 2 PRP reflects the basic requirement.

Workers

Reference Scale: Equal opportunities/discrimination 1		
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. (UNEP, 2021)		
Level	Performance Reference Point	Note/reference
1	Cooperation of employers' and workers' organisations and other appropriate bodies in promoting the acceptance and observance of this policy.	C111 - Discrimination (Employment and Occupation) Convention, 1958 (No. 111)
2	Presence of formal policies on equal opportunities and/or non descrimination.	
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.	
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.	

Reference Scale: Equal opportunities/discrimination 2		
Basic requirement: 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).		
Level	Performance Reference Point	Note/reference
1	The gender distribution of employees is better than that of the industry. For instance, if male workers predominate in the industry, the organization works to raise the share of female workers.	
2	Availability of information regarding the composition of governance bodies and breakdown of employees per cartegory according to gender, age group, minority group or other indincator of diversity. To meet the BR, the composition of employess by gender should be similar to that of the respective sector.	
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.	In this case a negative context can be perceived as a company that do not show any efforts to foster equal opportunities and to avoid descrimination. In this sense, the non existence of a diversity and inclusion policy, action plans etc., can be taken into account.
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.	

Reference Scale: Health and safety		
Basic requirement: Occupational accidents, incidents and diseases should be notified and reported (IFC, 2012; SAI, 2014; ILO, 2022)		
Level	Performance Reference Point	Note/reference
1	Employers implement occupational health and safety practices beyond the law requirements or industry practice, including for sanitation facilities. No injury is detected during the assessment period.	(Life Cycle Initiative & Social Life Cycle Alliance, 2022)
2	Annual reports include health and safety performance of the company, including records of occupational injuries or fatal accidents. AND The reported number of fatal accidents in the last three years is zero.	
3	Frequency of occupational accidents suffered by employees of the organization at the workplace (fatal and non-fatal) is lower than the frequency of occupational accidents (fatal and non-fatal) in the country/sector where the organization is located. 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.	
4	Frequency of occupational accidents suffered by employees of the organization at the workplace (fatal and non-fatal) is higher than the frequency of occupational accidents (fatal and non-fatal) in the country/sector where the organization is located. 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.	

Reference Scale: Health and safety		
Basic requirement: Adequate general occupational safety measures are taken.The organisation shall provide a safe and healthy workplace environment (2-5). 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 (Amfori, 2017; ILO, 2015).		
Level	Performance Reference Point	Note/reference
1	Workers and their representatives in the undertaking are given appropriate training in occupational safety and health.	C155 - Occupational Safety and Health Convention, 1981 (No. 155)
2	Presence of policy/guidelines or program related to the health and safety of employees. In addition, preventative measures and emergency protocols exist regarding accidents & injuries.	
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.	
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.	

Reference Scale: Social benefits/social security health		
Basic requirement: Organizations should accept the obligation of one or more of the following branches of social security: medical care, maternity benefit/protection, holidays, old-age benefit and ability to combine work with family responsibilities (ILO, 2015; OSHA, 2018)		
Level	Performance Reference Point	Note/reference
1	Presence of more than 2 (two) social benefits stipulated by ILO Conventions nos.130, 134, 128, 121, 168, 118, 157 and 183, as part of company's policy.	
2	Presence of at least two social benefits stipulated by ILO Conventions nos.130, 134, 128, 121, 168, 118, 157 and 183, as part of company's policy.	
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.	
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.	

Consumers

Reference Scale: Health and safety		
Basic requirement: Consumers have the right to be protected against products and services that may be hazardous to health or life (ISO 26000, 2008).		
Level	Performance Reference Point	Note/reference
1	Evidences that the organizations publicly communitcates the safety and risks of a product/service to relevant governments bodies, consumers and other stakeholders.	Recommendation of the Council on Consumer Product Safety OECD/LEGAL/0459
2	Presence of internal management measures to assess consumer health and safety. No evidence of health or safety incidents regarding the consumer.	
3	The organization has no proven cases that violate consumer health and safety within the last 3 years. 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.	
4	The organization has a record of proven cases that violate consumer health and safety within the last 3 years. 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.	

Reference Scale: Health and safety		
Basic requirement: Consumers have the right to express their displeasure (UNEP, 2021)		
Level	Performance Reference Point	Note/reference
1	–	
2	The organization has a complaints book where health and safety related issues can be mentioned. The book presents a low number of complaints.	
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 founs (no data), and the context is positive.	
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 founs (no data), and the context is negative.	

Local Community

Reference Scale: Access to material resources		
Basic requirement: Organizations should establish effective policies, waste management systems and procedures to ensure proper management of unavoidable pollution and waste (Amfori, 2017; IFC, 2012; OSHA, 2018)		
Level	Performance Reference Point	Note/reference
1	–	
2	Presence of an environmental management system, standards or certifications that ensures the sustainable use of natural resources, the prevention of pollution and the recycling of wastes.	Examples of environmental standards or certification schemes: IFC Performance Standards on Social & Environmental Sustainability, the ISO 14000, ISO 26000 ISO 95000, ISO 45000, ISO 50001
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 founs (no data), and the context is positive.	
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.	

Reference Scale: Access to material resources 2		
Basic requirement: Organizations should contribute for the improvement of the quality of local infrastructures and for the access to local natural resources. (UNEP, 2021)		
Level	Performance Reference Point	Note/reference
1	–	
2	Evidences of the development of projects and/or initiatives to improve local infrastructure and/or natural resources allowing mutual community access and benefits.	
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.	
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.	

Reference Scale: Safe and healthy living conditions		
Basic requirement: Organizations should contribute to the local community through environmental risk management systems or through participation with local organizations in communicating the potential health and safety impacts of their operations on surrounding communities. (UNEP, 2021)		
Level	Performance Reference Point	Note/reference
1	Organizations promote and contribute to the health of local communities through participation in public health campaigns (1,7).	
2	Presence of enviornmental risk management systems.	
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.	
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.	

Reference Scale: Safe and healthy living conditions		
Basic requirement: Organizations may contribute to the health of local communities, ensuring that no risks are exposed to the community. (UNEP, 2021)		
Level	Performance Reference Point	Note/reference
1	The presence of the organization significantly improves the community's water availability, hygiene and sanitation.	
2	No evidences of incidents on community health and safety.	
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.	
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.	

Reference Scale: Community engagement		
Basic requirement: Organizations should foster community engagement through direct involvement in community initiatives and/ or through financial support of community projects (e.g. Earth Day activities, recycling initiatives, and visits to local schools). (UNEP, 2021)		
Level	Performance Reference Point	Note/reference
1	The organizations continuously engage with the community and provide significant contributions.	(Life Cycle Initiative & Social Life Cycle Alliance, 2022)
2	The organizations occasionally engage with the community and provide significant contributions. For example: education projects and social initiatives.	
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.	
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.	

Reference Scale: Community engagement		
Basic requirement: Organizations should systematically consult representative community groups in determining priorities for social investment and community development activities (OSHA, 2018)		
Level	Performance Reference Point	Note/reference
1	Organizational offer support (volunteer-hours or financial) for community initiatives.	
2	Involvement of community stakeholders in organizational decision-making processes.	
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.	
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.	

Reference Scale: Community engagement		
Basic requirement: An organization should attempt to engage with a broad range of stakeholders that represent balanced community interests. (UNEP, 2021)		
Level	Performance Reference Point	Note/reference
1	-	Pilot projects SETAC/UNEP, 2021
2	Presence of written policies or puclic proves (website) on community engagement at organizational level.	
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.	
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.	

Reference Scale: Local Employment		
Basic requirement: Organizations should give preference and undertake initiatives to strengthen opportunities for local communitites and suppliers to contribute to value chains (UNEP, 2021; OSHA, 2018).		
Level	Performance Reference Point	Note/reference
1	Encouragement is given to the local community to apply for the jobs.	
2	Presence of a policy of local hiring preferences.	
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.	
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.	

Reference Scale: Local Employment 2		
Basic requirement: Organizations should give preference and undertake initiatives to strengthen opportunities for local communities and local suppliers to contribute to value chains (UNEP, 2021; OSHA, 2018)**.**		
Level	Performance Reference Point	Note/reference
1	_	
2	Percentage of workforce hired locally, at least 50% of the total employees of the organization were hired locally.	
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.	
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.	

Society

Reference Scale: Public commitments to sustainability issues 1		
Basic requirement: There is evidence of commitments or agreements related to sustainability, which are disseminated through the organization's website, promotional materials or other means (UNEP, 2021).		
Level	Performance Reference Point	Note/reference
1	Presence of mechanisms to follow-up the realization of promises.	
2	Managing sustainability issues as part of the company's policy, strategy and goals. Presence of publicly available documents or standards as promises or agreements on sustainability issues.	
3	There is no record of proven cases that the organization has violated its commitments to sustainability within the last three years. 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.	(Ramirez et al, 2014)
4	There is a record of proven cases that the organization has violated its commitments to sustainability within the last three years. 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.	(Ramirez et al, 2014)

Reference Scale: Contribution to economic development		
Basic requirement: Evidence that the organization contributes to the economy, which is demonstrated by the organization's website, promotional materials or other means (UNEP, 2021).		
Level	Performance Reference Point	Note/reference
1	The organization provides education and training, makes investments, or forward research.	
2	Evidence that the organization contributes to the economy, which is demonstrated by the organization's website, promotional materials or other means (UNEP and SETAC 2010).	For example, a contribution to the economy could be the revenues of the organization as reported in the annual financial report.
3	No evidence of damage or blockage of economic development by the organization. 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.	
4	Evidence of damage or blockage of economic development by the organization. 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.	

Value Chain Actors

Reference Scale: Promoting social responsibility 1		
Basic requirement: Suppliers and sub-contractors are expected to comply with a code of labour practice or contractual obligations. The organization shall conduct due diligence by effectively communicating the requirements to be achieved (SAI, 2014; OSHA, 2018)		
Level	Performance Reference Point	Note/reference
1	-	
2	Presence of explicit code of conduct that protect human rights of workers among value chain actors.	
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.	
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.	

Reference Scale: Promoting social responsibility 2		
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 (OSHA, 2018)		
Level	Performance Reference Point	Note/reference
1	Support to suppliers in terms of consciousness-raising and counselling concerning the social responsibility issues.	
2	Evidence of audits by the organization with regard to social responsibility of value chain actors in the last year.	
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.	
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.	

Appendix III

Sources used in the site-specific assessment to define the PRPs corresponding to level 2.

Stakeholders	Subcategories	Indicators	Indicators definition Source
Workers	**Equal opportunities/ Discrimination**	Presence of formal policies on equal opportunities and/or non discrimination.	UNEP (2021)
		Presence of unequal opportunities at the organization.	UNEP (2021)
	Health and safety	Presence of policy/guidelines or program related to the health and safety of employees. In addition, preventative measures and emergency protocols exist regarding accidents & injuries;	UNEP (2021)
		No fatal accidents in the last three years.	UNEP (2021)
	Social Benefits/social security health	Presence of at least 2 of the social benefits stipulated by ILO Conventions as part of company's policy. Presence of social benefits mandatory by national law.	UNEP (2021)
Consumers	**Health and safety**	Presence of internal management measures to assess consumer	UNEP (2021)
		No evidence of health or safety incidents regarding the consumer.	UNEP (2021)
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.	UNEP (2021)
		Evidences of the development of projects and/or initiatives to improve local infrastructure and natural resources allowing mutual community access and benefits.	UNEP (2021)
	Safe and healthy living conditions	Presence of environmental risk management systems	Ramirez et al. (2014)
		Evidence that the organization participates with local stakeholders in communicating the potential health and safety impacts of their operations on surrounding communities.	Ramirez et al. (2014)
		No evidence of incidents on community health and safety.	UNEP (2021)
	Community engagement	Presence of written policies on community engagement at organizational level.	UNEP (2021)
		The organization occasional engage with the community and provide significant contributions.	UNEP (2021)
		Involvement of community stakeholders in organizational decision-making processes.	UNEP (2021)
	Local employment	Presence of a policy of local hiring preferences and/or for locally based suppliers.	Ramirez et al. (2014)
		Percentage of workforce hired locally, at least 50% of the total employees of the organization were hired locally.	UNEP (2021)
Society	**Public commitments to sustainability issues**	Managing sustainability issues as part of the company's policy, strategy and goals.	UNEP (2021)
		Presence of publicly available documents or standards as promises or agreements on sustainability issues.	UNEP (2021)
	Contribution to economic development	Evidence that the organization contributes to the economy, which is demonstrated by the organization's website, promotional materials or other means.	Ramirez et al. (2014)
Value chain actors	**Promoting social responsibility**	Evidence of audits performed by the organization with regard to social responsibility of value chain actors in the last year.	UNEP (2021)
		Presence of a code of conduct for suppliers.	UNEP (2021)

Appendix IV

The excel file "Site specific LCIA_Support Spreadsheet_MCV_MasterThesis" contains the detailed scores and aggregation steps performed during in the LCIA. The final results, graphs and sensitivity analysis are also explained. In addition, the detailed calculations of the weighting factors and allocations factors can be consulted. Support information used to calculate the monetary flows can be consulted under the spreadsheet "Flows_support".

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