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Project Number	**LIFE15 ENV/IT/000332**

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PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
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Social Assessment of the full scale LIFE BITMAPS plant

1. Introduction

This report concerns the social assessment of the innovative technology developed within the BITMAPS - "Pilot technology for aerobic biodegradation of the TMAH photoresist solution used in the semiconductor industries" - project, in the framework of the LIFE European Program.

The project is aimed at demonstrating the biodegradability of TMAH (Tetramethylammonium hydroxide) through a pilot process for the treatment of industrial and civil wastewater from the LFoundry Srl production plant. The innovative process, capable of recycling a quite large amount of treated wastewater in a circular manner, also implements water saving measures to reduce the quantitative and qualitative pressures on water bodies.

The report is structured as follows: the next section illustrates the background of the scientific literature concerning the social assessment of wastewater treatment technologies. The specific objectives of the study, the methodology used, the boundaries of the system analyzed, the data collected, the impacts detected are then described. The results obtained are finally analyzed and discussed.

2. Literature review

Methodologies for the assessment of social impacts are still in the research phase. Social life Cycle Assessment (S-LCA) is a methodology used to assess the social and socioeconomic (the word “social” here covers both social and socioeconomic impacts) impacts of products and/or processes along their life cycle from the extraction of raw materials to the final disposal of waste (cradle to grave approach).

In order to conduct a socio-economic analysis, it is useful to make a review of what the literature proposes in this field.

The questions carried out in the search of the literature were as follows:

- Have any S-LCA studies been conducted on industrial wastewater treatment (WWT) or, more in general, in WWTs?
- Have social aspects been assessed in the S-LCA case-studies on WWTs? Through which methodology?
- Have any specific indicators been used to evaluate the social aspects of a WWT in all the S-LCA studies carried out?

The inclusion criteria were: any study on WWT that included the assessment of social aspects; studies published between 2009 and 2019.The exclusion criteria were: grey literature, duplicate studies, conference papers, the papers by the same authors on the same subject and the works not written in English.

The period of time chosen for the literature analysis (2009-2019) is because 2009 is the year in which the S-LCA guidelines were published.

For this purpose, Scopus, a database of scientific articles and abstracts created in 2004 by the publisher Elsevier, was consulted. The search topics were included in the Title-Abstract-Keyword box. Table 1 shows the words entered and the Boolean operators used.

Table 1- Keywords and Boolean operators used in the literature search

Social AND life AND cycle AND assessment AND waste AND water AND treatment	68 results
Social AND life AND cycle AND assessment AND "liquid waste"	1 result
Social AND life AND cycle AND assessment AND "wastewater"	96 results
"Social life cycle assessment" AND "wastewater treatment"	6 results
"social assessment" AND "waste water treatment"	0 results
"social assessment" AND "wastewater treatment"	4 results
"social aspects" AND assessment AND "wastewater treatment"	16 results
"social indicator" AND "wastewater treatment"	5 results
"social indicator" AND "wastewater treatment" AND assess	3 results
"social indicator" AND industry AND "wastewater treatment"	0 results

The most representative results are those obtained from the following searches: "Social life cycle assessment" AND "wastewater treatment"; "social assessment" AND "wastewater treatment".

The results that answer the research question and fit the research criteria are shown in table 2.

Table 2 - Analyzed papers for the literature review

Environmental and social life cycle assessment of urban water systems: The case of Mexico City	Garcia-Sanchez, Guereca 2019
A proposal metrics for sustainability evaluations of wastewater treatment system (SEWATS)	Padilla-Rivera, Guereca 2019
Novel macroalgae (seaweed) biorefinery systems for integrated chemical, protein, salt, nutrient and mineral extractions and environmental protection by green synthesis and life cycle sustainability assessment	Sadhukhan, Gadkari, Martinez-Hernandez, Torres-Garcia, Lynch 2019
Sustainability assessment of sludge and biogas management in wastewater treatment plants using the LCA technique	Amaral, Mansur Aisse, Collere, Possetti 2019
Sustainability criteria for assessing nanotechnology applicability in industrial wastewater treatment: Current status and future outlook	Kamali, Persson, Costa, Capela 2019
Social hotspot analysis and trade policy implications of the use of bioelectrochemical systems for resource recovery from wastewater	Shemfe, Gadkani, Sadhukhan 2018
A comparative social life cycle assessment of urban domestic water reuse alternatives	Opher, Shapira, Friedler 2018
Multi-criteria group decision-making based sustainability measurement of wastewater treatment processes	Ren, Liang 2017

Life cycle assessment (LCA) of urban water infrastructure: emerging approaches to balance objectives and inform comprehensive decision- making	Byrne, Lohman, Cook, Peters, Guest 2017
Multicriteria assessment of advanced treatment technologies for micropollutants removal at large-scale applications	Bui, Vo, Ngo, Guo, Nguyen 2016
Addressing social aspects associated with wastewater treatment facilities	Padilla-Rivera, Morgan-Sagastume, Noyola, Güereca 2015
Assessment of wastewater treatment alternatives for small communities: An analytic network process approach	Molinos-Senante, Gómez, Caballero, Hernández-Sancho, Sala-Garrido 2015
Assessing the sustainability of small wastewater treatment systems: A composite indicator approach	Molinos-Senante, Gómez, Garrido-Baserba, Caballero, Sala-Garrido 2014
Decision support in disinfection technologies for treated wastewater reuse	Gòmez-Lòpez, Bayo, Garcìa-Cascales, Angosto 2009

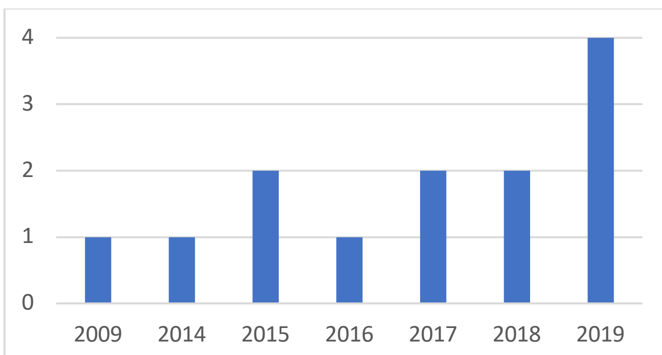


Fig 1 – Time distribution of the case studies within inclusion criteria

The low number of works found suggests that, as regards WWT, although considerable progress has been made on technologies, only few studies have evaluated the social consequences of the WWT processes. Given the limited results, the selected papers were analyzed one by one.

Garcia-Sanchez et al. (2019), by conducting an analysis of S-LCA on the WWT of Mexico city, considering only workers as stakeholders, obtained the best social performance average in the wastewater treatment phase with a very good rating, while the worst social performance was observed for storage. They concluded that, although the methodological guidelines of UNEP-SETAC (2009) define the impact categories for the different social actors, application in water systems would still require a specific methodology involving social actors, impact categories and relevant indicators for the decision-making process, as well as the integration of dynamic interactions between environmental, social and economic impact.

Padilla-Rivera et al. (2019) propose a useful metric to decide which is the best wastewater treatment from an environmental, social and economic point of view. In selecting the appropriate indicators, they considered that, up to now, the social focus of research on wastewater has been twofold: the first focus has been on epidemiological aspects and possible negative effects on health. The second focus has been on the social and anthropological aspects of wastewater use, mainly linked to irrigation. Another concern has been the role that institutions play in wastewater management. Therefore, they decided to consider the following indicators and stakeholders:

- Community and society: public participation, local employment, safe and healthy living conditions;
- Workers: working hours, fair salary, training, health and safety;
- Consumers: feedback mechanism;
- Supply chain: promoting social responsibility.

Sadhukhan et al (2019) proposes the use of macroalgae growing as a more sustainable option for wastewater treatment. In this case study a S-LCA was conducted with the help of the Social Hotspots Database (SHDB), the same database used by Shemfe et al. (2018) in the analysis of the sustainability of bioelectrochemical systems (BES), catalogued as a technological solution for three urgent global challenges: environmental pollution, scarcity of resources and scarcity of fresh water. Finally, this study positively assessed the results obtained from the analysis carried out with SHDB, on BES.

Amaral et al. (2019) used the Dashboard of Sustainability (DoS) (Traverso et al., 2012) method to evaluate the sustainability of four different scenarios for the treatment and final destination of biological sludge and biogas in a medium-sized wastewater treatment plant (WWTP) in South

Brazil. DoS converts the data into a single sustainability indicator, weights all the indicators for the same scale and represents them in mathematical or graphical form.

Kamali et al. (2019) assess the sustainability of the application of engineered nanomaterials for the treatment of industrial effluents. In this case, the social indicators used are odor, noise, visual impacts, public acceptance

In the paper by Opher et al. (2018) the benefits and social impacts of four alternative approaches to the re-use of non-potable domestic urban water are compared: (1) central WWT, no urban re-use, the recovery water is discharged into nature, (2) central WWT and urban re-use of the tertiary effluent of the WWTP, (3) semi-distributed grey water treatment and its re-use, (4) distributed gray water treatment and its re-use within each apartment building.

The selected tool of subcategories and indicators useful for evaluating them, are listed below.

• Public Water saving / Equity

• Local Community/ Community engagement / Local employment / Urban landscape

• Consumers Health Concerns (Level of contact with the reclaimed water, Source of the reclaimed water, Trust in supplier), Household expenses, Convenience

As for the case study, the re-use of distributed urban water resources was socially beneficial, both in terms of promoting public commitment for the conservation of natural water resources and promoting community commitment.

Ren and Liang (2017) propose a method to help decision-makers in choosing the most sustainable WWT among different processes, the social criteria used are related to the public acceptability of the plants, for the jobs created by the plants and from the policy supports, i.e. fiscal support and policy/regulation support.

Byrne et al. (2017) conducted a review to describe the state of the art for LCA applied to urban water infrastructure. They identified 22 studies in the water systems of different cities in the world and only two (Kobayashi et al., 2015; Sharma et al., 2009) assessed the social dimension without using S-LCA and without including the stakeholder Workers. The remaining 20 case studies focused only on the assessment of environmental impacts and, in three cases, of economic impacts.

Bui et al. (2016) used multicriteria analysis to assess micropollutants treatment methods using full scale and pilot-scale studies; the social indicator used was public acceptance of different treatment methods.

Padilla-Rivera et al. (2015) used 25 indicators as a framework for measuring social performance to evaluate and compare two different WWT in Mexico at both urban and rural locations.

Molinos-Senante et al. (2014-2015) propose to use analytic network process or to elaborate a composite indicator useful to favor the evaluation of various types of WWT. In reference to this, they consider the following indicators: odors, noise, visual impact, public acceptance, complexity. The authors want to select the most appropriate WWT technology because it is a complex problem as many alternatives are available and many criteria are involved in the decision-making process.

Gòmez-Lòpez et al. (2009) aimed to select the best methodologies concerning the disinfection of treated wastewater before reusing, and as a social indicator the authors considered the enterprise image.

Table A, in supplementary material, summarizes the methodology applied, the involved stakeholders and the social indicators used for each case studies.

From the analysis of the 14 papers using S-LCA or having assessed social aspects in WWT, the following considerations can be made:

- The analysis of the literature has not shown any element useful to draw methodological conclusions, the S-LCA studies are very few and among these, nobody evaluates an industry's WWT.
- In wastewater treatment facilities (WWTF), technical and financial aspects have been considered a priority, while other issues, such as social aspects, have not been completely evaluated and there is no systematic methodology for their assessment.

- At present, the majority of research focuses on finding the most economically and environmentally sustainable method for wastewater treatment. Furthermore, the social aspects have been considered almost exclusively in studies that deal with the treatment of wastewater from civil plants, although it is evident that the greatest problems for humans arise from wastewater from industries and agriculture (UN Water).
- From 2009 to 2015 (figure 1) only two case studies were found, in this period the assessment of the sustainability of WWT systems mainly considered environmental and economic aspects and the social aspects evaluated, concerned the external physical aspects of the WWT that determined public acceptance. Most of the analised studies are from 2015 to 2019.
- Therefore, the case study we are dealing with is absolutely innovative, and has no precedent known to us

3. Goal of the study

The aim of this study is to assess the socio-economic aspects of the wastewater treatment technologies used to control the pollution arising from the production of semiconductors carried out in the LFoundry facilities located in Avezzano (Italy).

4. Methodology

This study was carried out by using PSILCA v 2.0 (Product Social Impact Life Cycle Assessment), a comprehensive database developed by Green-Delta GmbH in Berlin, available in the open source LCA software openLCA (www.openlca.org). The database uses Eora as its

Global Input/output Model and provides information for 189 countries and almost 15.000 different sectors. The sectors are divided into industries and commodities.
Social indicators are structured in a manner similar to the structure outlined in the Guidelines for Social Lifecycle Assessment of Products (UNEP/SETAC, 2009).
PSILCA uses worker-hours as its activity variable in order to quantify the impacts of a process along its life cycle, although the addition of further variables is currently being analyzed.
65 qualitative and quantitative indicators are provided in the PSILCA database. They are measured in different units such as single values or percentages; some are also qualitative. The indicators are organized in clusters describing 19 social and socio-economic subcategories inspired by UNEP/SETAC (2009). In order to make indicator results comparable across countries and different sectors, the PSILCA database provides all indicator values as "intensive" values. For intensive indicators, the value is independent of the system size (size of the sector or economy density for example).
The indicators are quantified in medium risk hours, hours with average risk that a given social issue occurs.
The subcategories address five stakeholder categories: workers, local community, society, consumers and value chain actors.

5. Scope of the study

5.1 Functional unit

The LIFE BITMAPS plant treats three different kinds of wastewater, with different treatment needs. The social assessment is consistent with the environmental Life Cycle Assessment (LCA) conducted on the pilot plant, the full scale and the current management.
The functional unit used for the analysis is the same as that chosen for the LCA, i.e. the current annual generated amounts for each kind of wastewater considered, as specified below:

1) 6300 t of wastewater with TMAH and photoresist (line 1);
2) 435 t of wastewater with NH_4F (BOE) (line 2);
3) 145 t of wastewater with nitrates, fluorides, phosphoric acid and acetic acid (SEZ) (line 3).

5.2 System boundaries

The system boundaries were also defined consistently with the environmental LCA study (figure 2).

In the current management option, the wastewater with TMAH and photoresist is treated internally (ion exchange and neutralization) and then managed by external companies. While, the other two types of wastewater are not currently treated within the LFoundry facilities but are sent as hazardous wastewater to external companies for treatment.

As regards the plant with LIFE BITMAPS innovative processes, the system boundaries include, for line 1, sulfuric acid and biological treatments. While for the other two lines, a precipitation and a filtration were included. Finally, a treatment in a biological reactor for all the three lines is included.

In principle, for the comparison between the full-scale system with LIFE BITMAPS technology and the current system to be meaningful, the overall social impacts generated by both systems should be assessed. To that aim, as regards the current system, also the processes carried out by the companies currently treating the wastewater (for line 2 BOE and line 3 SEZ) should be included in the system boundaries. However, for consistency reasons, the system boundaries of this study are the same as those of the environmental LCA study and, therefore, as regards the current system, they include only transportation to the external companies that treat wastewater.

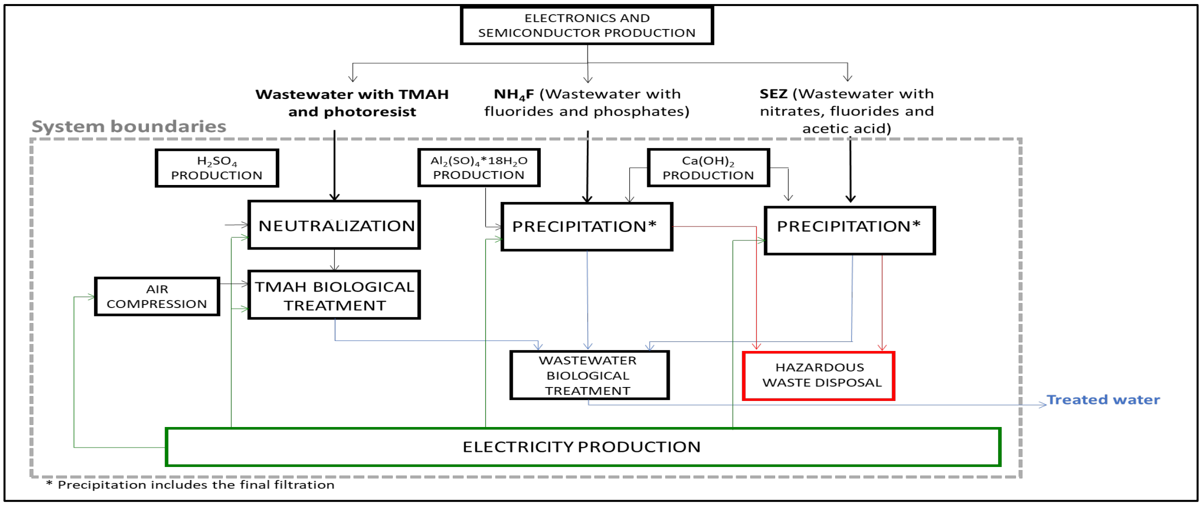


Figure 2 – LIFE BITMAPS system boundaries for LCA and S-LCA (source: Report about the Life Cycle Assessment of the full scale LIFE BITMAPS plant)

5.3 Assumptions

The material inputs shown in table 3 were entered in PSILCA as economic value and were provided by the company.

The economic value of all the inputs has been converted from euro to USD using a deflator into USD 2011, as the current version of PSILCA is based on USD 2011 ($1.2939).

6. Inventory Analysis

6.1 Full scale plant, data collection

The data required by the PSILCA database to model the product systems are: input materials, their origin, the Eora MRIO database category, the total cost of each input material and the working hours needed for the 3 WWT.

The product systems modelled on PSILCA are the three wastewater lines of the LIFE BITMAPS full scale plant.

Table 3 summarizes the input data, their country of origin and the Eora sector category for the full scale LIFE BITMAPS plant. All data and estimates were provided by the company.

Table 3 - Input data, origin, Eora sector category for the three lines of wastewater treated within the full scale LIFE BITMAPS innovative processes

Material	Input (tons per year)	Originating from	Eora sector
Wastewater with TMAH and photoresist			
Wastewater	6300 t	Italy	Waste Flow
Sulfuric acid (98%)	23.62 t	Italy	Chemicals, chemical products and man-made fibres (commodities)
Water	55.12 t	Italy	Collection, purification and distribution of water (commodities)
Electricity	630000 kWh	Italy	Electrical energy, gas, steam and hot water (commodities)
Wastewater with fluorides and phosphates NH_4F (BOE)			
Wastewater	435 t	Italy	Waste Flow
Lime	102.6 t	Italy	Chemicals, chemical products and man-made fibres (commodities)
Water	410.25 t	Italy	Collection, purification and distribution of water (commodities)
$Al_2(SO_4)_3$ *$18H_2O$	17.4 t	Italy	Chemicals, chemical products and man-made fibres (commodities)
Electricity	7500 kWh	Italy	Electrical energy, gas, steam and hot water (commodities)
Wastewater with nitrates, fluorides and acetic acid (SEZ)			
Wastewater	145 t	Italy	Waste Flow
Lime	33.95 t	Italy	Chemicals, chemical products and man-made fibres (commodities)
Water	135.7 t	Italy	Collection, purification and distribution of water (commodities)
$Al_2(SO_4)_3$ *$18H_2O$	5.8 t	Italy	Chemicals, chemical products and man-made fibres (commodities)
Electricity	2500 kWh	Italy	Electrical energy, gas, steam and hot water (commodities)

7. Life cycle impact assessment

7.1 Characterization

For each process, the risk-assessed indicators are represented as elementary flows, "characterised" by the activity variable. For the time being, all indicators use worker hours as activity variable, i.e. the time workers spend to produce a certain amount of product in the given process or sector. Activity variables are necessary to describe the relevance of impacts caused by a process in a life cycle. They "reflect the share of a given activity associated with each unit process" (UNEP/SETAC 2009, p. 98) thereby quantifying the corresponding social indicators related to the product system.
The amount of worker hours is calculated in relation to 1 USD output for each process and has, therefore, the same amount for each risk-assessed indicator, within a process.

$$\textbf{Worker hours} = \frac{unit\ labour\ cost}{mean\ hourly\ labour\ cost}$$

The unit labour cost is the compensation of employees per 1 USD output within a sector.
Table 4 shows the stakeholders, the subcategories and all indicators in PSILCA (the 36 indicators used to assess the three lines of wastewater in the LIFE BITMAPS plant are highlighted in light blue) as well as the risk level of each indicator.
The assignment of risk levels to the indicators was carried out by consulting various databases (Istat, Ministero del Lavoro e delle Politiche Sociali, Wage indicator org, ILOSTAT, OECD, WHO,..) and specific literature, referring to Italy or to Europe, to better reflect the specific goal and scope of the study.
For the remaing indicators the risk levels were entered as "no data"; and analyzed by the database with a value equal to very low risk. The impacts included in the final results concerning the "no data" indicators refer to the supply chain.

Table 4 - Stakeholders, subcategories and indicators in the PSILCA database

Stakeholder	Subcategory	Indicator	Risk level
Workers	CHILD LABOUR	Children in employment, male	
		Children in employment, female	
		Children in employment, total	No risk
	FORCED LABOUR	Goods produced by forced labour	
		Frequency of forced labour	Very low risk
		Trafficking in persons	
	FAIR SALARY	Living wage, per month	Very low risk
		Minimum wage, per month	Very low risk
		Sector average wage, per month	Very low risk
	WORKING TIME	Weekly hours of work per employee	Medium risk
	DISCRIMINATION	Women in the sectoral labour force	Medium risk
		Men in the sectoral labour force	Very low risk
		Gender wage gap	Medium risk
	HEALTH AND SAFETY	Rate of non-fatal accidents at workplace	Very low risk
		Rate of fatal accidents at workplace	Very low risk
		DALYs due to indoor and outdoor air and water pollution	Low risk
		Presence of sufficient safety measures	Medium risk
		Workers affected by natural disasters	Low risk
	SOCIAL BENEFITS, LEGAL ISSUES	Social security expenditures out of the total GDP	Very low risk
		Evidence of violations of laws and employment regulations	Very low risk
	FREEDOM OF ASSOCIATION	Trade union density	Low risk
		Right of association	
		Rigth of collective bargaining	
		Right to strike	No risk
Value chain actors	FAIR COMPETITION	Presence of anti-competitive behaviour or violation of anti- trust and monopoly legislation	Low risk
	CORRUPTION	Public sector corruption	Low risk
		Active involvement of the enterprises in corruption and bribery	Low risk
	PROMOTING SOCIAL RESPONSIBILITY	Social responsibility along the supply chain	
Society	CONTRIBUTION TO ECONOMIC DEVELOPMENT	Contribution of the sector to economic development	Low Opportunity
		Public expenditure on education	

Society	CONTRIBUTION TO ECONOMIC DEVELOPMENT	Adult illiteracy rate (15+ years), male	
		Adult illiteracy rate (15+ years), female	
		Adult illiteracy rate (15+ years), total	
		Youth illiteracy rate, male	
		Youth illiteracy rate, female	
		Youth illiteracy rate, total	
	HEALTH AND SAFETY	Health expenditure, total	Medium risk
		Health expenditure, public	Low risk
		Health expenditure, out-of-pocket	Medium risk
		Health expenditure, external resources	Very low risk
		Life expectancy at birth	No risk
Local community	ACCESS TO MATERIAL RESOURCES	Level of industrial water use (related to total withdrawal)	Very low risk
		Level of industrial water use (related to actual renewable resources)	Very low risk
		Extraction of biomass (related to area)	
		Extraction of biomass (related to population)	
		Extraction of fossil fuels	
		Extraction of industrial and construction minerals	
		Extraction of ores	
		Certified environmental management systems (CEMs)	Low risk
	RESPECT OF INDIGENOUS RIGHTS	Presence of indigenous population	
		Human rights issues faced by indigenous peoples	
	SAFE AND HEALTHY LIVING CONDITIONS	Pollution level of the country	Medium risk
		Drinking water coverage	Very low risk
		Sanitation coverage	No risk
	LOCAL EMPLOYMENT	Unemployment rate in the country	Medium risk
	MIGRATION	International migrant workers in the sector	
		International migrant stock	
		Net migration rate	Low risk
Consumers	TRANSPARENCY	Presence of business practices deceptive or unfair to consumers	Low risk

7.2 Impact Assessment Method

In order to express impacts in an aggregated form for the entire supply chain, PSILCA used an impact assessment method (Social Impacts Weighting Method) that assigns characterization factors to the different impact categories per sector, previously assessed on an ordinal scale. The final results are then expressed in relation to the medium risk level as medium risk hours per impact category. The characterization factors used in the PSILCA impact assessment method, are typically divided into 6 different levels distinguished on a scale: no risk, very low risk, low risk, medium risk, high risk, and very high risk.

8. Results

Figure 3 show the results referred to 1 m^3 of treated wastewater, and highlights that the line 1 with TMAH generates lower social impacts than the other two lines.

The greatest impact observed in all three lines concerns the public sector corruption impact category. This indicator is measured by the Corruption Perceptions Index (Transparency International 2012); corruption normally refers to public institutions or governments and can affect daily life. In this case study it comes from the electricity and the chemical sectors, despite the risk assessment assigned was “very low risk”.

The other impact categories affected are (figure 3 and figure B, in supplementary materials):

- “Social responsibility along the supply chain”; the relevant indicator examines to what extent the social responsibility is taken seriously and assured by companies within specific sectors.
- “Contribution to environmental load”; this indicator measures the emissions of different gases and chemical compounds into air per sector and, therefore, a sector´s contribution to environmental pollution, global warming and, finally, health risks. It is evaluated for 6 emissions (table 4) that have negative impacts on the environment. in this case study they refer to the supply chain of the sectors involved.

- "Certified environmental management systems"; this indicator assesses the number of certified environmental management systems (EMS) per sector, in relation to the number of employees in the same sector.
- "Sanitation coverage"; populations with lower sanitation coverage are exposed to a higher risk of infectious diseases and epidemics, assuming that low access to improved sanitation facilities is accompanied by lower water treatment rates the indicator also provides information about general water quality.
- "Trade union density"; this indicator serves to assess how liberal and vivid a trade union culture is, and, in the end, to what degree the right to organize freely is assured in different sectors.
- "Industrial water depletion"; this indicator wants to assess the level of industrial water use, i.e. the quantity of freshwater, desalinated water and treated wastewater withdrawn for industrial purposes related to total water withdrawal (for agricultural, industrial and municipal use) and to total actual renewable water resources.

The positive impact of the indicator "Contribution of the sector to economic development" is very significant. This indicator assesses to what extent a sector contributes to the economic development of the country. It is measured as the monetary contribution to a country´s Gross Domestic Product (GDP). This is the first indicator determined to measure positive impacts on the society.

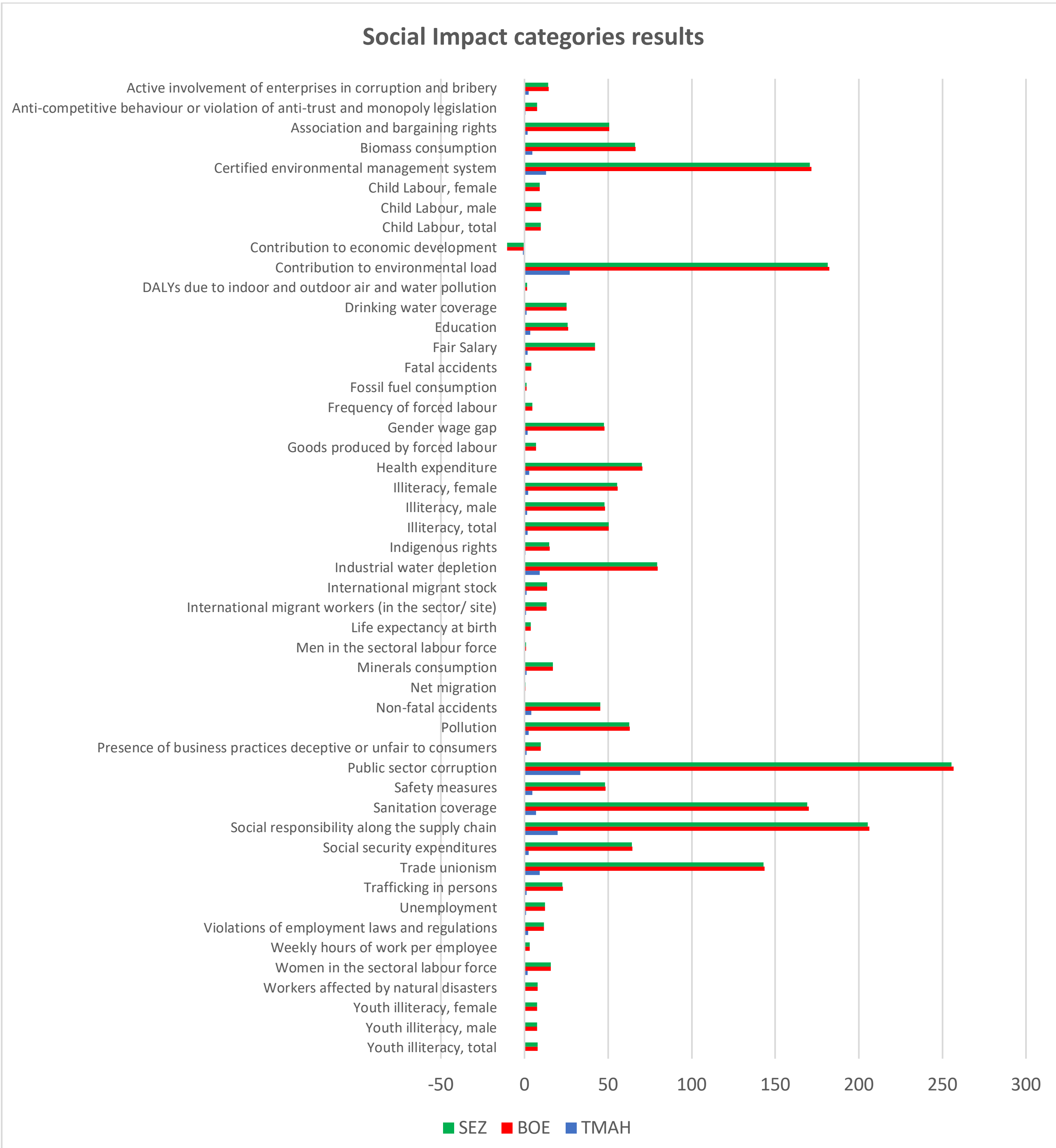
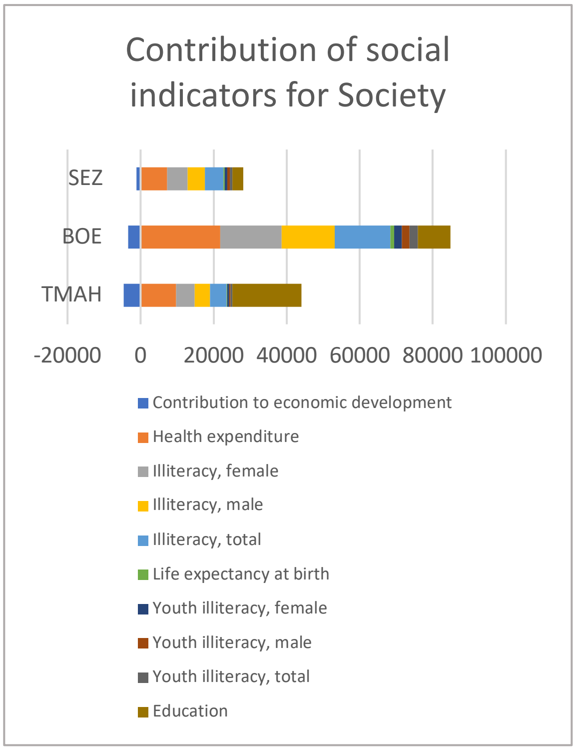
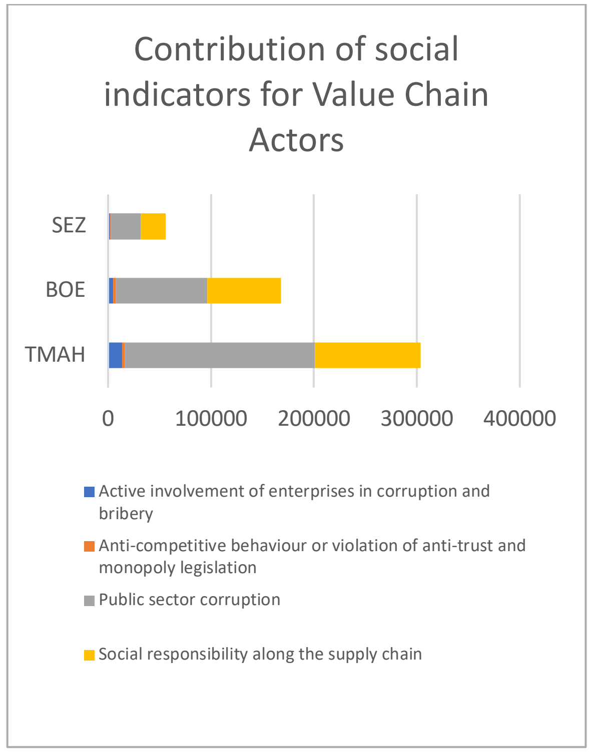
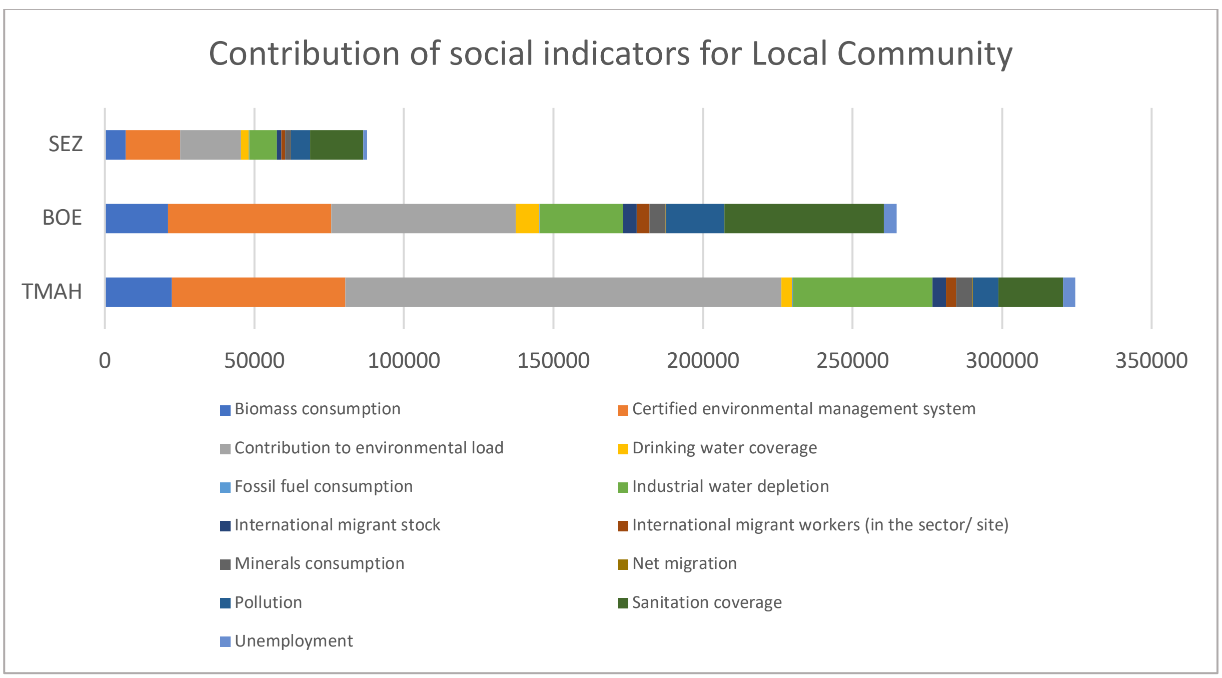


Figure 3 - Social impacts generated by the 3 water treatment lines of the LIFE BITMAPS system per m^3 of wastewater treated


Contribution of social indicators for Society
SEZ
BOE
TMAH
-20000
0
20000
40000
60000
80000
100000
Contribution to economic development
Health expenditure
Illiteracy, female
Illiteracy, male
Illiteracy, total
Life expectancy at birth
Youth illiteracy, female
Youth illiteracy, male
Youth illiteracy, total
Education


Contribution of social indicators for Value Chain Actors
SEZ
BOE
TMAH
0
100000
200000
300000
400000
Active involvement of enterprises in corruption and bribery
Anti-competitive behaviour or violation of anti-trust and monopoly legislation
Public sector corruption
Social responsibility along the supply chain


Contribution of social indicators for Local Community
SEZ
BOE
TMAH
0
50000
100000
150000
200000
250000
300000
350000
Biomass consumption
Certified environmental management system
Contribution to environmental load
Drinking water coverage
Fossil fuel consumption
Industrial water depletion
International migrant stock
International migrant workers (in the sector/ site)
Minerals consumption
Net migration
Pollution
Sanitation coverage
Unemployment

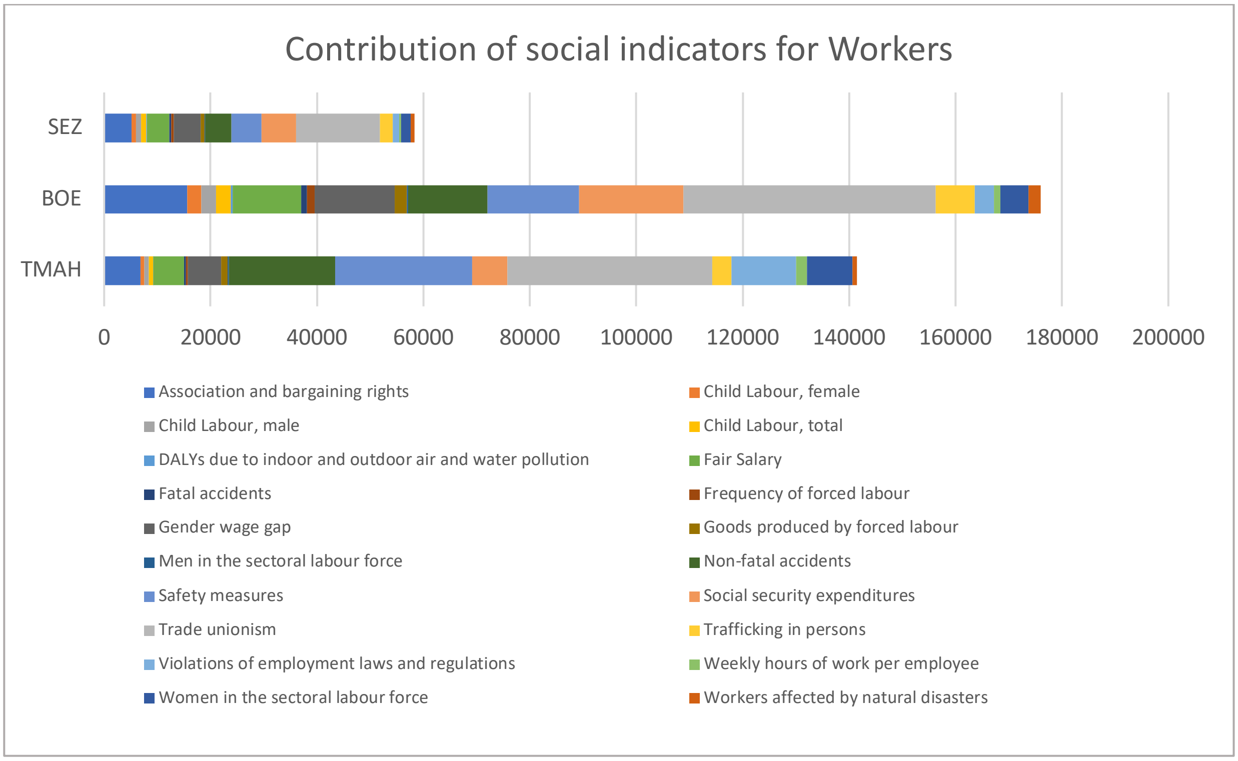


Figure 4 - Relative contribution to social indicators in the stakeholders Society, Value Chain Actors, Workers and Local Community considered for line 1 TMAH, line 2 BOE and line 3 SEZ processes (Functional unit: annual generation of wastewater, 6300 t TMAH, 435 t BOE, 145 t SEZ)

The results of the PSILCA analysis for stakeholders show that the most affected group is the local community (figures 4).

The impacts on "Local Communities" are mainly generated by: contribution to environmental load, certified environmental management system and the use of industrial water. These indicators have negative impacts on the environment, even though they are here considered for their associated health risks.

Social implications for workers across the three lines show a high vulnerability concerning the protection of workers gender inequality, the safety measures and the amount of working hours.

Figure 5 shows that the direct contribution from the TMAH line to the impact category “contribution to environmental load” is very low (0.041%), compared to the indirect (upstream sectors) one (97.37%). The risk is spread throughout the supply chain, according to the results of our analysis from the 3 WWT lines with LIFE BITMAPS technology; this means that most of the overall risk derives from upstream sectors supplying the TMAH, BOE and SEZ processes.

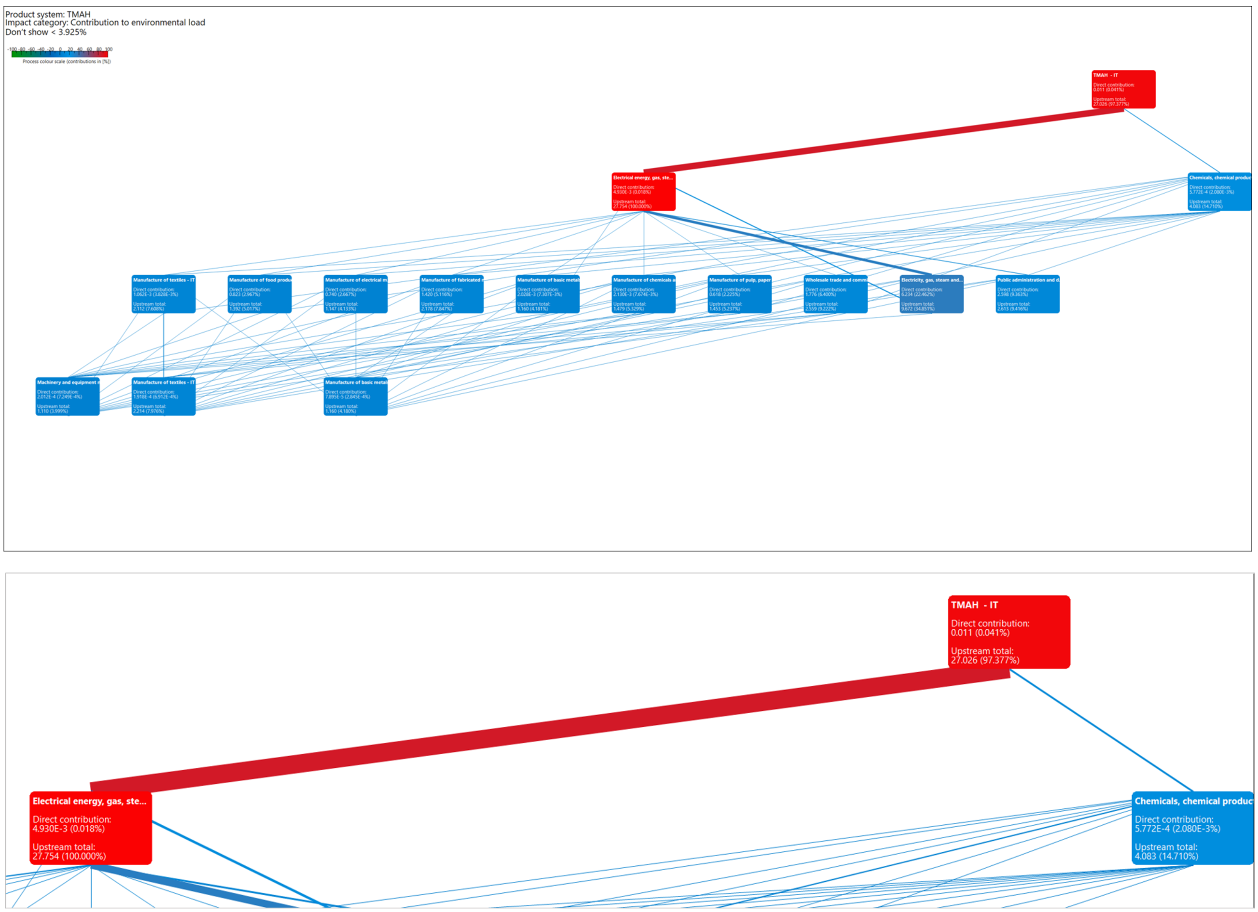


Figure 5 – Sankey diagram for TMAH line, overall structure and zoom. The figure shows the contribution of the different Country Specific Sector to the overall risk in the social impact category "contribution to environmental load".

9. Conclusions

The comparison between the current management and the LIFE BITMAPS plant would certainly have allowed us to appreciate the difference between the social impacts. To do this, external companies had to be included in the system boundaries.

The most meaningful social impacts concern aspects related to the supply chain, however it is necessary to highlight the presence of a positive impact, related to sectors that contribute to the economic development of the country.

The S-LCA analysis accounts for the contribution of all the upstream phases of the supply chain The fact that most of the social risks are to be detected especially in the sectors providing inputs to WWT with LIFE BITMAPS technology shows the significant analytical capacity of the life-cycle analysis and pointed out the country-sectors and locations that are mostly contributing to the risk. The high share of indirect impact confirms the importance of a life cycle-based approach to understanding and managing social risk, in global supply chain.

References

Amaral K.G.C.; Aisse M. M., Possetti G. R. C., 2019, Sustainability assessment of sludge and biogas management in wastewater treatment plants using the LCA technique. Rev. Ambient. Água, vol.14, n.5, e2371. ISSN 1980-993X

Bui, XT, Vo, T. P. T, Ngo, H. H, Guo, W. S, Nguyen, T. T, 2016, Multicriteria Assessment of Advanced Treatment Technologies for Micropollutants Removal at Large-Scale Applications, Science of The Total Environment in press; vol. 563-564, pp. 1050-1067

Byrne, D. M., Lohman, H. A., Cook, S. M., Peters, G. M., & Guest, J. S. (2017). Life cycle assessment (LCA) of urban water infrastructure: emerging approaches to balance objectives and inform comprehensive decision-making. Environmental Science: Water Research & Technology, 3(6), 1002-1014

Eisfeldt, F., Ciroth, A. (2017). PSILCA—A Product Social Impact Life Cycle Assessment database. Database version 2. Berlin: GreenDelta GmbH

Franze J, Ciroth A, 2011, A comparison of cut roses from Ecuador and the Netherlands. Int. J. Life Cycle Assess. 16:366–379

García-Sánchez M, Güereca LP, 2019, Environmental and social life cycle assessment of urban water systems: The case of Mexico City, Science of The Total Environment, vol. 693, p. 133464

Gómez-López MD, Bayo J, García-Cascales MS, Angosto JM, Decision support in disinfection technologies for treated wastewater reuse, Journal of Cleaner Production 17 (16), 1504-1511

Guest, J.S., Cook, S.M., 2017. Life cycle assessment (LCA) of urban water infrastructure: emerging approaches to balance objectives and inform comprehensive decision- making. Environ. Sci.: Water Res. Technol. 3 (6), 1002–1014

Kamali M, Persson KM, Costa ME, Capela I, 2019, Sustainability criteria for assessing nanotechnology applicability in industrial wastewater treatment: Current status and future outlook, Environ Int. 2019 Apr;125:261-276

Molinos-Senante M, Gómez T, Caballero R, Hernández-Sancho F, Sala-Garrido R, 2015. Assessment of wastewater treatment alternatives for small communities: an analytic network process approach. Sci. Total Environ. 532, 676–687

Molinos-Senante M, Gómez T, Garrido-Baserba M, Caballero R, Sala-Garrido R, 2014 Assessing the sustainability of small wastewater treatment systems: a composite indicator approach. Sci Total Environ.; 607-617

Opher T, A Shapira, Friedler E, 2017, A comparative social life cycle assessment of urban domestic water reuse alternatives, The International Journal of Life Cycle Assessment 23 (6), 1315-1330

Opher T, Shapira A, Friedler E, 2018, A comparative social life cycle assessment of urban domestic water reuse alternatives, The International Journal of Life Cycle Assessment; Dordrecht Vol. 23, Fasc. 6, 1315-1330

Padilla-Rivera A, Morgan-Sagastume JM, Güereca-Hernández LP, 2019. Sustainability assessment of wastewater systems: an environmental and economic approach. J. Environ. Prot. (Irvine, Calif). 10, 241–259

Padilla-Rivera A, Morgan-Sagastume JM, Noyola A, Güereca LP, 2016. Addressing social aspects associated with wastewater treatment facilities. Environ. Impact Assess. Rev. 57, 101–113

Ren J, Liang H, 2017, Multi-criteria group decision-making based sustainability measurement of wastewater treatment processes, Environmental Assessment Review, vol 65 p91-99

Sadhukhan J, Gadkari S., Martinez-Hernandez E., Ng KS, Shemfe B, Torres Garcia E, Lynch J, 2019, Novel macroalgae (seaweed) biorefinery systems for integrated chemical, protein, salt, nutrient and mineral extractions and environmental protection by green synthesis and life cycle sustainability assessments, Green Chemistry 21:2635

Shemfe M.B., Gadkari S., Sadhukhan M., Social Hotspot Analysis and Trade Policy Implications of the Use of Bioelectrochemical Systems for Resource Recovery from Wastewater, Sustainability 2018, 10(9), 3193

Traverso M, Finkbeiner M, Jorgensen, Schneider L, 2012, Life Cycle Sustainability Dashboard, Journal of Industrial Ecology 16(5):680–688

UN Water https://www.unwater.org/water-facts/quality-and-wastewater/ accessed 02/03/2020

UNEP/SETAC, 2009. Guidelines for social life cycle assessment of products. http://www.unep.org/pdf/DTIE_PDFS/DTIx1164xPA-guidelines_sLCA.pdf, accessed 10/02/2020

UNEP/SETAC, 2013. The methodological sheets for subcategories in social life cycle assessment (S-LCA). http://www.lifecycleinitiative.org/wp-content/uploads/2013/11/S- LCA_methodological_sheets_11.11.13.pdf, accessed 14/02/2020

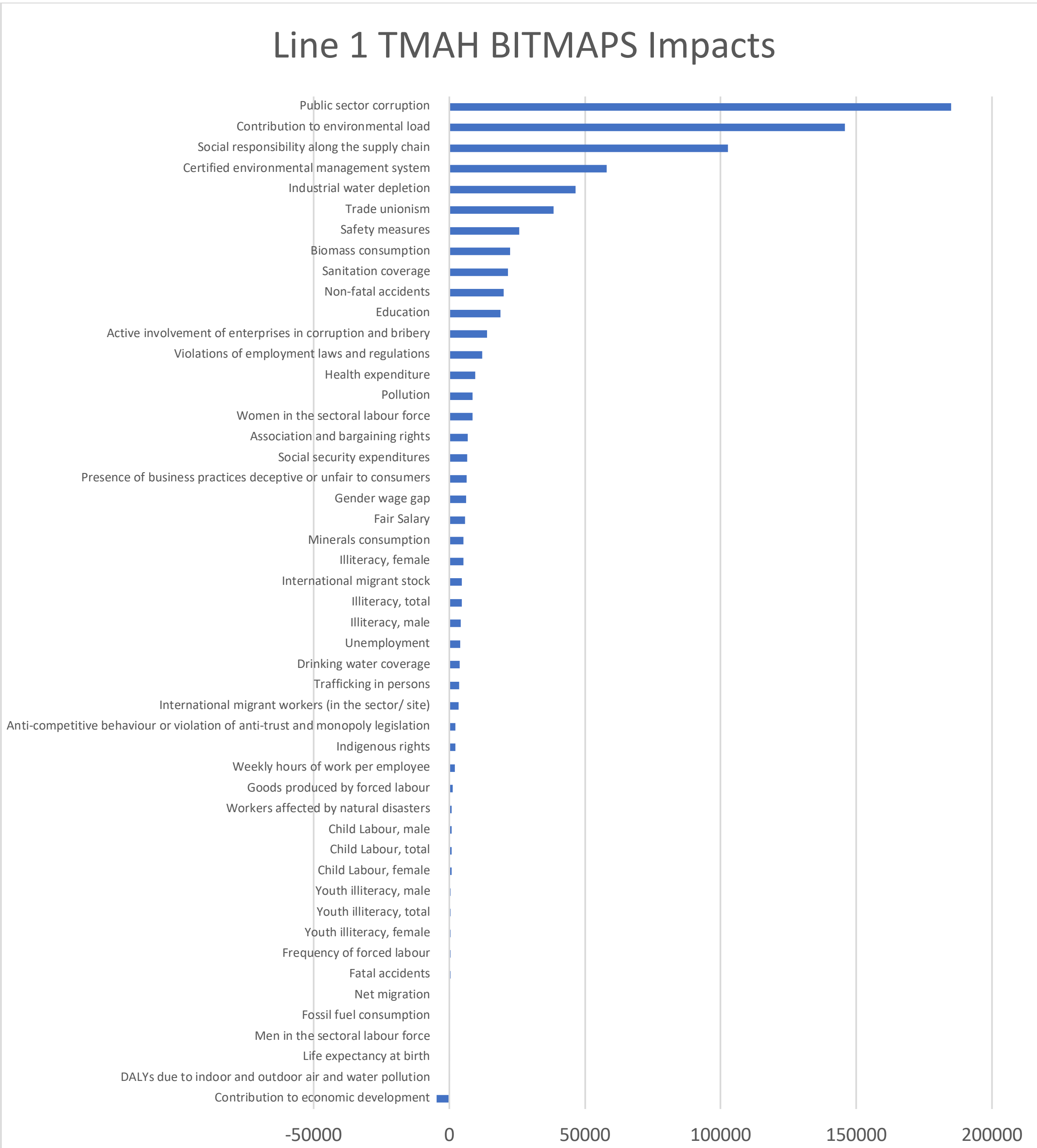
SUPPLEMENTARY MATERIALS

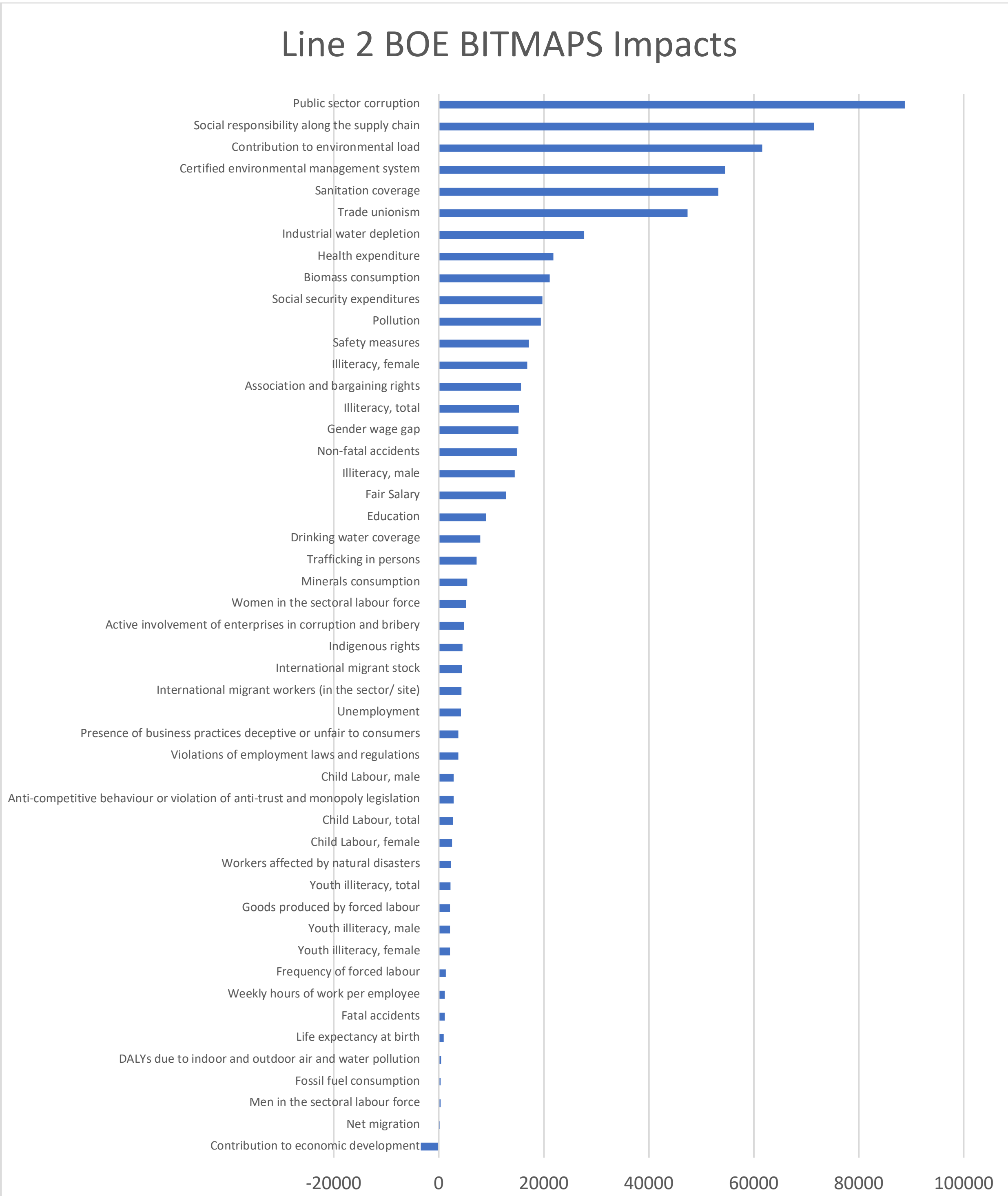
Table A – Literature review results – Authors, methodology applied, involved stakeholders and social indicators used.

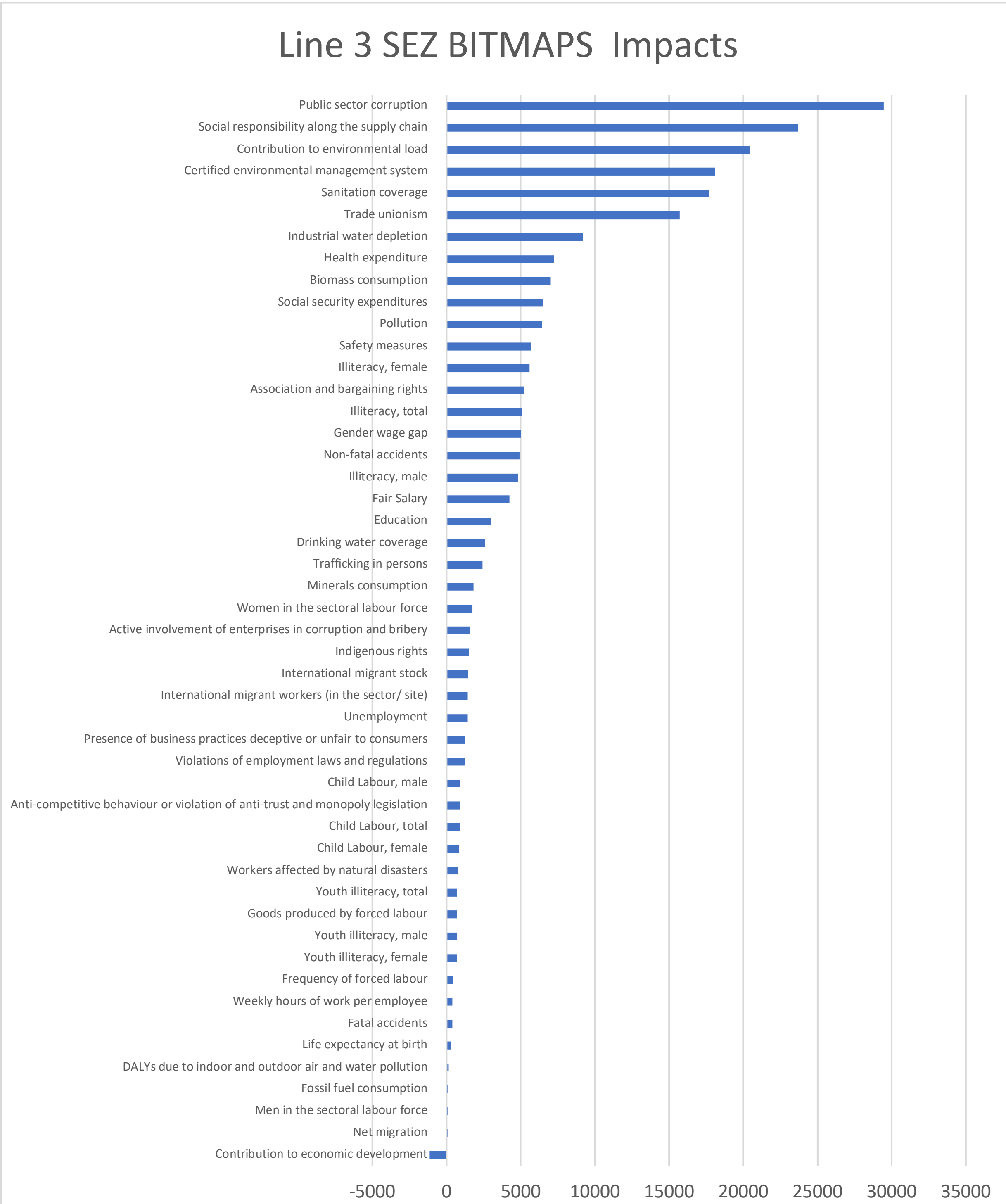
Authors	Methodology applied	Stakeholder involved	Indicators
Garcia-Sanchez et al. (2019)	S-LCA (method developed by Franze Ciroth 2011)	workers	working hours fair wage health and safety conditions (Exposure to risks in the facility, Basic requirements for installation security, Personal safety equipment Work accidents, Emergency plans, Health) social security (social benefits) professional development (training)
Padilla-Rivera, Güereca (2019)	S-LCA Subcategory Assessment Method (SAM) The methodology evaluates indicators that were developed using different sources of data: questionnaires, household interviews and observations, based on a previous identification of the relevant stakeholders involved in WWTF. Transforming qualitative information into quantitative data (1 to 4; with 1 being the worst and 4 the best assessment)	Community and society Workers Consumers Supply chain	(public participation, local employment, safe and healthy living conditions) (working hours, fair salary, training, health and safety) (feedback mechanism) (promoting social responsibility
Sadhukhan et al. (2019)	S-LCA Social Hotspots Database (SHDB)	no	labour rights & decent work health & safety human rights governance community infrastructure
Amaral et al. (2019)	S-LCA Subcategory Assessment Method (SAM) An adaptation of the methodologies described by Ramirez *et al.* (2014), Zortea *et al.* (2017) and Padilla-Rivera *et al.* (2016) was used for the assessment of social impacts	Workers Consumers local community and society	Wages paid to workers, Noise level, Odor emission (H_2S and NH_3) Values of pathogens present in sludge, Noise level, Odor emission Biological risks Ability to generate employment Use of hazardous chemicals Biological risks (bacteria, fungi, viruses) N and P content in the sludge Capacity to generate employment
Kamali et al. (2019)	Fuzzy-Delphi method	50 experts from 19 countries	Odor, noise, visual impacts, public acceptance

Shemfe et al (2018)	S-LCA SHDB	Workers Workers and society Society and local community Society and value chain actors Society and local community	Labour rights and decent work (child labour, forced labour, excessive working time, Poverty, Wage assessment, Migrant labour, Wage assessment, Collective bargaining, Inadequate social benefits) Health and safety (injuries and fatalities, toxics and hazards) Human rights (indigenous rights, gender equity, high conflict) Governance (legal system, corruption) Community infrastructure (drinking water, improved sanitation, hospital beds)
Opher et al. (2018)	S-LCA AHP (analytical hierarchy process)	Public Local Community Consumers	(Water saving/ Equity) (Community engagement/ Local employment/ Urban landscape) Health Concerns (Level of contact with the reclaimed water, Source of the reclaimed water, Trust in supplier); Household expenses; Convenience (supply reliability, Consumption habits)
Ren, Liang (2017)	Multi-criteria group decision-making	Researchers Administrators Local residents	Social-political (public acceptability, added jobs, governmental support)
Bui et al. (2016)	Multicriteria assessment	all relevant stakeholders (public, scientists, practitioners, politicians)	Public acceptance of the different methods
Padilla-Rivera et al. (2015)	S-LCA (Franze Ciroth 2011)	Community and society Workers Consumers Supply chain	(public participation, social acceptance, community engagement, sustainable behavior, local employment; safe, healthy and secure living conditions, public committements to sustainable issues, contribution to economic development) (freedom a f association and collective bargaining, child labour, working hours, fair salary, equal opportunities/discrimination, training, health and safety, availability of WWM documentation, Management performance, monitoring program) (effluent quality, demand satisfaction, health a nd safety, feedback mechanism, consumer satisfaction) (fair competition, supplier relationship, promoting social responsibility)
Molinos-Senante et al. (2015)	Analytic network process (ANP) Multi-criteria decision-making	experts from the academic, research and industrial fields	odors, noise, visual impact, public acceptance, complexity of construction, operation
Molinos-Senante et al. (2014)	Composite indicator	Standard stakeholders (decision makers, experts, planners and analysts involved in preparing and managing the process)	odors, noise, visual impact, public acceptance, complexity of construction, operation
Gòmez-Lòpez, Bayo, Garcia-Cascales, Angosto (2009)	Multicriteria decision making	Experts and decision makers	Enterprise image

Figure B - Results by social impact category of the LIFE BITMAPS plant three lines (Functional unit: annual production of wastewater, 6300 t TMAH, 435 t BOE, 145 t SEZ)




Line 2 BOE BITMAPS Impacts
Public sector corruption
Social responsibility along the supply chain
Contribution to environmental load
Certified environmental management system
Sanitation coverage
Trade unionism
Industrial water depletion
Health expenditure
Biomass consumption
Social security expenditures
Pollution
Safety measures
Illiteracy, female
Association and bargaining rights
Illiteracy, total
Gender wage gap
Non-fatal accidents
Illiteracy, male
Fair Salary
Education
Drinking water coverage
Trafficking in persons
Minerals consumption
Women in the sectoral labour force
Active involvement of enterprises in corruption and bribery
Indigenous rights
International migrant stock
International migrant workers (in the sector/ site)
Unemployment
Presence of business practices deceptive or unfair to consumers
Violations of employment laws and regulations
Child Labour, male
Anti-competitive behaviour or violation of anti-trust and monopoly legislation
Child Labour, total
Child Labour, female
Workers affected by natural disasters
Youth illiteracy, total
Goods produced by forced labour
Youth illiteracy, male
Youth illiteracy, female
Frequency of forced labour
Weekly hours of work per employee
Fatal accidents
Life expectancy at birth
DALYs due to indoor and outdoor air and water pollution
Fossil fuel consumption
Men in the sectoral labour force
Net migration
Contribution to economic development
-20000
0
20000
40000
60000
80000
100000


Line 3 SEZ BITMAPS Impacts
Public sector corruption
Social responsibility along the supply chain
Contribution to environmental load
Certified environmental management system
Sanitation coverage
Trade unionism
Industrial water depletion
Health expenditure
Biomass consumption
Social security expenditures
Pollution
Safety measures
Illiteracy, female
Association and bargaining rights
Illiteracy, total
Gender wage gap
Non-fatal accidents
Illiteracy, male
Fair Salary
Education
Drinking water coverage
Trafficking in persons
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Youth illiteracy, total
Goods produced by forced labour
Youth illiteracy, male
Youth illiteracy, female
Frequency of forced labour
Weekly hours of work per employee
Fatal accidents
Life expectancy at birth
DALYs due to indoor and outdoor air and water pollution
Fossil fuel consumption
Men in the sectoral labour force
Net migration
Contribution to economic development
-5000
0
5000
10000
15000
20000
25000
30000
35000