D7.6 Report on the life cycle sustainability assessment (LCSA) results

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Deliverable lead	Delft University of Technology (TUD)
Author(s)	Gijsbert Korevaar (TUD) George Tsalidis (TUD) Nilay Elginoz Kanat (IVL) Steve Harris (IVL)
Contact	g.korevaar@tudelft.nl
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[1] **R**=Document, report; **DEM**=Demonstrator, pilot, prototype; **DEC**=website, patent fillings, videos, etc.; **OTHER**=other

[2] **PU**=Public, **CO**=Confidential, only for members of the consortium (including the Commission Services), **CI**=Classified

Executive Summary

The ZERO BRINE project wants to achieve sustainability in the waste water treatment sector and the several sectors that the waste water treatment sector serves. Therefore, in four demonstration locations, experiments have been performed with several configurations for brine treatment. In order to judge upon the sustainability of these four demonstration locations, the three pillars of sustainability are taken into account: people, planet, and profit. In Deliverable 7.3, the unified approach is presented of Work Package 7 that shows how the analysis of the four locations are aligned and how the three impacts are taken together. In this Deliverable 7.6, the focus is on the social aspects of sustainability and on the integration of these social aspects into the framework of Life Cycle Assessment (LCA). This integration is presented in the form of a Life Cycle Sustainability Analysis (LCSA).

The underlying report on social aspects and LCSA has to be read together with Deliverable 7.7 in which LCA and Life Cycle Costing results are presented. The environmental outcomes of an LCA (that also can be named an environmental LCA or E-LCA), combined with the economic aspects of a Life Cycle Costing and the societal aspects of a Social LCA, or S-LCA, form together a LCSA. The results are presented in this report in the form of spider diagrams that show how the balance between the several pillars of sustainability lead to different insights into the sustainability of the case studies.

There is still quite some room for improvement, especially in terms of critical material depletion and social indicators. The level of sustainability and the balance between the various parts of sustainability differ per demonstration location. In the Dutch case, no technological reference case exists, the current brine effluent is released directly to the environment, this makes it hard to see the sustainable benefits of ZERO BRINE technology. The locations in Poland and Turkey score not so much different from the reference case, this could mean that with further exploration more sustainability gains are possible in process optimisation and detailed process design. In Spain, especially the OPEX needs more attention, which also could be looked at through further process optimisation.

In conclusion, it can be stated that the ZERO BRINE technology is a sustainable solution for brine treatment. The level of sustainability and the balance between the various parts of sustainability differ per demonstration location. This also gives recommendations for innovation policy and technology management in the water sectors, the outcomes of that are taken to Work Package 9 in which European policy reviews, acceptance by stakeholders in the water sector, and policy recommendations are presented.

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1. Introduction

This report focuses on the assessment of the four demonstration locations of the ZERO BRINE project, which is a European Union funded public-private partnership that works on zero liquid discharge technology for water, salt and magnesium recovery from brine effluents. Pilot projects for ZERO BRINE are implemented in several locations in Europe, such as Spain, Poland, Turkey and the Netherlands. The official requirements as set out by the project owners are to evaluate the sustainability performance of the ZERO BRINE systems. Therefore, in four demonstration locations, experiments have been performed with several configurations for brine treatment.

To assess the sustainability of the four demonstration locations, the three pillars of sustainability are taken into account: people, planet, and profit. In this report the focus is on the social aspects of sustainability and on the integration of these social aspects into the framework of Life Cycle Assessment (LCA). This integration is presented in the form of a Life Cycle Sustainability Assessment (LCSA).

1.1. Objectives

Work package 7 of the ZERO BRINE project is concerned with the technology assessment of the various locations (Deliverable 7.2), with the full-scale implementation of the ZERO BRINE technology in the four locations (Deliverable 7.4) and with the Environmental Life Cycle Assessment (E-LCA) and Life Cycle Costing (LCC) of the ZERO BRINE technology (Deliverable 7.7). Amid these deliverables, Deliverable 7.6 deals specifically with the Social Life Cycle Assessment, with the following objectives:

1) Social indicators are introduced.
2) The framework for Social Life Cycle Assessment (S-LCA) is described.
3) The framework of Life Cycle Sustainability Assessment (LCSA) is given as composed of the combination of S-LCA with Environmental Life Cycle Assessment (E-LCA) and Life Cycle Costing (LCC).
4) Results of LCSA are presented.
5) Conclusions about the LCSA results for the ZERO BRINE case studies are given.

1.2. Importance of Social Life Cycle Assessment

With sustainability becoming an increasingly important target for many organizations, collecting, analysing and communicating information about sustainability performance is crucial for helping them to better understand their current situation and for supporting internal management decisions for development over time. Sustainability performance assessment methods are key for enabling business decision makers to understand their companies' sustainability performance and translate sustainability intents into concrete action. When it comes to the Triple Bottom Line (TBL) of sustainability – which states that sustainability has economic, environmental and social dimensions (Elkington, 1997) – the social dimension is the main topic of this Deliverable 7.6.

The Social Life Cycle Assessment (S-LCA) tool was developed for the assessment of dimensions of sustainability that are not related directly to environmental impacts, for example the impact on society, employees, etc. In 2009, United Nations Environment Program (UNEP) and the Society for Environmental Toxicologists and Chemists (SETAC) developed S-LCA Guidelines and Methodological Sheets for assessing the social impacts of products and services across the life cycle to complement the Environmental Life Cycle Assessment (E-LCA) approach (UNEP/SETAC, 2009). As opposed to E-LCA which is a well-established tool, S-LCA is at an early stage of research and is not commonly applied in literature or in practice. Even though more and more S-LCA publications have surfaced in recent years, the S-LCA methodology is still an emerging area of research and there is still no standardized methodology to operationalize it. Thus, it is urged to conduct more research in the field of S-LCA, and a main way to contribute to its further development are through case studies.

The ZERO BRINE project offers a nice opportunity to work on S-LCA related to various case studies and demonstration locations. The case studies are rather diverse in terms of location and population, placed in four different types of industries, working on different sources of brine water, which effluents have also different types of impact on the surroundings. In this report, the results of an S-LCA will be presented and conclusions are drawn on the feasibility of performing an S-LCA in diverse technological contexts and the feasibility of combining an S-LCA with other types of impact assessment (LCC and E-LCA).

1.3. Literature background

In this introduction, a short literature review is provided to discuss the background of Social Life Cycle Assessment (S-LCA) with support of the definition of social indicators and the presentation of the framework for Life Cycle Sustainability Assessment (LCSA).

Framework of Social Life Cycle Assessment

S-LCA follows the same 4-phase framework as LCA, see also Figure 1 (UNEP/SETAC, 2009):

1. The goal and scope is the first phase and involves the description of the process or product under study as well as selecting and describing the aim, functional unit, impacts and system boundaries.
2. The Life Cycle Inventory phase concerns the collection and organization of social data. However, unlike in Environmental LCA, the data for a Social LCA are not always quantitative, data in S-LCA can be qualitative or semi-quantitative. The qualitative data comes from stakeholder conversations or from databases of research that has been done with stakeholders.
3. The Social Life Cycle Impact Assessment phase concerns characterization of impact subcategories. It should be noted that it is not always possible to express social impacts per functional unit due to the qualitative nature of data.

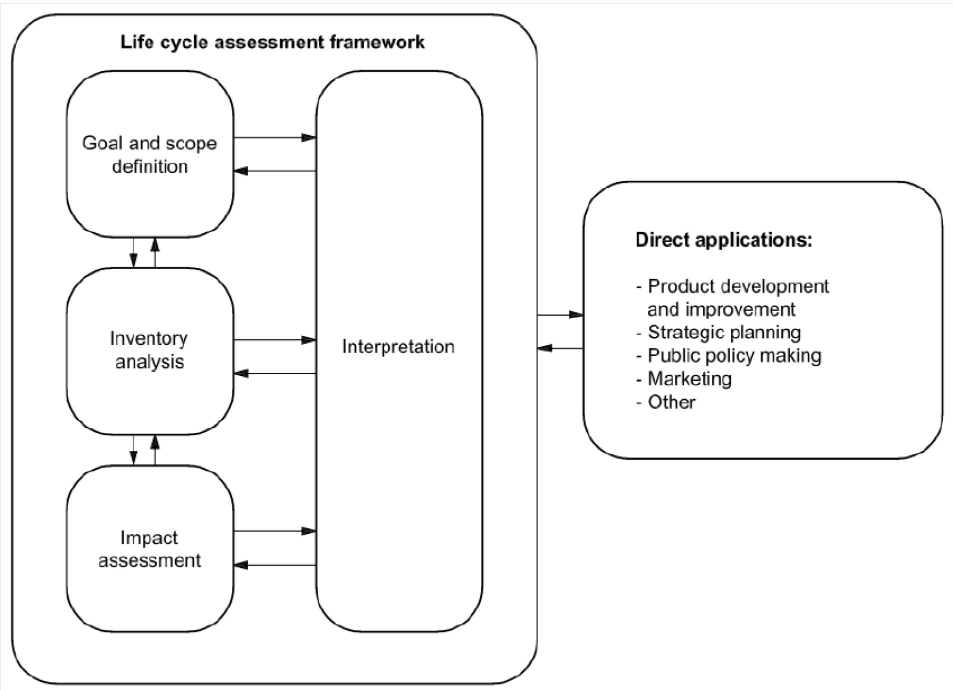

Figure 1 – Steps in the E- LCA Framework

4. During the interpretation, the impact subcategories may be aggregated to stakeholder categories. These stakeholder categories are:

a) the local community (e.g. citizens that live nearby and might experience an impact by the industry),

b) worker (e.g. employees in the industry or that work with suppliers or elsewhere in the value chain),

c) consumer (e.g. participants in the supply chain, mostly B2B or B2C),

d) value chain actors (e.g. institutions, market players)

e) society (e.g. regulators, policy makers).

The guidelines suggest aggregating the subcategory indicator results to stakeholder category results but no characterization models were suggested. Lastly, the last phase of S-LCA concerns the analysis of the results, conclusions and recommendations (UNEP/SETAC, 2009).

Literature review on S-LCA and social indicators

S-LCA fits well with the selected industries and the ZERO BRINE project due to its product and site-specific assessment characteristics (De Santo, 2019). Water produced through water treatment processes in the chemical process industry, textile industry, coal mining industry or silica industry require the input of various materials to enable the chemical reactions that are required for achieving the desired process outputs.

Rasouli and Kumarasuriyar (Rasouli & Kumarasuriyar, 2016) have composed a table containing some of the key elements of social sustainability. In their paper, an extensive literature review has been presented that will not be repeated here. The key elements of social sustainability by Rasouli and Kumarasuriyar are based on nine papers, for the proper reference to these publications, we refer to the original publication (Rasouli & Kumarasuriyar, 2016). Here only the table of key elements is taken over in Table 1. Although the list is not claimed to be exclusive, the work of key authors in the social sustainability definition field is highlighted which still makes it comprehensive. From the review of the literature, it can be concluded that basic human needs and equity are main recurring themes and concepts.

Table 1 – Key Themes of Social Sustainability (Rasouli & Kumarasuriyar, 2016)

Publication as in (Rasouli & Kumarasuriyar, 2016)	Key theme of social sustainability
1	Equity, diversity, quality of life, interconnectedness democracy government
2	Marco level: distribution of income and assets Micro level: Education, training, income, social contacts, communication and participation, social security
3	Social quality
4	Basic needs: physical aspects of society and human life such as health, housing, and food Equity: social disparities
5	Social capital, social infrastructure, social justice and equity and engaged governance
6	Equity
7	Social and cultural life, social amenities, systems for citizen engagement space for people and places to evolve
8	Equity: education, quality of life, social capital, social cohesion, integration and diversity, sense of place
9	Human capital, social capital, and well-being

The S-LCA focuses on the plant-level, which means that the plant locations that are directly responsible for their respective life cycle stage are included in the assessment. This decision is made because plants or factories are managed independently within a company, having their own functions and operational targets. In this approach, three value-added processes are included:

- procurement,
- production,
- distribution.

The procurement stage targets the assessment of suppliers' social sustainability performance on various stakeholder groups. In the production stage, it is determined what the social impacts derived from the focal organization's operations and behaviour towards its stakeholders are. Lastly, distribution is centred on the social sustainability performances of relating to the distribution of sale of products. Stakeholder groups and social impact subcategories are selected on the basis of their importance and relevance for assessing social sustainability for the ZERO BRINE case study.

The three goals for the ZERO BRINE locations were outlined first to:

1) Determine the social impacts of the project on various stakeholders by assessing the social sustainability performances of the main organizations in the ZERO BRINE value chain.
2) Identify the social hotspots in the value chain.
3) Provide recommendations for the potential improvement of negative hotspots.

Thereby, the S-LCA framework was modelled in a way to so as to be able to achieve these goals in the outcome of the study. The scope definition consisted of several parts. It was first described that a company's conduct approach is taken and as opposed to a process-approach. With this methodological decision it is attempted to make clear that it is the conduct of the organizations in a value chain that is of interest for the assessment. A set of criteria and a scoring system were defined for converting qualitative inventory information into quantitative social inventory data. In this way, different subcategories can be presented together and the social sustainability performances can be determined of all organizations with a stake in the ZERO BRINE project.

Life Cycle Sustainability Assessment approach

In 2011, UNEP published the document "Towards a life cycle sustainability assessment: Making informed choices on products" on how to conduct LCSA, which can be considered as a key guidance document on LCSA (Ciroth, et al., 2011). In this document, the term LSCA is defined as "… evaluation of all environmental, social and economic negative impacts and benefits in decision-making processes towards more sustainable products throughout their life cycle." Guinée states LCSA as the future of LCA since it widens the scope of LCA to include all three sustainability aspects and to answer not only product level questions but also sector and economy level questions (Guinée, et al., 2011).

The below scheme was proposed for LCSA by Kloepffer (Kloepffer, 2008):

$$LCSA = LCA + LCC + SLCA$$

Kloepffer puts consistent system boundaries in LCA, LCC and S-LCA as a prerequisite for application of this scheme (Kloepffer, 2008). However, Zamagni questioned the feasibility and correctness of this prerequisite and underlined the different maturity levels of the three methods (Zamagni, 2012). LCC was developed for calculating financial costs back in 30s (Ciroth, et al., 2011) and then widened to cover externalities being the most mature one, S-LCA as an emerging technique and LCA in between.

There are two approaches to present LCSA results:

1) to introduce indicators of social, economy and environmental aspects side by side
2) integrating them to generate combined impact scores

Multi-criteria decision analysis (MCDA) has been widely used to integrate three pillars of sustainability. Multi-attribute value theory (MAVT), multi-attribute utility theory (MAUT), and analytic hierarchy process (AHP) are amongst widely used methods for decision analysis, as presented in: (Azapagic & Perdan, 2005a) & (Azapagic & Perdan, 2005b).

2. ZERO BRINE Locations

The ZERO BRINE project has four demonstration locations. Although the technical details are presented elsewhere (for example in Deliverable 7.2 and also in Deliverable 7.7), also here a short description of the case studies is given. The focus is on the relevant details for the Social Life Cycle Assessment. The texts below are based on a publication by Tsalidis et al, based on ZERO BRINE results and written in the framework of the project (Tsalidis, Espi Gallart, Berzosa-Corbera, Clarens Blanco, & Korevaar, 2020).

2.1. The Netherlands - demineralized water plant

The Dutch case study is located in Rotterdam and it is a plant that produces ultra- pure demineralized water for the local chemical industry. The demineralized water plant (DWP) consumes lake water to produce demineralized water and purchases vacuum salt for regenerating ion exchange (IEX) softening units. The DWP is currently discharging approximately 2,5 million m^3/year of brine to the sea. The brine does not undergo any treatment, but the plant managers consider improving its environmental performance by recovering and reusing the water and sodium chloride. Nanofiltration (NF), evaporation, membrane crystallization (MC), eutectic freeze crystallization, IEX and reverse osmosis technologies are employed to recover salts and clean water. Recovered sodium chloride and clean water will be reused internally in the DWP, sodium chloride will be used for regeneration of the IEX units and clean water will replace water input from the nearby Brielse lake, lastly the rest recovered salts will be sold externally.

2.2. Spain - precipitated silica plant

The Spanish case study is located in Zaragoza. It is a company focusing on chemicals production, mainly in silicate derivatives and its operation is an important economic activity in Zaragoza area, as it generates jobs and has high influence on the economy of the region. However, large amounts of brine are produced, approximately 438 thousand m^3/year, from the precipitated silica production. The technological scheme consists of a pre-treatment where pH is modified to precipitate aluminium and iron followed by an ultrafiltration system to remove solids operating at dead-end mode. Afterwards the permeate of the NF is dosed with an anti-scalant to minimize the impact of silica and barium in the next membrane step. This next step is based on tailor-made regenerated membranes with tuned properties to maximize the recovery and module the rejection. During operation, the conductivity of the concentrate is fixed in order to obtain process water and concentrated sodium sulfate (Na_2SO_4) in a desired quality. Water will be reused in the precipitated silica plant to replace part of the water input in the silica production process, while the sodium sulfate is expected to be sold externally.

2.3. Poland - coal mine

The Polish case study concerns a coal mine in ZG Bolesław Smiały. The owner is state-run and the largest bituminous coal mining company in Europe producing approximately 30 million tons of bituminous coal per year. The coal mine currently discharges approximately 730 thousand m_3/year of saline coal mine wastewater. Currently, the drainage from the coal mine undergoes a two stage treatment process. First, large suspended solids are removed in settling ponds, before the remaining effluent is diluted so that constituents conform to discharge threshold for in surface water. However, due to tightening environmental regulations, coalmining company plans to decrease the salt load in wastewater. Brine from the coal mine will be treated with two-stage NF, reverse osmosis, single-pass electrodialysis and MC technologies. The NF unit separates the coal mine water into two streams: salt-rich concentrate and magnesium-rich permeate. The latter will be used for recovery of magnesium hydroxide ($Mg(OH)_2$). The NF concentrate is treated by reverse osmosis, electro dialysis and crystallization, which produces waste water, sodium chloride and gypsum. All recovered products are expected to be sold externally.

2.4. Turkey - textile industry

The Turkish case study concerns a textile plant at Büyükkaris, Kirklareli. The main environmental concern in the textile industry is the discharge of untreated process effluents mainly due to the high organic content, color, toxicity and salinity. Salts are directly used for dyeing at a dosage of approximately 0.6 kg salt/kg fibre and considerable amounts are also used in water softening processes. At the Turkish plant, the former accounts for 325 tons/year of refined salt, while the latter accounts for 275 tons/year both of which result in large brine effluents. Brine from reverse osmosis process of the waste water treatment train of the textile plant will be treated with IEX, ozonation and reverse osmosis technologies to recover clean water and concentrated brine. Cationic and anionic resins will be employed in the IEX process, ozonation aims to oxidize remained carbon material and, lastly, reverse osmosis produces clean water and concentrated brine. Both recovered materials will be reused internally at the textile plant for normal operations.

3. Methodology

3.1. E-LCA and LCC framework

Environmental Life Cycle Assessment (E-LCA) provides the framework for both Life Cycle Costing (LCC) and Social Life Cycle Assessment (S-LCA). This framework also has been described Deliverable 7.3 and deliverable 7.7 for this Work Package 7 in more detail and the results for E-LCA and LCC will be presented in Deliverable 7.7. Therefore, here only a short reference will be given to the E-LCA framework, see Figure 1, for more details the reader is referred to the other mentioned documents and also to the thesis by Elena De Santo (De Santo, 2019).

The S-LCA methodology adheres to the same major steps of the E-LCA per the ISO 14040 and 14044 standards (International Standarization Organization, 2006):

1) Goal and scope definition.
2) Life cycle inventory analysis.
3) Life cycle impact assessment.
4) Interpretation.

Note that the arrows between steps indicate that the LCA is conducted in an iterative process.

3.2. S-LCA

For all ZERO BRINE case studies the goal of the waste water treatment train modification is to process brine and produce clean water and salt(s) through building the demo plants. Thus, the functional unit (FU) is 1 m^3 of brine treated. The configuration of the unit process technologies for waste water treatment are depended on brine composition. Zero liquid discharge is achieved in all case studies, except for the Polish case study. System boundaries for the development of the demo plants start with the production of relevant commodities and finish when clean water and salt(s) are recovered at the plant. Therefore, the system boundaries of each system under study is cradle-to-gate. Based on previous work, certain stakeholders, such as workers and local community are mostly affected by companies (Tsalidis & Korevaar, 2019).

3.3. Integrated results

In this study, indicators are chosen for each sustainability aspect, revealing the trade-offs, strengths, and weaknesses for different aspects. The LCSA results of each case were also compared to LCSA results of its currently available reference technology.

Two indicators were chosen for environmental aspects: Climate change and resource depletion. Climate change was chosen because of high energy consumption of ZERO BRINE processes and being the most important environmental issue of present day. Mineral, fossil and renewable resource depletion was chosen because one of the most important strength of ZERO BRINE technology is providing resource recovery rates compared to its incumbent counterparts.

Capital expenditures (CAPEX) plus operating expenses (OPEX), and externalities were chosen to evaluate economic sustainability aspect. OPEX covers energy, raw materials, auxiliaries, waste management expenses and revenues gained by selling recovered resources. It is important to compare CAPEX and OPEX of ZERO BRINE technologies to reference technologies to evaluate their cost-effectiveness since operation of new and advanced technologies might cost more than conventional ones. The externalities were also investigated to cover the external costs caused by ZERO BRINE technologies on the environment. Total external cost is the summation of ecosystem services, access to water, biodiversity, building technology, human health and abiotic resources externalities. This is also reported in Deliverable 7.4.

Access to water resources is chosen as the social indicators in this LCSA study to evaluate the effect of ZERO BRINE water recovery on water resources accessibility. The chosen indicator results for all cases and their reference counterparts were listed and a radar chart were drawn to observe them together and analyse.

The indicators are given in Table 2.

Table 2 – Indicators of LCSA (FU is 1 m^3 of brine)

Climate change (kg CO_2 eq/FU)	Greenhouse Gas Emissions are calculated with E-LCA software and given in CO_2 equivalents. The details of the calculation and the data are presented in Deliverable 7.7
Mineral, fossil and renewable resource depletion (Sb eq/FU)	Resource depletion is calculated with E-LCA software and given in Sb equivalents. The details of the calculation and the data are presented in Deliverable 7.7
CAPEX + OPEX (EUR/FU)	CAPEX and OPEX are calculated through LCC, the details of the calculation and the data are presented in Deliverable 7.7
Externalities (ELU/FU)	Externalities are calculated through LCC, the details of the calculation and the data are presented in Deliverable 7.7
Access to material resources: Water (% m^3 in region)/FU	Access to material resources follow from the experimental setup and full scale calculations of Deliverables 7.2 and 7.4

4. LCSA analysis

In Table 3, the LCSA results are given as derived through the method described above and based on that data collected in Deliverables 7.2, Deliverable 7.4 and Deliverable 7.7 of Work Package 7. Table 4 provides the LCSA results for the reference case. From Table 3 and Table 4 are then the normalised results derived in relation to the reference case, as presented in Table 5.

Table 3 – LCSA results (FU is 1 m³ of brine)

	DWP	Silica plant	Coal mine	Textile plant
Climate change (kg CO_2 eq/FU)	2.56	-4.59	12.50	13.49
Mineral, fossil and renewable resource depletion (Sb eq/FU)	0.004	-489.4	-3.8	5
CAPEX + OPEX (EUR/FU)	1.57	0.61	-0.45	0.30
Externalities (ELU/FU)	27.8	-22.6	-1.18	36.2
Access to material resources: Water (% m³ in region)/FU	18.7	2.0	0.2	7.1

Table 4 – LCSA results in relation to reference case (FU is 1 m³ of brine)

	Reference DWP	Reference Silica	Reference Coal mine	Reference Textile
Climate change (kg CO_2 eq/FU)	2.97	0.30	18.6	4.07
Mineral, fossil and renewable resource depletion (Sb eq/FU)	0.00	13.2	-9.4	2.15
CAPEX + OPEX (EUR/FU)	0.42	0.50	7.97	12.25
Externalities (ELU/FU)	0.70	0.73	2.81	11.0
Access to material resources: Water (% m³ in region)/FU	20.7	20.0	1.0	7.5

Table 5 – LCSA results normalized to reference cases (Reference = 1 in all aspects)

	DWP	Silica plant	Coal mine	Textile plant
Climate change	0.87	-15.30	0.67	3.31
Mineral, fossil and renewable resource depletion	269.36	-37.08	0.40	2.33
CAPEX + OPEX (EUR)	3.78	1.22	-0.06	0.02
Externalities	39.90	-30.90	-0.42	3.29
Access to material resources: Water	0.90	0.10	0.20	0.95

The following reflections can be made on these tables and results:

- In the DWP case, climate change impact is slightly lower than in the reference case, "mineral, fossil and renewable resource depletion" on the other hand is much higher than in the reference case. CAPEX + OPEX and externalities are also higher than in the reference case, where externalities for the ZERO BRINE technology are 40 times higher than in the reference case. In the DWP reference case, no technology is applied, the diluted brine water is released directly to the sea. That means that ZERO BRINE technology is always an addition to the existing treatment system, that explains the 40 times higher impact.

- In the Silica plant, the ZERO BRINE technology performs much better than the reference case in terms of both environmental indicators which are negative. This means that the positive impacts gained due to resource recovery is higher than the environmental burdens caused by the ZERO BRINE system. CAPEX + OPEX is slightly higher compared to reference case, but externalities are negative, and it means the ZB system has positive impact in terms of externalities. On the other hand, the reference case performs much better in the social indicator.

- In the coal mine, the reference case performs better for resource depletion but worse for climate change. For both economic indicators, coal mine case performs better providing economic gain. On the other hand, social indicator shows better results for reference case. In the reference case, less technology is needed, making it less sensitive for material supply.

- In the textile plant, the ZERO BRINE system performs worse than the reference case in environmental indicators. However, CAPEX + OPEX of ZB system is much lower than reference case, but externalities of the ZB system are three times higher than the reference case. According to the social indicator both systems perform similarly.

From Table 5, the radar chart covering all four locations with all chosen indicators is given in Figure 2. However, since the DWP is an outliner on the "mineral, fossil and renewable resource depletion", also the graph without DWP is given in Figure 3.

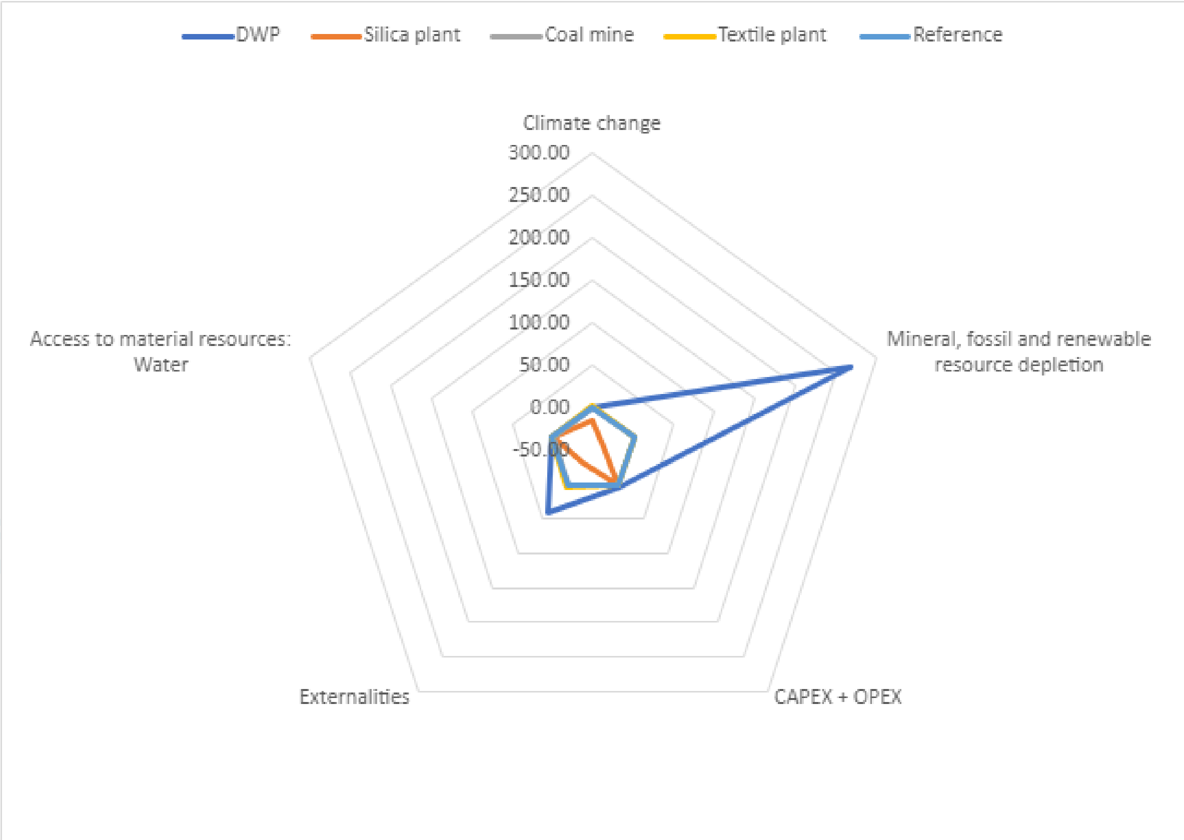

Figure 2 – LCSA chart with 5 indicators and 4 demonstration locations

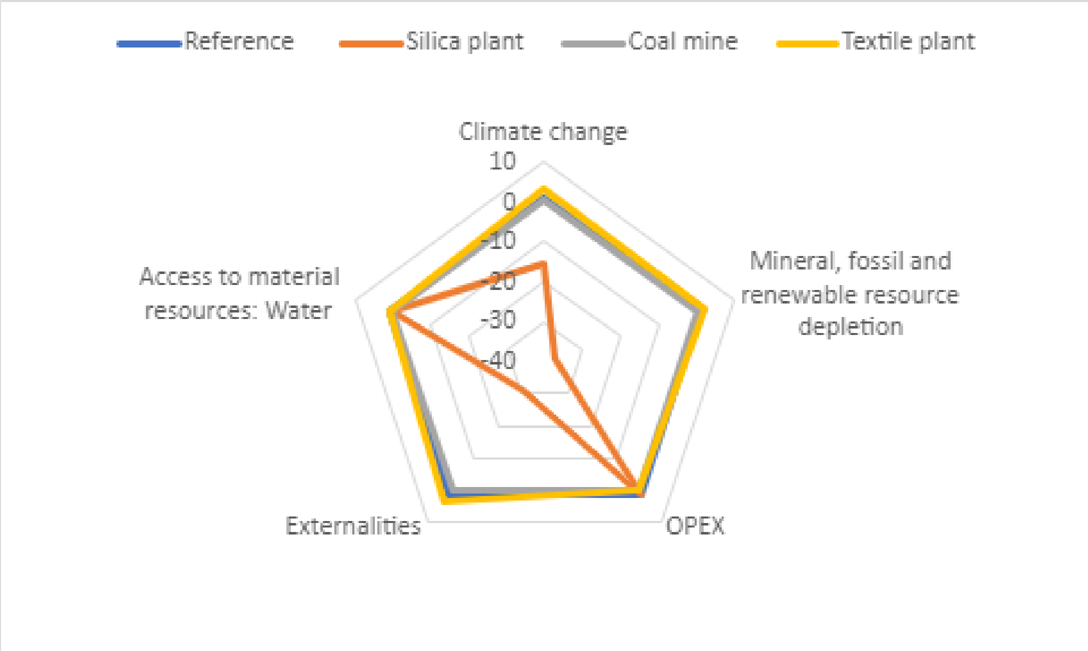

Figure 3 – LCSA chart with 5 indicators and 3 demonstration locations (without DWP)

In the graphs of Figure 3, it is clearly visible that the performance of the coal mine and the textile plant is not that different from the reference cases. The silica plant performs better than the reference case and also than the other three demonstration locations in terms of "reduction of climate change", "reduction of mineral, fossil, and renewable resource depletion", and "externalities" in comparison to the reference case. The DWP plant performs quite similarly to the coal mine and textile plant in terms of improvement in comparison to the reference case, but, as discussed, performs much worse for "reduction of mineral, fossil, and renewable resource depletion".

5. Conclusions

It can be stated that the ZERO BRINE technology has the potential to improve the sustainability performance of brine treatment. This strongly depends on the water being treated and the “sustainability value” of the constituents within the brine and whether their recovery counteracts the impacts of increased energy and resource use of the ZERO BRINE systems.

There is still quite some room for improvement, especially in terms of critical material depletion and social indicators. The level of sustainability and the balance between the various parts of sustainability differ per demonstration location. In the DWP case, no technological reference case exists, the current brine effluent is released directly to the environment, this makes it hard to see the sustainable benefits of ZERO BRINE technology. The coal mine and textile industry score not so much different from the reference case, this could mean that with further exploration more sustainability gains are possible in process optimisation and detailed process design. In the silica industry, especially the OPEX needs more attention, which also could be looked at through further process optimisation.

These conclusions provide the basis for further recommendations on innovation policy and technology management in the water sectors, the outcomes of that are taken to Work Package 9 in which European policy reviews, social acceptance by stakeholders in the water sector, and policy recommendations are presented.

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