Sustainable Production and Consumption 22 (2020) 77–87

Contents lists available at ScienceDirect

Sustainable Production and Consumption

journal homepage: www.elsevier.com/locate/spc

Research article

Social life cycle assessment of brine treatment and recovery technology: A social hotspot and site-specific evaluation

Georgios Archimidis Tsalidis[a,*], Jose Jorge Espí Gallart[b], Joan Berzosa Corberá[b], Frederic Clarens Blanco[b], Steve Harris[c], Gijsbert Korevaar[a]

[a] Engineering Systems and Services department, Faculty of Technology, Policy, and Management Delft University of Technology, Jaffalaan 5, 2628 BX Delft, the Netherlands
[b] Eurecat Technology Centre – Innovating for Businesses, Carrer de Bilbao 72, 08005 Barcelona, Spain
[c] IVL Swedish Environmental Research Institute, Valhallavägen 81, 114 27 Stockholm, Sweden

ARTICLE INFO

Article history:
Received 9 December 2019
Revised 3 February 2020
Accepted 4 February 2020
Available online 6 February 2020

Keywords:
Social life cycle assessment
Brine
Process industry
Site-specific
Social Hotspot Database

ABSTRACT

Environmental pollution, resource scarcity, and freshwater shortage are critical world challenges facing humanity. Process industry produces large amounts of brine, a waste water with a high salinity level and often critical raw materials. This study applies the social life cycle assessment (S-LCA) to quantify societal benefits and risks in developing brine treatment systems. S-LCA is implemented for hotspot and site-specific levels on four case studies of the Zero Brine project. Hotspot analysis focused on the major commodities. Social Hotspot Database was used as source for data and endpoint indicators. In addition, site-specific analysis regarded the social performance of the case studies companies; interviews and questionnaires were performed with representatives of the four case studies. The collected data were converted to scores with subcategory assessment method and performance reference points. The results show that for all case studies "Labor rights and decent work" and "Health and safety" indicators result in the largest impacts due to imports of commodities from developing countries. Site-specific results show that the overall social sustainability performance of the case study companies is at a good level. The only potential areas for improvement are the "Occupational accidents" and "Contribution to the local community". The former are minimally higher for silica plant and higher for coal mine in relation to these sectors average accidents rates. Furthermore, the coal mine company can contribute more to the local community and reduce conflicts concerning environmental impacts at the city level. Common identified hotspots among the case studies are: China, India and Congo. Reducing imports from these countries will significantly improve the societal performance of the brine systems.

1. Introduction

Environmental pollution, resource scarcity and freshwater shortage are critical world challenges facing humanity in this century (Keijer et al., 2019). The process industry is the main source of brine production in Europe. Europe is responsible for approximately 5.9% of the estimated 51.7 billion m^3 produced each year globally (Jones et al., 2019). Brine is a high-concentration solution of salt in water, and its disposal is problematic due to impacts on aquatic ecosystems and loss of critical raw materials (European Commission, 2014). Therefore, processing industrial brine may result in decreasing environmental pollution, and recovery of clean water and scarce resources. The latter can replace natural resources in a circular economy context.

Brine consists of water with high-concentration of salt between 35,000 and 260,000 ppm (with sea water being around 30–40,000 ppm) (Xevgenos et al., 2016). Brine can be a waste product of various industrial processes, but it is also a product in salt solution mining. Solution mining is used by the chlor-alkali industry and involves drilling wells down to a salt layer, produce saturated brine and purify the latter in a brine purification facility to produce specialty salt, vacuum salt and low-purity salt (Sediyi, 2006; Warren, 2016). Among these three products, vacuum salt consists of high purity salt and is manufactured for industrial use. This industrial use covers regeneration of resins used in various chemical processes, textile dying and water treatment facilities (Roskill, 2018). As a result, the salt consumed in these processes ends-up as waste brine effluent. Furthermore, another major brine source is coal mining, due to brine being part of the coal mine wastewater (Turek, 2004). Due to brine's high-concentration of salt, European regulation prohibits organizations from disposing industrial brine

* Corresponding author.
E-mail address: g.a.tsalidis@tudelft.nl (G.A. Tsalidis).

https://doi.org/10.1016/j.spc.2020.02.003
2352-5509/

to surface water (US EPA, 2014). Furthermore, brine contains substances that the European Union has identified as critical raw materials (European Commission, 2014). The recovery of these, such as magnesium, is a priority under the Circular Economy Package due to current reliance on imports of magnesium from China and Russia (Bourguignon, 2016).

The chemical industry alone utilizes approximately 11.5 million tons of salt every year. Therefore, the need for a solution to treating large brine flows and recovering valuable materials, led to the development of zero liquid discharge (ZLD) concept. ZLD concept currently represents the state of the art in brine treatment (Sajid Hussain, 2012), since it eliminates brine disposal via its conversion to high quality clean water and salt(s). ZLD typically consists of a crystallizer and an evaporator, and enables the industry to conform to the strictest regulations. It is recognized as the most promising approach to eliminate the discharge of brine to surface water bodies. The Zero Brine project aims to apply ZLD technology to four process industries case studies: (1) a demineralized water plant in the Netherlands, (2) a precipitated silica plant in Spain, (3) a coal mine in Poland and (4) a textile plant in Turkey. The build-up stage of the Zero Brine industrial systems requires materials. Therefore, when demo plants will be patented and installed in industries with similar brine composition in Europe or elsewhere, it is important to identify social hotspots due to these materials requirements.

The 2005 World Summit on Social Development (United Nations General Assembly, 2005) identified sustainable development goals based on three pillars of sustainability, such as economic development, social development and environmental protection. The environmental, economic and social facets can be evaluated with life cycle assessment (LCA), life cycle costing and social LCA (S-LCA). Unlike LCA, S-LCA is not yet standardized and researchers are not consistent in applying frameworks and selecting social impact indicators. As a result, 14 frameworks have been developed so far for S-LCA (Sureau et al., 2018) and various indicators have been selected in literature since S-LCA is still undergoing evolution (Benoît et al., 2010; Clift et al., 2017). The S-LCA guidelines which were developed by the UN Environment Programme and SETAC follow the same framework as LCA, from goal and scope definition phase to life cycle inventory, life cycle impact assessment and interpretation phases (UNEP/SETAC Life Cycle Initiative, 2013, 2009). S-LCA can be described as "a social impact assessment technique that aims to assess the social and socioeconomic aspects of products and their potential positive and negative impacts along their life cycle" (UNEP/SETAC Life Cycle Initiative, 2009, p. 37). Therefore, researchers suggest that decision-making based on S-LCA will lead to more beneficial situations for society (Jørgensen, 2013).

So far S-LCA has been applied to various sectors, from manufacturing and energy to agriculture, and with various system boundary types, although 41% of the studies are restricted to cradle-to-gate (as opposed to cradle to cradle that envelopes the complete life cycle) (Petti et al., 2018). Furthermore, to date there are no accepted characterization models which convert subcategories into impact categories due to causal models in social sciences being fairly well undeveloped and the qualitative nature of S-LCA indicators (Cadena et al., 2019). The S-LCA guidelines (UNEP/SETAC Life Cycle Initiative, 2009) describe two levels of analysis, a hotspot level (throughout the life cycle) and a site-specific level. They advise the collection of site-specific data or a combination of both data kinds when needed. The hotspot level of analysis consists of more generic data to the case study usually on a national level, while the site-specific level consists of data collected from the involved stakeholders.

The chemical industry has developed social sustainability strategies based on its effects on supply chain actors and workers. Few companies have performed S-LCA studies to investigate the effects of their products on a life cycle perspective. Many companies prefer to join the Global Reporting Initiative index, develop their own tools, for instance BASF with the SEEBalance method (Kolsch et al., 2008), or develop methods that are simpler in terms of application when compared to S-LCA, such as the Handbook for Product Social Impact Assessment (Fontes, 2016).

The aim of this study is to complement the decision making of the four process industries at two levels: (a) hotspot analysis aims to complement decision making regarding of purchasing equipment and (b) site-specific analysis aims to identify social impacts due to business-as-usual of the four case studies companies in order to improve social performance.

In next sections the methodology that we followed and the four case studies are described. This is followed by results which are presented by level of analysis and, lastly the conclusions are presented with suggestions for the four case study companies.

2. Methodology

In this section the S-LCA method and the case studies are described in detail.

2.1. Social LCA framework

S-LCA follows the same 4-phase framework as LCA. 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. The Life Cycle Inventory phase concerns the collection and organization of social data. However, unlike LCA, data are not always quantitative, data in S-LCA can be qualitative or semi-quantitative. 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. Impact subcategories may be aggregated to stakeholder categories. These stakeholder categories are: the local community, worker, consumer, value chain actors and society. 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 Life Cycle Initiative, 2009).

2.2. Case studies in Zero Brine project

This subsection presents the "Goal and Scope Definition", "Life Cycle Inventory" and "Life Cycle Impact Assessment" steps of the S-LCA framework, along with the four Zero Brine case studies.

2.2.1. Goal and scope definition of Zero Brine systems

For all of the 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 is 1 Zero Brine demo plant. The configuration of the unit process technologies for waste water treatment ware depended on brine composition. Zero liquid discharge is achieved in all case studies (described below), 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. Selecting subcategories in S-LCA is based on the aim of the S-LCA study. Based on previous work, certain stakeholders, such as workers and local community are mostly affected by companies (Tsalidis and Korevaar, 2019). Furthermore, since significant differences were expected between developed countries (i.e. where the case studies are located) and developing countries (i.e. countries

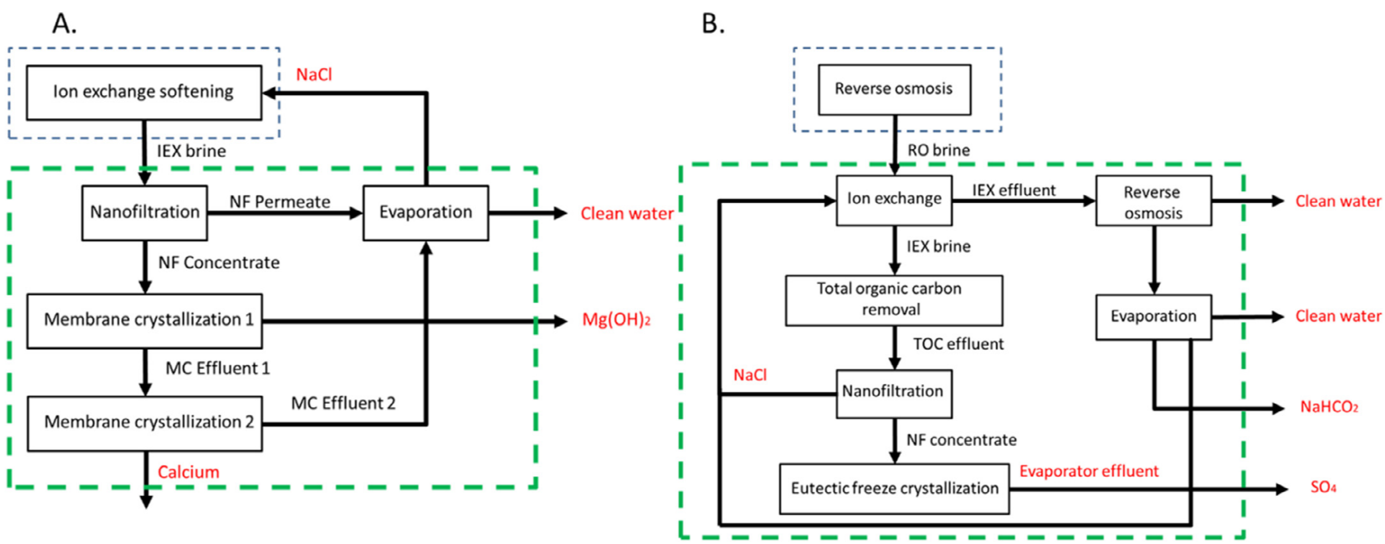

Fig. 1. Zero Brine system for DWP, modifications in waste water treatment processes. (A) Treatment train of IEX brine. (B) Treatment train of reverse osmosis brine.

exporting commodities) in terms of how the industry treats workers and local community and it was not possible to include all subcategories, as no reliable data existed for each subcategory. Thus, we focused on workers, society and local community stakeholder groups and aimed to focus on social indicators to investigate the societal performance of the companies in each case study and complement these results with datasets from the Social Hotspot database (SHDB) regarding the supply chain.

The Netherlands: demineralized water plant: The Dutch case study is located in Rotterdam and is a plant that produces ultrapure 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 2,530,000 m^3/year of brine to 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. Fig. 1 shows the schematic of the Zero Brine demo plant, with the involved technologies, in the DWP. Brine from two sources in the DWP is treated, brine from the IEX unit (Fig. 1(A)) and brine from the reverse osmosis unit (Fig. 1(B)). Nanofiltration (NF), evaporation, membrane crystallization (MC), eutectic freeze crystallization, IEX and reverse osmosis technologies are employed to recover salts and clean water. The purpose of design in Fig. 1(A) is for NF process to concentrate the bivalent cations in the NF concentrate, which is then fed to a double crystallization stage to recover inorganic salts. Conversely, the NF permeate and MC effluent 2 are sent to a evaporator, where NaCl concentration reaches the requirements for the IEX process (Micari et al., 2019; Xevgenos et al., 2015). Similarly, the design in Fig. 1(B) aims to remove organic carbon material, recover primarily clean water and NaCl. 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 Brielse lake, lastly the rest recovered salts will be sold externally.

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 (Travesi, 2010). However, large amounts of brine are produced, approximately 438,000 m^3/year, from the precipitated silica production. Fig. 2 shows the schematic of the Zero Brine plant, with the unit process

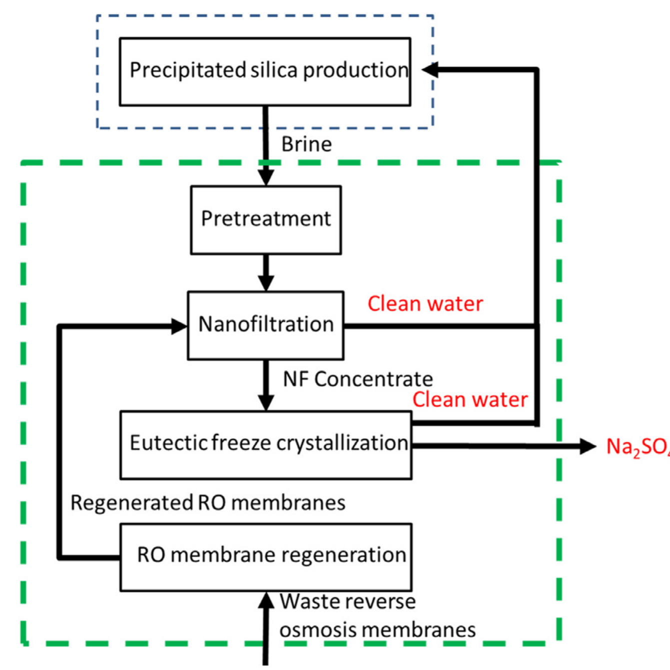

Fig. 2. Zero Brine system for precipitated silica plant, treatment of saline wastewater (brine).

technologies designed to treat the brine resulting from the precipitated silica production. Its technological scheme consists of a pretreatment where pH is modified to precipitate aluminum 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 antiscalant 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.

Poland: coal mine: The Polish case study concerns a coal mine in ZG Bolesław Śmiały. The owner is state-run and the largest

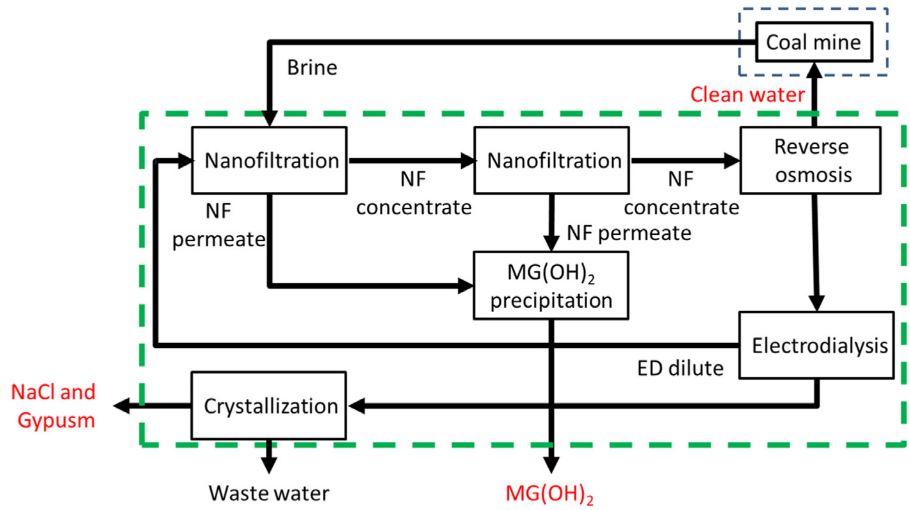

Fig. 3. Zero Brine system for coal mine, treatment of brine.

bituminous coal mining company in Europe producing approximately 30 million tons of bituminous coal per year (total European Union production is approximately 100 million tons) (Polska Grupa Górnicza (PGG), 2019). The coal mine currently discharges approximately 730,000 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, coal mining company plans to decrease the salt load in wastewater. Fig. 3 shows the schematic of the Zero Brine plant, with the unit process technologies in the coal mine. 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, electrodialysis and crystallization, which produces waste water, sodium chloride and gypsum. All recovered products are expected to be sold externally.

Turkey: textile industry: The Turkish case study concerns a textile plant at Büyükkarıştıran-Lüleburgaz, Kırklareli. 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 (Burkinshaw and Salihu, 2018) and considerable amounts are also used in water softening processes (Alekseev, 2018). 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. Fig. 4 shows the schematic of the Zero Brine plant, with the unit process technology configurations for the textile plant. 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.

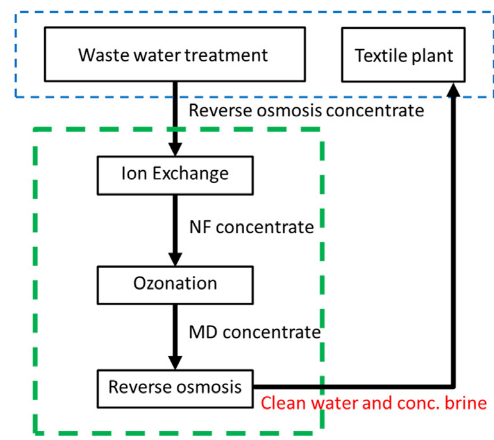

Fig. 4. Zero Brine system for textile plant, treatment of reverse osmosis concentrate (brine).

2.2.2. Inventory analysis of Zero Brine

The inventory data concern SHDB datasets for the commodities needed for the Zero Brine demo plants, and questionnaires with case study companies' representatives. For the hotspot analysis, data was collected based on the supply chains of the relevant commodities (such as equipment). The hotspot analysis started with the selection of the country and commodity class within the SHDB. This study focused on the four case study countries: the Netherlands, Spain, Poland and Turkey, and their imports with respect to needed commodities. Data collection regarding the import of commodities was performed via the Observatory of Economic Complexity (Macro Connections Group, 2018) for 2016. The Observatory of Economic Complexity is a tool that allows users to quickly compose a visual narrative about countries and the products they exchange. The top countries that constitute at least 90% of the imports in US Dollars of the Zero Brine systems' commodities to the Netherlands, Spain, Poland and Turkey were identified. Each commodity's import value is subsequently mapped to relevant country-specific economic sectors on the SHDB 2.1, Update 2016 (Benoit-Noriss et al., 2013; Norris et al., 2012; Norris and Norris, 2015).

The SHDB was developed by New Earth and links economic input/output data from the Global Trade Analysis Project model with labour intensity factors and social indicators of country-specific sectors from reputable international organizations, such as the International Labor Organization, Organization for Economic Co-operation and Development, United Nations Industrial Development Organization, Food and Agriculture Organization, World Bank and World Health Organization. The database consists of social

Table 1
Assumptions made for hotspot analysis for countries that did not exist in SHDB.

Case study	Original countries	Replaced with
Spanish case study	Democratic Republic of Congo	Angola
	Republic of the Congo	Angola
Polish case study	Saudi Arabia	Qatar
	Iraq	Iran
Turkish case study	United Arab Emirates	Qatar
	Tajikistan	Uzbekistan
	Bahrain	Qatar
	Saudi Arabia	Qatar

theme tables which cover 22 themes within five social endpoint impact categories: "Labor Rights and Decent Work", "Health and Safety", "Human Rights", "Governance" and "Community Impacts". The data tables identify social risks for 100 indicators. The ranking of worker hour intensity and the risk levels across multiple social themes for country specific sectors are used to calculate weighted risks using an additive weighting method.

The SHDB covers almost all countries worldwide, however, some of the relevant countries identified did not exist in the SHDB. These were developing countries where high chances of social risks exist, and part of the supply chains for the Spanish, Polish and Turkish case studies. Therefore, it was decided not to exclude them but replace them with neighbouring countries which have similar political regimes and exhibit similar social conditions, as shown in Table 1. For site-specific analysis, data collection was performed using questionnaires distributed to company representatives in the Zero Brine project and corporate social responsibility reports. The questionnaires with replies can be found in Supplementary Material (S1-4).

2.2.3. Impact assessment of Zero Brine

The social life cycle impact assessment (SLCIA) was performed with method V2.00, which is provided in the SHDB package for hotspot analysis, and the Subcategory Assessment Method (SAM) (Ramirez et al., 2014) for site-specific analysis. Table 2 presents the stakeholder groups and social impact categories that were considered in this study based on the two levels of analysis. SLCIA characterization model algorithms based on the distribution of data across the entire population of sectors and countries on the SHDB are classified into quartiles and show how the national sectors compare globally. These quartiles refer to four risk levels, low, medium, high or very high risk, and each risk level is assigned to a weighting factor as presented in Table 3. The weighting factors indicate the relative probability that a negative situation will happen (Norris and Norris, 2015). SAM transforms qualitative data into quantitative data and compares different data types in a standardized manner to arrive at meaningful results. This is achieved with Performance Reference Points (PRPs) which are used as thresholds (e.g. based on international agreements) to understand the magnitude and significance of the collected site-specific data. SAM assesses organizations at four levels (A, B, C or D) for each Social impact category in relation to the fulfilment of PRPs called basic requirements, as presented in Table 3. Furthermore, we added one intermediate level to SAM when no site-specific data could be found to decrease uncertainty. It was decided that "no data" result was assigned the value between B (Organization fulfils the BR) and C (Organization does not fulfil the BR in a negative context) levels.

3. Results and discussion

In this section, the results of the four case studies are presented and analysed based on the hotspot and site-specific analysis levels.

3.1. Trade values of Zero Brine commodities

Figs. 5–8 show the top countries (country codes abbreviations can be found in Table S14 of Supplementary material) that supply at least 90% of the commodity imports per Zero Brine case study. These commodities are presented in groups, based on the SHDB classification and all trade values were converted to 2002 $USD due to SHDB requirements. The full list with all specific commodities, global regions and trade values can be found in the

Table 2
Selected social impact categories per stakeholder group and level of analysis (grouped).

Stakeholder group	Social impact category	Hotspot level	Site-specific level
Society and Local community	Human Rights	X	
	Community Infrastructure	X	
	Local employment		X
	Community engagement		X
	Public commitment to sustainability issues		X
	Contribution to economic development		X
	Access to material resources		X
Society and Value chain actors	Governance	X	
Consumer	Feedback mechanism		X
	Regulation		X
Workers	Labour Rights and Decent Work	X	
	Health and safety	X	X
	Prevention and mitigation of conflicts		X

Table 3
Weighting factors for each risk level for method V2.00 and SAM levels.

Weighting factor	Risk level method V2.00	Weighting factor	SAM levels
10	Very high	D=4	Organization does not fulfil the BR in a positive context
5	High	C=3	Organization does not fulfil the BR in a negative context
1		BC=2.5	No data was found
	Medium	B=2	Organization fulfils the BR
0.1	Low	A=1	Positive and proactive organization behavior

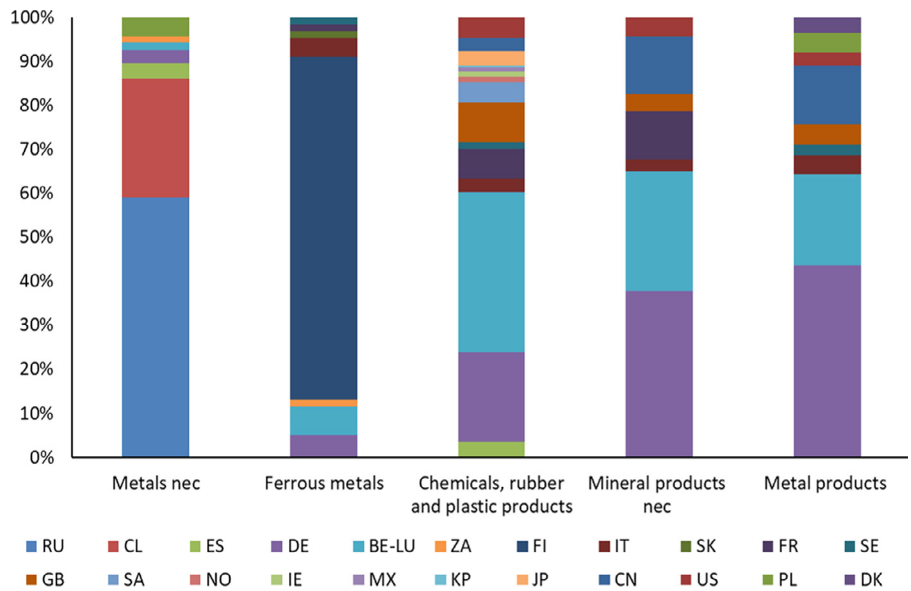

Fig. 5. Relative imports of commodities required for the Dutch Zero Brine system by country of origin.

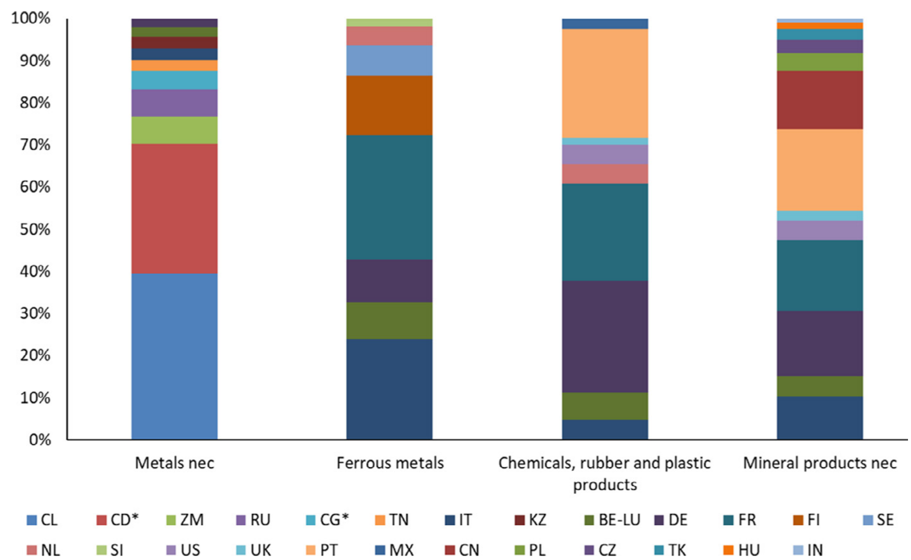

Fig. 6. Relative imports of commodities required for the Spanish Zero Brine system by country of origin.

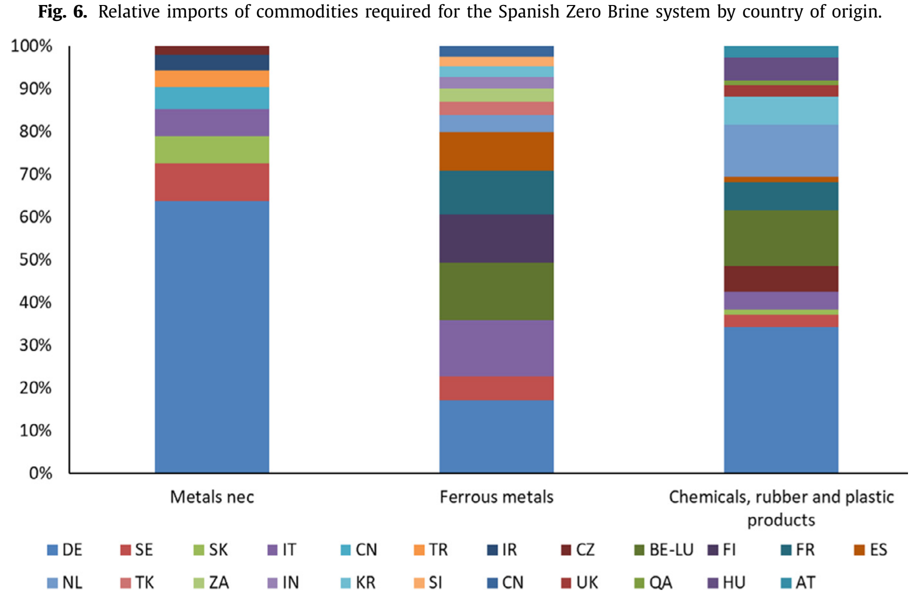

Fig. 7. Relative imports of commodities required for the Polish Zero Brine system by country of origin.

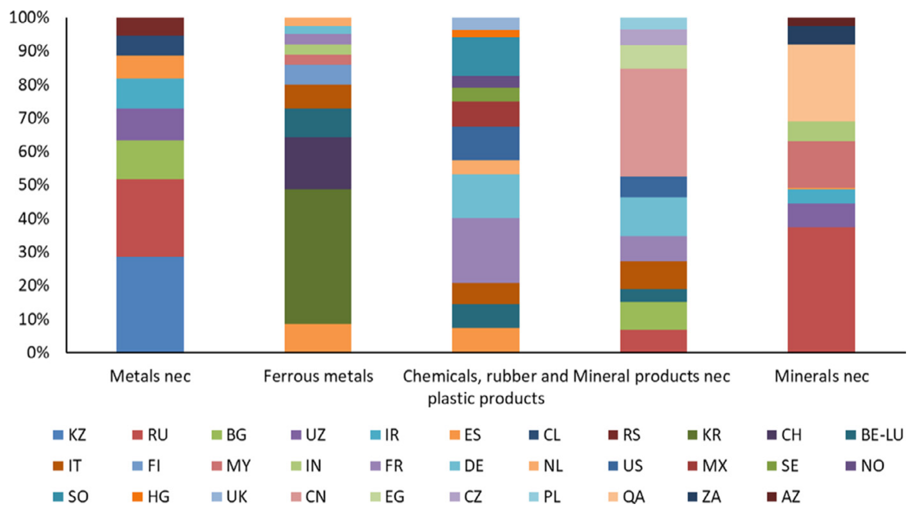

Fig. 8. Relative imports of commodities required for the Turkish Zero Brine system by country of origin.

Supplementary Material (Table S1–4). For the Netherlands, Turkey and Poland case studies, most commodities are imported from other European countries. At least 91% is imported from Europe, including Russia and the United Kingdom, but several commodities are imported from Asian countries (such as China and Japan) as well. Only Spain shows a larger range in imports for the investigated commodities, 76% is imported from Europe (including Russia and the United Kingdom), 9.6% from Asia, 9.6% from America and 4.8% from Africa. African and Asian countries are expected to show higher societal risks than Europe and North America due to less strict regulations. Nevertheless, since the risk of imports is a combination of the country of origin and the amount of imported commodity, the Spanish case study will not necessarily result in larger societal risks than the other case studies.

3.2. Social hotspot analysis of Zero Brine system commodities

Fig. 9 shows the endpoint social indicators results of each case study. A detailed list of all the values used for Fig. 9 can be found in Tables S5–8 of Supplementary material. The *Y*-axis in Fig. 9 is in medium risk hours, which is the number of worker hours along the supply chain that are characterized by a certain social risk. Thus, higher values correspond to higher risks (i.e. more negative performance). The results obtained with the SHDB are a combination of the counties of origin for the imported commodities and the total financial value (in relation to the amount) of commodities that are imported in the four countries. For example, for the Dutch case study the total financial value of "Ferrous metals" that is imported into the Netherlands is two to three orders of magnitude

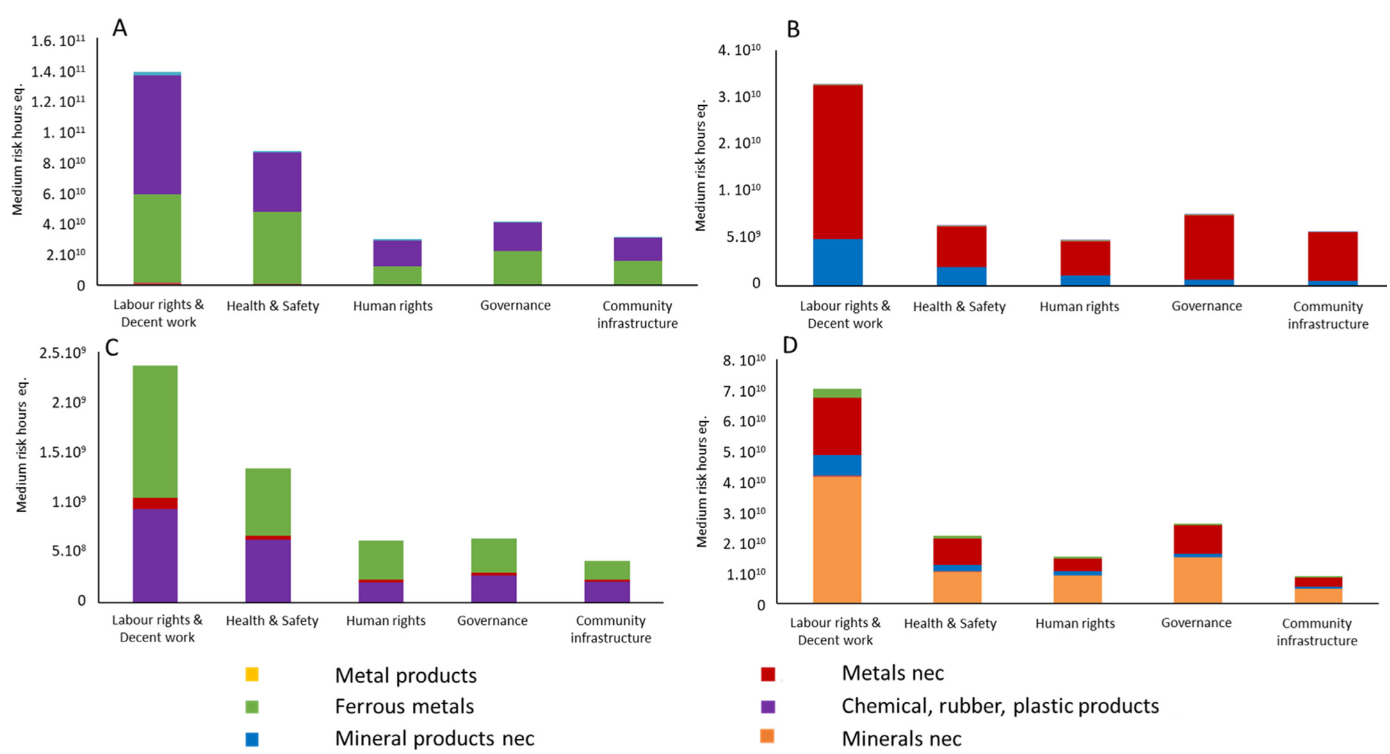

Fig. 9. Endpoint social indicators of case studies, (A) Dutch case study, (B) Spanish case study, (C) Polish case study and (D) Turkish case study.

larger than for the rest commodities. Moreover, 75% of the imported "Ferrous metals" had Finland as the country of origin, Finland dominated the negative social impacts for all endpoint indicators. However, this did not show that Finland is a country of high risk, since a closer look at midpoint indicators shows a moderate contribution between 50% and 75%; except for "Hospital beds" where Finland contributed to 83%.

In general, the "Labor rights and decent work" impact category exhibit the largest risk for each case study, whereas, the "Community infrastructure" resulted in the lowest risk, except for Spain. The large risk presented by "Labor rights and decent work" may be due to consisting of more midpoint indicators than the rest endpoints, whereas, "Community infrastructure" risk was attributed to the social contribution of Angola. In the next paragraphs, endpoint indicators are presented per case study, and all endpoint indicator results by country can be found in the Supplementary material (Tables S5–S8).

The social impacts for the Dutch Zero Brine system is dominated by the two commodities', "Ferrous metals" and "Chemicals, rubber and plastic products". Furthermore, the "Labor rights and decent work" endpoint indicator is the highest and "Health and safety" indicator follows. As mentioned above the financial value of the "Ferrous metals" category which are imported in the Netherlands is much larger than the rest commodity classes. Nevertheless, Finland is dominating the endpoint result and all midpoint indicators results. Concerning "Chemicals, rubber and plastic products", imports from China and Belgium contribute highly. On one hand, the imports from China are not high, representing 3.2% of the total but the midpoint indicators "Collective bargaining" and "Toxics and hazards" result in large risks. On the other hand, the contribution of Belgium is high approximately 37% of total commodity class imports originate from there.

Concerning the Spanish Zero Brine system, we observe something similar as two commodity classes dominate the endpoint results, i.e., "Metals nec" and "Mineral products nec". Furthermore, the "Labor rights and decent work" endpoint indicator is the highest and "Governance" indicator follows. The "Metal nec" class makes a large contribution to all endpoint indicators due to the social risks linked with Angola. Angola was selected because neither the Democratic Republic of Congo nor Republic of the Congo existed in the SHDB, and they both represent in total approximately 42% of Spanish imports for that commodity class. In addition, the contribution of "Mineral products nec" is high which is primarily due to imports from China (approximately 14%) and to a much lesser extent from India (1%). In general, Chinese imports result in a large risk for all midpoint indicators.

In the Polish Zero Brine system, all three considered commodity classes contribute to the endpoint result, but "Ferrous metals" and "Chemicals, rubber and plastic products" dominate the score. Furthermore, the "Labour rights and decent work" endpoint indicator is the highest, followed by "Health and safety". The "Ferrous metals" class has a large contribution primarily due to imports from India and China, even though they represent only approximately 2.7% and 1.9% of imports, respectively. These two countries make a large consistent contribution to all endpoint and midpoint indicators. In particular, India poses significant risks for the "Injuries and fatalities" midpoint indicator. In addition, the high contribution of "Chemicals, rubber and plastic products" class derives from Belgium (approximately 12%), Germany (9.3%), Hungary (5.3%) and South Korea (2.3%). Among these countries Belgium and Germany are consistent in contributing to all endpoint indicators, especially to "Toxics and hazards" and "Collective bargaining" midpoint indicators.

Finally, for the Turkish case study "Minerals nec" and "Metals nec" have a large contribution, with "Mineral products nec" and "Ferrous metals" following. Furthermore, the "Labor rights and decent work" endpoint indicator is the highest and "Health and safety" and "Governance" indicators follow. The "Minerals nec" class large contribution is due to imports from Uzbekistan (in place of Tajikistan) and India. Both countries are not major importers with 7.3% and 7.1%, respectively. However, "Collective bargaining" and "Forced labour" midpoint indicators are hotspots for these two countries. In addition, "Metals nec" contribution is due to Uzbekistan (9%) and Kazakhstan (27%). Even though Uzbekistan is not a major exporter, there are high risks from "Collective bargaining", "Forced labour" and "Poverty" midpoint indicators. On the other hand, Kazakhstan does not pose a risk in these midpoint indicators, but is a major exporter to Turkey.

Our hotspot results are in agreement with Werker et al. (2019) who limited their analysis to working conditions in hydrogen production industry in Spain. They concluded that social impacts derived mainly from upstream global processes, especially in India and China. Overall, labour rights have progressed in China and India but remain significantly lower than in to developed countries (Chan and Hui, 2014; Puddington and Roylance, 2016; Sarkar, 2019).

3.3. Site-specific analysis of Zero Brine systems

Table 4 shows the results for the site-specific analysis based on SAM. Table S13 in Supplementary material exhibits all collected qualitative and (semi)quantitative data before conversion with SAM. Furthermore, all data can be found in Tables S9–12 of the Supplementary material as well. All four case study companies score well in most impact indicators. Furthermore, although they score differently based on the site-specific indicators, the silica plant and DWP result in the same score. The only identified areas which can be improved are the occupational accidents and contribution to the local community. Occupational accident rates are high for the silica plant and coal mine in relation to these sectors' average accidents rates. Furthermore, the coal mine can contribute more to the local community and reduce conflicts over environmental damage at city level, but no serious escalation has occurred. The coal mine currently contributes less than 10% to the local economy, but its contribution to the local community is limited to what they have to pay by law. Another identified negative social impact is the large water consumption of the silica plant. However, this is expected to change the installation of the Zero Brine plant is operational.

In general, more social positive effects were identified than negative. For instance, all case study companies prefer hiring from the local community. However, only the textile plant has developed specific policies to encourage this and is the only company that supports the community with initiatives for education, health and sports. Additionally, in 2007 it also signed the United Nations Global Compact initiative that demonstrates its dedication to improving the social aspects of employment (Zorlu, 2019). Meanwhile, the silica plant, textile plant and DWP publish annual reports on their business, including impacts to the environment (limited to greenhouse gas emissions) and employment figures. Among them, only the DWP is obliged to do so due to national regulations. The DWP could improve on that aspect, and elaborate more on its social and environmental performance. Among the case study companies, the coal mine and textile plant are the biggest contributors to the local economies with a share less than 10% in both cases. This depends not only on the size of the stakeholder, but also to the size of the local economy. For instance, the textile plant contributes approximately 3.9% to the local economy of Istanbul, and Istanbul has a much larger economy than ZG Bolesław Śmiały and Zaragoza. However, the share to the local economy means that an improvement of the social and environmental performance of the

Table 4
Site specific results.

Stakeholder	Impact	Indicator	**Silica plant** (Cano Escario, 2019)	**Coal mine** (Mitko, 2019)	**DWP** (Mulder and van der Broek, 2018)	**Textile plant** (Baban, 2019)
Local community	Local employment	Percentage of workforce hired locally	1	2	2	2
		Employment increase	2	2.5	1	2
		Strength of policies on local hiring preferences (Ramirez et al., 2014)	3	3	3	1
		Percentage of spending on locally based suppliers (Ramirez et al., 2014)	1	2.5	3	1
		Organizational support for community initiatives (UNEP/SETAC Life Cycle Initiative, 2013)	1	3	1	1
	Access to material resources	Water consumption (Eurostat, 2010)	4	1	3	2
Consumer	Feedback mechanism	Presence of feedback mechanisms (UNEP/SETAC Life Cycle Initiative, 2013)	1	1	1	1
	Regulation	Is regulation needed to treat the brine?	1	1	1	1
Worker	Health and safety	Occupational accident rate (Abad et al., 2013; Coleman and Kerkering, 2007)	3	4	1	1
	Prevention and mitigation of conflicts	Does conflict exist between the organization and the workers	2	3	2	2.5
Society	Public commitment to sustainability issues	Applying Corporate Social Responsibility (Global Strategic Alliances, 2019)	1	3	2	1
	Contribution to economic development	Relevance of the involved organization to the (local) economy	3	1	3	2
Total			23	27	23	17.5

textile plant and coal mine will result in a larger impact to the local community than the rest case studies.

On the other hand, only on a few social indicators result in social burdens. For instance, the 20% of water consumption by the silica plant is extremely large for only one organization. Fortunately, participating in the Zero Brine project will improve this aspect. In addition, the “Occupational accident rate” indicator of the coal mine is much larger than the average for the mining sector and “Applying Corporate Social Responsibility” indicator is non-existent. However, regarding the latter, the Corporate Social Responsibility concept is still not well developed in the Polish mining sector. Furthermore, there are recurring conflicts between the workers and management of the coal mine, that occasionally ends with miners clashing with the police. For the DWP and textile plant, no such large relative social impacts were identified.

Site-specific results of this study are partially in agreement with Cadena et al. (2019) who investigated social risks for a bio refinery in the Netherlands. These researchers identified “Occupational health and safety”, “Local community” and “Regulatory compliance” being social hotspots. “Occupational health and safety” is identified only for the plants in Poland and Spain (the latter is most similar industrial plant of our study to a bio refinery) but not for the DWP in the Netherlands. Furthermore, both these plants are treating the local communities well and there is no need for extra permits to be requested in order to treat brine due to regulations.

3.4. Limitations

A major limitation of this study derives from the structure of the SHDB. The database is structured into various classes of commodities, which results in classes that consist of a large number of commodities, and for this study we considered only a few commodities per class. For example, polyethylene, silicone and poly(methyl) methacrylate are part of the class “Chemicals, rubber and plastic products”, but in the same class other commodities exist as well, such as pesticides, activated natural mineral products, etc. In addition, a couple of countries did not exist in the SHDB and were replaced with neighbouring countries with similar political regimes and working conditions. If this assumption is not correct, then the Spanish case study results for imported commodities (Fig. 5(c)) will change considerably due to Angola contributing at least 63% to all endpoint indicators and for “Governance” and “Community infrastructure” approximately 88%. Similarly, but to a lesser extent, Uzbekistan contributes between 6.1% (in “Health and Safety) and 18% (in “Governance”) to the endpoint indicators for the Turkish case study. The use of weighting systems in method V2.00 and SAM also influences the S-LCA results due to weighting inserting uncertainty. Especially, in the case of S-LCA, this is more apparent as weighting is applied on quantitative and qualitative data. The latter is a limitation for all S-LCA studies due to their qualitative nature. Nonetheless, since S-LCA is still in the initial stage of development, there are ongoing research efforts in the field to undertake such methodological challenges.

4. Conclusions

The technical, environmental and economic aspects of brine treatment systems are well addressed in literature. However, the social performance of the industry and brine treatment systems is still missing. This study aims to provide process plant managers with increased knowledge and understanding of social hotspots in the Zero Brine component supply chain to aid corporate social performance.

For instance, the use of the SHDB has identified key hotspots for social risk in each case study. This opens up the prospect to switch the supply of some commodities based on country of origin in order to decrease social risks and impact. Common identified hotspots among the case studies are: China and India, and potentially Democratic Republic of Congo and Republic of the Congo (for which Angola was used as a proxy) and Tajikistan (for which Uzbekistan was used as a proxy). It is apparent that the products derived from these exporting countries are selected by European industries due to their low cost, but recommendations only based on cost is out of the scope of this study.

Using S-LCA at the site-specific level for case studies involving developed countries is expected to result in positive metrics regarding the social performance of the involved case study companies. Developed countries have well developed regulations that require a high level of ethical and social consideration amongst companies that operate within their borders, leading to (mostly) positive social performances. This is true, in general all companies social score is at a good level. Nevertheless, areas of concern were identified with "Water consumption", "Occupational accidents rate" and "Organizational support for community initiatives" indicators. The former will depend on the type of sector and national laws. Whereas the latter depends (in most cases) explicitly to initiatives taken from organizations. Companies that recruit from the local community should be encouraged to invest in the local communities (through not only jobs, but skills development, education, investing in local communities landscape, etc.) more if they aim at improving their social sustainability.

Therefore, we recommend the involved case study companies to consider the following in their decision-making:

I. All companies should aim to purchase equipment for the Zero Brine systems from suppliers globally which promote social equality or developed countries with strict environmental, social and ethical regulations if possible.
II. The Dutch DWP and Turkish textile plant systems do not result in negative SAM level = 4, and therefore no specific suggestions are made on a company level. For instance, it is out of the scope of this study to identify ways for the DWP to improve its positive effect on the local economy.
III. The Spanish silica plant should aim to further reduce the accident rate, which is minimally higher than the Spanish chemical industry average, to improve its social sustainability profile.
IV. The coal mine company should focus on reducing occupational accidents and developing a stronger a stronger interaction with the local community, such as environmental, educational and skills development initiatives. Both social indicators score relatively low. Integration of a corporate social responsibility strategy into operations would provide structure for the suggested actions and improvements.

In summary, we recommend the use of hotspot analysis to identify risks in the supply chains of the companies and the use of site-specific analysis to identify social behaviours impacts. Suggestion for further suggested work includes the use of the SHDB with operating expenses and life cycle costing data to investigate avoided social burden or identified social benefits due to the replacement of existing commodities with the recovered products from the Zero Brine systems.

Declaration of Competing Interest

The authors declare that there is no conflict of interest.

Acknowledgements

This work is carried out in the framework of the H2020 European project "ZeroBrine" – project no. 730390. The authors thank Jan Willem Mulder and Wilbert van den Broek from Evides Industriewater, Dr. Miguel Cano from Groupo IQE, Dr. Ahmet Baban from TUBITAK Scientific and Technological Research Council of Turkey who was the intermediary with Zorlu Textiles, Dr. Krzysztof Mitko from Silesian University of Technology who was the intermediary with PGG Coal, for the interviews. Furthermore, the authors thank Edoardo Bologna from Lenntech, Dr. Dimitris Xevgenos from Sealeau, Dr. Andrea Cipollina from University of Palermo, Xavier Martinez from Eurecat Technology centre, Argyris Panagopoulos from National University of Athens and Nigel Brown from Arvia Technology Limited for their contribution on the commodities used in the designed Zero Brine systems. Lastly, the authors would like to than the three anonymous reviewers and the editor their suggestions that led to improvements of this manuscript our manuscript.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.spc.2020.02.003.

References

Abad, J., Lafuente, E., Vilajosana, J., 2013. An assessment of the OHSAS 18001 certification process: Objective drivers and consequences on safety performance and labour productivity. Saf. Sci. 60, 47–56. https://doi.org/10.1016/j.ssci.2013.06.011.
Alekseev, E.V., 2018. Waste from water softening stations for treatment wastewater containing dyes. Mater. Sci. 949–953. doi:10.4028/www.scientific.net/MSF.931.949, Forum 931 MSF.
Baban, B., 2019. Personal communication with Ahmet Baban. TUBITAK, Turkey.
Benoît, C., Norris, G.A., Valdivia, S., Ciroth, A., Moberg, A., Bos, U., Prakash, S., Ugaya, C., Beck, T., 2010. The guidelines for social life cycle assessment of products: Just in time!. Int. J. Life Cycle Assess 15, 156–163. https://doi.org/10.1007/s11367-009-0147-8.
Benoît, C., Norris, G.A., Valdivia, S., Ciroth, A., Moberg, A., Bos, U., Prakash, S., Ugaya, C., Beck, T., 2010. The guidelines for social life cycle assessment of products: just in time!. Int. J. Life Cycle Assess. 15, 156–163. doi:10.1007/s11367-009-0147-8.
Benoit-Noriss, C., Norris, G., Cavan, D.A., 2013. Social hotspots database – supporting documentation.
Bourguignon, D., 2016. Circular economy package. Four legislative proposals on waste (No. PE 573 . 936). EPRS | European Parliamentary Research Service.
Brundtland, G.H., 1987. Report of the World Commission on Environment and Development: Our Common Future. United Nations Comm. (No. 4. 300).
Burkinshaw, S.M., Salihu, G., 2018. The role of auxiliaries in the immersion dyeing of textile fibres: part 10 the influence of inorganic electrolyte on the wash-off of reactive dyes. Dyes Pigments 149, 652–661. doi:10.1016/j.dyepig.2017.11.034.
Cadena, E., Rocca, F., Gutierrez, J.A., Carvalho, A., 2019. Social life cycle assessment methodology for evaluating production process design: Biorefinery case study. J. Clean. Prod. 238, 117718. doi:10.1016/j.jclepro.2019.117718.
Cano Escario, M., 2019. Personal communication with Miguel Cano Escario. IQE, Spain.
Chan, C.K.-C., Hui, E.S.-I., 2014. The development of collective bargaining in China: from "Collective bargaining by riot" to "Party state-led wage bargaining". China Q. 217, 221–242. doi:10.1017/S0305741013001409.
Clift, R., Sim, S., King, H., Chenoweth, J., Christie, I., Clavreul, J., Mueller, C., Posthuma, L., Boulay, A.-M., Chaplin-Kramer, R., Chatterton, J., DeClerck, F., Druckman, A., France, C., Franco, A., Gerten, D., Goedkoop, M., Hauschild, M.Z., Huijbregts, M.A.J., Koellner, T., Lambin, E.F., Lee, J., Mair, S., Marshall, S., McLachlan, M.S., Milà i Canals, L., Mitchell, C., Price, E., Rockström, J., Suckling, J., Murphy, R., 2017. The challenges of applying planetary boundaries as a basis for strategic decision-making in companies with global supply chains. Sustainability 9.
Coleman, P.J., Kerkering, J.C., 2007. Measuring mining safety with injury statistics: Lost workdays as indicators of risk. J. Safety Res. 38, 523–533. https://doi.org/10.1016/j.jsr.2007.06.005.
European Commission, 2014. Report on critical raw materials for the EU. Report of the Ad hoc Working Group on defining critical raw materials (No. Ref. Ares(2015)1819503). Ref. Ares(2015)1819503.
Eurostat, 2010. Share of industrial categories in the total water use in industry (%).
Fontes, J., 2016. Handbook for Product Social Impact Assessment. Roundtable for Social Metrics. Version 3.0. PRé Sustainability.
Global Strategic Alliances, 2019. Global Reporting Initiative [WWW Document]. URL https://www.globalreporting.org/Pages/default.aspx (accessed 8.21.19).
Jones, E., Qadir, M., van Vliet, M.T.H., Smakhtin, V., Kang, S., 2019. The state of desalination and brine production: a global outlook. Sci. Total Environ. 657, 1343–1356. doi:10.1016/j.scitotenv.2018.12.076.
Jørgensen, A., 2013. Social LCA – a way ahead? Int. J. Life Cycle Assess. 18, 296–299. doi:10.1007/s11367-012-0517-5.

Keijer, T., Bakker, V., Slootweg, J.C., 2019. Circular chemistry to enable a circular economy. Nat. Chem. 11, 190. doi:10.1038/s41557-019-0226-9.
Kolsch, D., Saling, P., Kicherer, A., Sommer, A.G., Schmidt, I., 2008. How to measure social impacts? A socio-eco-efficiency analysis by the SEEBALANCE® method. Int. J. Sustain. Dev. 11, 1. doi:10.1504/IJSD.2008.020380.
Lehmann, A., Zschieschang, E., Traverso, M., Finkbeiner, M., Schebek, L., 2013. Social aspects for sustainability assessment of technologies - Challenges for social life cycle assessment (SLCA). Int. J. Life Cycle Assess. 18, 1581–1592. https://doi.org/10.1007/s11367-013-0594-0.
Macro Connections Group, 2018. OEC: the observatory of economic complexity. The world's leading visualization engine for international trade data [WWW Document]. URL https://atlas.media.mit.edu/en/ (accessed 4.4.19).
Mathe, S., 2014. Integrating participatory approaches into social life cycle assessment: The SLCA participatory approach. Int. J. Life Cycle Assess. 19, 1506–1514. https://doi.org/10.1007/s11367-014-0758-6.
Micari, M., Cipollina, A., Tamburini, A., Moser, M., Bertsch, V., Micale, G., 2019. Combined membrane and thermal desalination processes for the treatment of ion exchange resins spent brine. Appl. Energy 254. doi:10.1016/j.apenergy.2019.113699.
Mitko, K., 2019. Personal communication with Krzysztof Mitko. Silesian University of Technology, Poland.
Mulder, J.W., van der Broek, W., 2018. Personal communication with J.W. Mulder and W. van der Broek. Manager process and technology at Evides Industriewater B.V., the Netherlands.
Norris, C.B., Aulisio, D., Norris, G.A., 2012. Working with the social hotspots database – methodology and findings from 7 social scoping assessments. In: Proceedings of the Leveraging Technology for a Sustainable World – Proceedings of the Ninteenth CIRP Conference on Life Cycle Engineering, pp. 581–586.
Norris, C.B., Norris, G.A., 2015. Chapter 8: The Social Hotspots Database Context of the SHDB, 200th ed. Sustain. Pract. Guid. Soc. Anal. Assess.
Petti, L., Serreli, M., Di, C., 2018. Systematic literature review in social life cycle assessment. Int. J. Life Cycle Assess. 23, 422–431. doi:10.1007/s11367-016-1135-4.
Polska Grupa Górnicza (PGG), 2019. Polska grupa górnicza S.A. [WWW Document]. URL https://www.pgg.pl/en (accessed 7.3.19).
Puddington, A., Roylance, T., 2016. Anxious Dictators, Wavering Democracies: Global Freedom under Pressure. Freedom House, Washington, DC.
Ramirez, P.K.S., Petti, L., Haberland, N.T., Ugaya, C.M.L., 2014. Subcategory assessment method for social life cycle assessment. Part 1: methodological framework. Int. J. Life Cycle Assess. 19, 1515–1523. doi:10.1007/s11367-014-0761-y.
Roskill, 2018. Salt – Market Report.
Sajid Hussain, I., 2012. Case study of a zero liquid discharge facility in textile dyeing effluents at Tirupur.
Sarkar, S., 2019. How independent is India's labour law framework from the state's changing economic policies? Econ. Labour Relat. Rev. 30, 422–440. doi:10.1177/1035304619863550.
Sediyi, V.M., 2006. Environmental balance of salt production speaks in favour of solar saltworks. In: Proceedings of the First International Conference on Ecological Importance of Solar Saltworks, Santorini, p. 9.
Sureau, S., Mazijn, B., Garrido, S.R., Achten, W.M.J., 2018. Social life-cycle assessment frameworks: a review of criteria and indicators proposed to assess social and socioeconomic impacts. Int. J. Life Cycle Assess. 23, 904–920. doi:10.1007/s11367-017-1336-5.
Travesi, B., 2010. IQE amplía su capacidad productiva casi un 40% con su nueva planta de aditivos. heraldo.es.
Tsalidis, G.A., Korevaar, G., 2019. Social Life Cycle Assessment of Brine Treatment in the Process Industry: a Consequential Approach Case Study. Sustainability 11, 5945. doi:10.3390/su11215945.
Turek, M., 2004. Electrodialytic desalination and concentration of coal-mine brine. Desalination 162, 355–359. doi:10.1016/S0011-9164(04)00069-4.
UNEP/SETAC Life Cycle Initiative, 2013. The methodological sheets for subcategories in social life cycle assessment (S-LCA).
UNEP/SETAC Life Cycle Initiative, 2009. Guidelines for social life cycle assessment of products. social and socio-economic LCA guidelines complementing environmental LCA and life cycle costing, contributing to the full assessment of goods and services within the context of sustainable development. UNEP/SETAC Life Cycle Initiat.
United Nations General Assembly, 2005. Resolution A/60/1 adopted by the general assembly. 2005 World Summit Outcome (No. 05-48760).
US EPA, 2014. National pollutant discharge elimination system (NPDES) [WWW document]. US EPA. URL https://www.epa.gov/npdes (accessed 11.25.18).
Warren, J.K., 2016. Evaporites: A Geological Compendium, 2nd ed. Springer International Publishing.
Weidema, B., 2005. ISO 14044 also applies to social LCA. Int. J. Life Cycle Assess. 10, 381. https://doi.org/10.1065/lca2005.11.002.
Werker, J., Wulf, C., Zapp, P., 2019. Working conditions in hydrogen production: a social life cycle assessment. J. Ind. Ecol. 23, 1052–1061. doi:10.1111/jiec.12840.
Xevgenos, D., Michailidis, P., Dimopoulos, K., Krokida, M., Loizidou, M., 2015. Design of an innovative vacuum evaporator system for brine concentration assisted by software tool simulation. Desalination Water Treat. 53, 3407–3417. doi:10.1080/19443994.2014.948660.
Xevgenos, D., Moustakas, K., Malamis, D., Loizidou, M., 2016. An overview on desalination & sustainability: renewable energy-driven desalination and brine management. Desalination Water Treat. 57, 2304–2314. doi:10.1080/19443994.2014.984927.
Zero Brine, 2017. ZERO BRINE Project [WWW Document]. ZERO BRINE. URL https://zerobrine.eu/ (accessed 7.4.19).
Zorlu, 2019. History | Zorlu [WWW Document]. URL http://www.zorlu.com.tr/en/corporate/history (accessed 7.5.19).