Final reports regarding sustainability and replicability of the pilot actions

Final version of 31/12/2021

Deliverable number D.5.2.1

Project Acronym: NETWAP

Project ID Number: 10047692

Project Title: NETwork of small "in situ" WAste Prevention and management initiatives

Priority Axis: 3 Environment And Cultural Heritage

Specific objective: 3.3 Improve the environmental quality conditions of the sea and coastal area by use of sustainable and innovative technologies and approaches

Work Package Number: 5

Work Package Title: Pilot actions and sustainability evaluations

Activity Number: 5.2

Activity Title: Sustainability evaluations

Partner in Charge: ENEA

Partners involved: ENEA, Čistoća d.o.o. City of Zadar, GAL Molise Verso il 2000

Status: Final

Distribution: Public

Table of content

Introduction

Within the NETWAP project, in the framework of WP5, ENEA is in charge of the sustainability evaluations of the pilot actions implemented in Fossalto and Ist Island, to assess the environmental, economic and social benefits deriving from the specific actions proposed for the management of organic waste in the involved territories and, in the case of Ist Island, for the reduction of plastic waste in the sea and on the beaches throughout an enhanced collection system. The comparison of the results achieved in both territories is helpful for validating the replicability and effectiveness of the implemented actions. In this deliverable, the baseline scenarios, both in Fossalto and in Ist Island, are thoroughly examined according to the three (environmental, economic and social) pillars of sustainability.

The evaluations are based on the Life Cycle Thinking (LCT) approach. LCT is a conceptual approach that seeks to identify improvements and to lower the impacts of goods or services (products) at all stages of associated life cycles, from raw material extraction and conversion, product manufacture, through distribution, use and eventual fate at end-of-life. The concept of LCT helps to avoid the situation of resolving one problem while creating another, the so-called “shifting of burdens”, e.g. from one stage in the life cycle to another, from one region to another, from one generation to the next or amongst different types of impacts. A life-cycle perspective on natural resources addresses several environmental concerns related to production and consumption, and ties together the use of resources and the generation of waste. While both resource use and waste generation have distinct environmental impacts, the two issues share many of the same driving forces — largely related to how and where we produce and consume goods, and how we use natural capital to sustain economic development and consumption patterns. However, it also offers the possibility of significant advantages from the knowledge gained – for example through identifying process efficiencies or good management practices. Focus is here on the assessment of waste management activities. LCT applied to waste management systems has been widely published in the scientific literature and many models have been developed over the years. The European Commission calls for increased use of Life Cycle Thinking [1], to complement the waste hierarchy of priorities, since LCT is recognized to be an excellent tool for assessing different waste management systems, especially for comparisons between different treatment and disposal systems, leading to two main different applications:

- Study of certain waste components in the waste. For example, there have been several studies comparing material recycling and energy recovery for paper packages and for plastic packages. In these cases, the studied waste components are only a marginal part of the total waste stream.

- Study of waste management systems, where different waste management systems for a waste typology, e.g. municipal solid waste, are compared, e.g. incineration *versus* landfilling. In these cases, the study comprises the total waste stream.

1. Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a methodology used to evaluate the potential environmental impacts of products or services along all their entire life cycle, with a «cradle to grave» approach. LCA allows (i) to evaluate the environmental burdens associated with a product, process or activity, by identifying and quantifying energy and materials used and wastes released to the environment and (ii) to identify and evaluate opportunities to affect environmental improvements. The LCA represents an analytical methodology providing qualitative, quantitative, confirmable and manageable environmental performance of production processes or products, as defined by ISO standards 14040-44 [2][3] and ILCD Handbook guidelines [4]. According to the ISO standard procedures (Figure 1), the LCA stages are:

1) Goal and scope definition,
2) Life Cycle Inventory (LCI),
3) Life Cycle Impact Assessment (LCIA),
4) Interpretation of results.

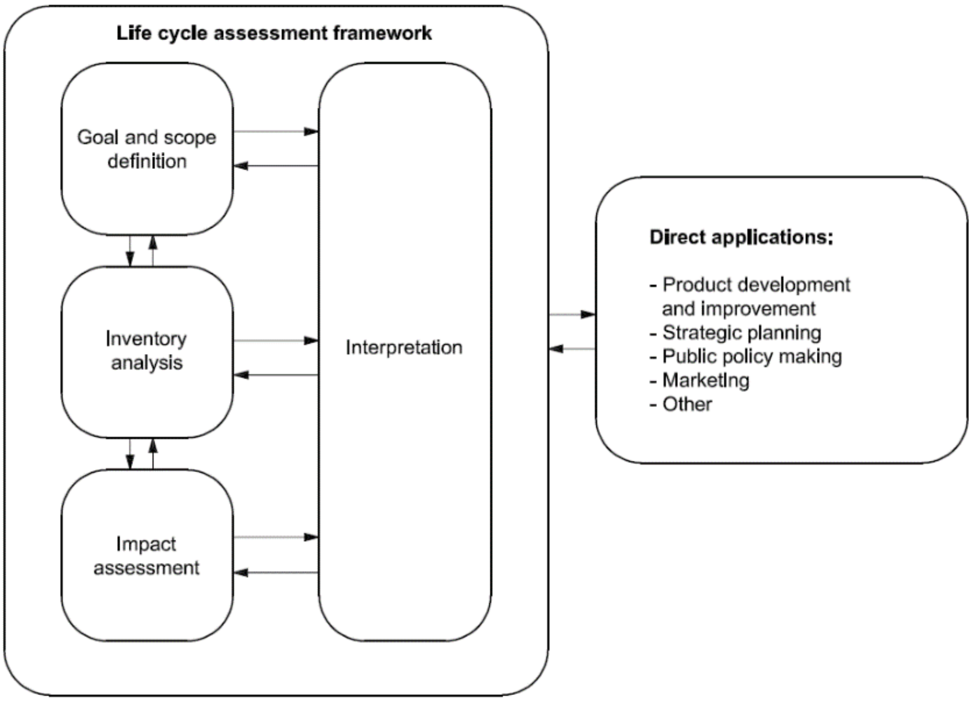

Figure 1. Framework for life cycle assessment (source: [2]).

In the Goal and scope definition phase, the objective of the LCA study as well as the main parameters, such as functional unit, system boundaries and data quality, are defined. The Functional Unit (FU) is the quantification of the identified functions (performance characteristics) of the product; its primary purpose is to provide a reference to relate inputs and outputs and to ensure comparability of the LCA results. It is important to determine the reference flow in each product system, in order to fulfil the intended function, i.e. the amount of products needed to fulfil the function. The system boundary defines the unit processes to be included in the system, whereas data quality, set in this phase, defines the characteristics of data related to their ability to satisfy stated requirements.

The Life Cycle Inventory (LCI) analysis is the second phase of LCA. It consists of an inventory of all input/output flows with regard to the analysed system. LCI involves the collection of the data necessary to meet the goals of the study. The qualitative and quantitative data included in the inventory are collected for each unit process within the system boundaries.

The data collected may include:

- energy inputs, raw material inputs, ancillary inputs, other physical inputs;
- products, co-products and waste;
- emissions to air, water and soil;
- other environmental aspects.

Life Cycle Impact Assessment (LCIA) aims at evaluating the significance of potential environmental impacts of the investigated product, process or service using the LCI results. In general, this process involves associating inventory data with specific environmental impact categories. Some examples of impact categories are Global Warming potential, Acidification potential, Eutrophication potential, Fossil Depletion, among others. The LCIA phase provides information for the life cycle interpretation phase.

The Interpretation of results is the phase of LCA in which the findings from the inventory analysis and the impact assessment are jointly considered. The interpretation phase should deliver results that are consistent with the defined goal and scope and which reach conclusions, explain limitations and provide recommendations.

All the LCA phases may involve an iterative process of reviewing and revising the scope of the LCA, as well as the nature and quality of the data collected to evaluate the consistency with the defined goal.

A detailed description of the LCA methodology is reported in the Deliverable D3.1.1.

It is widely recognized that the LCA method provides an excellent framework for evaluating waste management strategies: through its holistic perspective in quantifying environmental impacts, it has proved to be very helpful in identifying appropriate solutions for managing solid waste [5]. Numerous studies have been published in recent years in which this tool is applied for the environmental assessment of different scenarios of municipal waste management in different European countries. The focus is put on designing alternative scenarios for waste management, with the aim of identifying the best practices in terms of typology of separate collection and treatments both for the recyclable materials and for the residual mixed waste [6][7][8][9]. Several of these studies indicated LCA as a decision support tool in the selection of the best MSW management strategy (from an environmental point of view).

1.1 Fossalto pilot

One of the pilot actions planned in the framework of the NETWAP project was settled in Fossalto. Fossalto is a little hilltop village, belonging to the province of Campobasso, in the Molise Region, in the Southern part of Italy. It is located at the foot of the Appenines mountain chain, about 50 km far from the Adriatic Sea. Its municipal territory extends over an area of about 28 km2 with a total population of 1258 inhabitants. Fossalto includes two different districts: an historical centre and a rural district named “Sant’Agnese”, 2.3 km far from Fossalto centre. In Fossalto, the waste management is directly organised by the municipal administration and separate collection concerns the following waste fractions: organic (EWC 200108), paper and cardboard (EWC 200101), glass (EWC 150107), mixed packaging (EWC 150106), mixed waste (EWC 200301), whereas biomass from wood cutting and prunings (EWC 200201) is not collected. The involved households in the historical centre are 187, with 401 residents, and 57 in Sant’Agnese district, with 140 residents. In the households settled in the countryside, compostable waste is partly used as feed for pets and courtyard animals and partly as feed in domestic composters. Separated waste fractions are transported to the facility of Colle Santo Ianni in Montagano (CB), 15 km far from Fossalto, managed by Giuliani Environment Srl. This facility encompasses composting, mechanical and biological treatment (MBT) and landfilling for the separated waste fractions of 60 municipalities in the Molise Region. Detailed information about waste production and waste separate collection in Fossalto in 2019 and 2020 are reported in the Deliverable 3.2.1. In particular, focusing on the organic waste fraction, with reference to year 2020, it represents 15.3% of the total waste and is door-to-door collected three times per week in July and August and twice a week in the rest of the year. Once collected, the organic waste is transported to the treatment facility of Montagano, where it undergoes a composting process by means of aerobic fermentation in dynamic biocells. The fermentation is then completed in static cells and is followed by a curing phase, consisting of a mild biodegradation realised by mechanical turning of the organic matter arranged into a heap, leading to the production of a soil improver with a yield of 12.5%, according to the annual report of Montagano facility in 2019 [10]. In the framework of the NETWAP project, an electromechanical composter was installed in November 2021 for treating the organic waste locally, in order to avoid the transportation thus reducing the generated environmental impacts. More details about the composter can be found in the Deliverable 5.1.1.

1.1.1 Goal and scope definition

This LCA study was performed to analyze the environmental impacts of different management strategies for the Organic Fraction (OF) of Municipal Solid Waste (MSW) produced in Fossalto (CB). In particular, the baseline scenario of organic waste treatment in Fossalto was evaluated and compared to the scenario implemented within the framework of the NETWAP project (hereinafter referred to as NETWAP scenario).

The results may provide a basis for making decisions about the future management of organic waste in small villages with features similar to Fossalto, thus the target audience is represented by all the interested stakeholders and decision-makers, such as the public administration. In fact, this study is aimed at providing decision-makers with potentially useful recommendations for local waste management planning.

In agreement with the ILCD Handbook, in this study the attributional modelling principle was chosen for comparing systems (Situation A in the ILCD Handbook). As far as waste management is concerned, the input material is waste; therefore, when applying LCA to waste management, the classical cradle-to-grave approach has to be modified to gate-to-cradle or gate-to-grave [11], depending on if recycling or disposal operations are analyzed. In the investigated system, a gate-to-cradle approach was applied, considering the production of a soil improver. The functional unit (FU) chosen for this assessment is the treatment of 1 ton of organic waste treated in Fossalto in 2020 (out of the total amount of 43.14 tons/yr): all materials, emissions, cost, energy consumption, and recovery levels are referred to the selected FU.

The boundaries of the system under study are not limited to the physical and geographical boundaries of Fossalto pilot, but are extended to encompass the whole organic waste chain: from the generation of waste (a zero burden approach was assumed, not including the generation of waste or the life cycle of the products before they became waste) to the treatment in the Montagano facility (in the baseline scenario) or in the electromechanical composter (in the NETWAP scenario), through the collection and transportation, up to the final disposal of residual waste (i.e. waste deriving from the composting treatment that does not undergo further treatment and is landfilled).

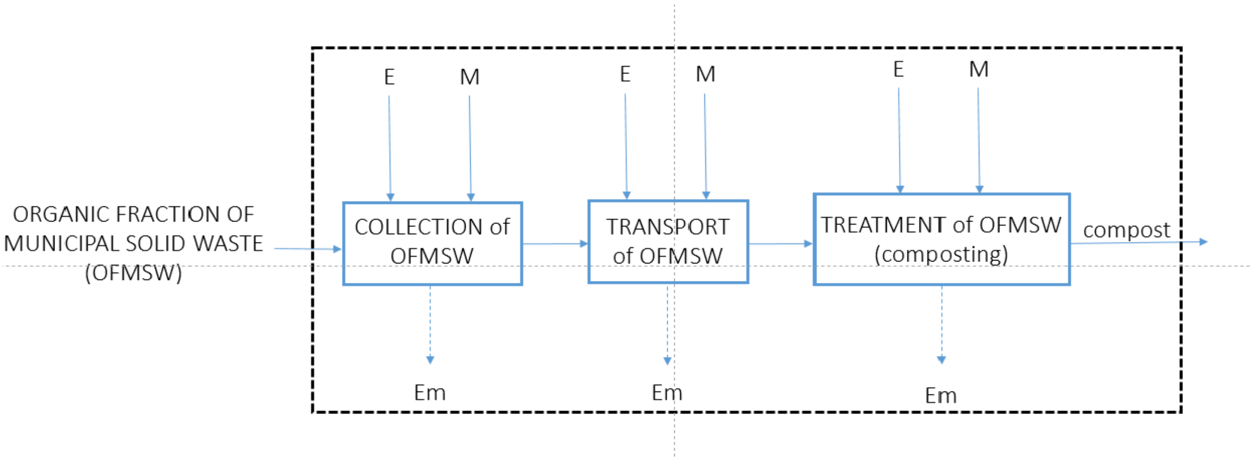

Figure 2. System boundary of Fossalto pilot action.

The relevant processes included within the boundary of the investigated system are shown in Figure 2:

- Collection of the organic fraction of Municipal Solid Waste in the historical centre and in the rural district of Sant'Agnese, including containers, bins and compostable bags;
- Transportation, including the transportation of organic waste within the Fossalto Municipality (an average value of 10 km was considered) and, only in the baseline scenario, from Fossalto to the treatment facility placed in Montagano, at a distance of around 15 km;
- Processing/treatment of organic fractions (including composting and final disposal of residual flows downstream of composting process).

Timeframe of this study only refers to one-year data to generate the results. If LCA becomes a routinely applied tool at administrative level, time series data would strengthen results and allow bolder scenarios. Furthermore, the achieved results are greatly dependent on the features of the investigated system, although some extrapolations can be valid also for other similar areas.

Finally, in order to inform policy makers about potential benefits linked to the different waste management strategies, a system expansion (or avoided burden approach) was also performed, based on average data (i.e. market mix): in particular, the avoided production of fertilizers was included for crediting the production of compost. Taking into account the quality of the products from waste in comparison with that of the corresponding avoided product, 1 ton of compost was assumed to substitute 23 kg of N-fertilizer, 9.5 kg of P-fertilizer and 9 kg of K-fertilizer [8].

1.1.2 Life Cycle Inventory

In this study, data from different sources have been used. Foreground data, i.e. specific information about material and energy flows related to the collection, transportation and treatment of the organic fraction of Municipal Solid Waste, were provided by Fossalto Municipality. When direct measurements were not available, estimations were made based on the information collected locally and their consistency was verified in scientific literature. In particular, for the NETWAP scenario, only preliminary experimental data from the local composting activities were available so far. Therefore, in order to provide a comprehensive and reliable assessment, data referring to energy and material requirements, emissions and compost production were gathered from a previous composting campaign, based on an electromechanical composter similar to the one installed in Fossalto, and used as a reference for modelling the NETWAP scenario. For background data, the EcoInvent v.3.5 database (allocation at point of substitution, dataset of unit processes) was chosen, since it includes average European data for most existing materials and energy supply processes and/or services. Data regarding the treatment of organic waste in a composting industrial plant were derived from the Ecoinvent database, including the treatment of residuals in sanitary landfill, the wastewater treatment as well as the airborne and waterborne emissions. The environmental impacts generated from capital goods and infrastructures were also included in the analysis, as well as the transport costs related to waste transported by truck. All the values were referred to the functional unit, as defined earlier. Table 1 lists the main foreground input and output flows involved in the organic waste collection, transportation and treatment steps, together with the main sources of the reported data, for both the investigated scenarios (baseline *versus* NETWAP).

Table 1. Life Cycle Inventory for the organic waste fraction in the baseline scenario of Fossalto (CB). Values refer to the total amount of waste produced in the reference year (2020).

Organic Fraction of Municipal Solid Waste in Fossalto (CB) (total amount 43.14 ton; reference year 2020)			
Inputs	**Unit**	**Value**	**Reference**
Collection phase			
Container number (HDPE)	#	244	Fossalto Municipality (families in the Historical Centre + families in Sant'Agnese)
Container volume	l/item	10	Fossalto Municipality
Estimated lifetime	yrs	7	[12]
Compostable bags number	#	27606.86	Our assumption (considering the collection events in 1 year)
Compostable bags weight	kg/item	0.013	https://www.ekoe.org/sacchetti-shopper-media-biodegradabili-e-compostabili-cm-3018x53-13gr/
Transportation phase			
Average distance	km/trip	45	Fossalto Municipality (distance from Fossalto to the treatment plant roundtrip + distance run within Fossalto)
Total run distance (within Fossalto)	km/yr	1697.14	Fossalto Municipality
Total run distance (outside Fossalto)	km/yr	3394.29	Fossalto Municipality
Treatment phase			
Montagano facility			
Processing loss	%	15.8	[10]
Produced compost	kg	4539.46	[10]
Avoided N-fertilizer	kg	104.41	[8]
Avoided P_2O_5-fertilizer	kg	43.12	[8]
Avoided K_2O-fertilizer	kg	40.86	[8]

NETWAP composter			
Electricity requirement	kWh	30592.76	Our assumption (based on a previous composting campaign)
CO_2 emissions	kg	22237.73	Our assumption (based on a previous composting campaign)
NH_3 emissions	kg	746.85	Our assumption (based on a previous composting campaign)
Produced compost	kg	2444.03	Our assumption (based on a previous composting campaign)
Avoided N-fertilizer	kg	56.21	[8]
Avoided P_2O_5-fertilizer	kg	23.22	[8]
Avoided K_2O-fertilizer	kg	22.00	[8]

1.1.3 Life Cycle Impact Assessment

The professional software SimaPro v.9.0.0.48 (Pre-Consultants), coupled with the EcoInvent v.3.5 database, was used to set up the LCA model of the investigated system and implement the impact assessment calculations. Among the impact assessment methods, the ReCiPe Midpoint (H) (http://www.lcia-recipe.net/) was preferred, since it provides a common framework in which midpoint impact categories can be investigated [13]. In this study, the impact categories reported in Table 2 were analysed, in order to support decision making by means of a simplified overall assessment.

Table 2. Impact Categories considered within the ReCiPe 2016 Midpoint (H) v.1.03 impact assessment method.

Impact category	**Unit**	**Abbreviation**
Global warming potential	kg CO_2 eq	GWP
Fine particulate matter formation potential	kg PM2.5 eq	PMFP
Terrestrial acidification potential	kg SO_2 eq	TAP
Freshwater eutrophication potential	kg P eq	FEP
Marine eutrophication potential	kg N eq	MEP
Human carcinogenic toxicity potential	kg 1,4-DCB	HTP_c

Mineral resource scarcity potential	kg Cu eq	MRS
Fossil resource scarcity potential	kg oil eq	FRS
Water consumption potential	m^3	WCP

Environmental indicators were chosen using a top–down approach according to ISO (2006) recommendations. These indicators are internationally recognized and widely exploited in waste management LCA studies [8] [12].

1.1.4 Interpretation

The baseline scenario of organic waste management was firstly assessed in order to model physical flows, resources consumption and emissions to the environment, with reference to the treatment of 1 ton of organic waste produced in Fossalto in 2020. The characterized results of the impact assessment of this scenario are summarized in Table 3. Hereby all LCA results are disaggregated to visualize the contributions of each investigated phase (collection, transportation and treatment phases) to the environmental loads. The % values are also displayed in Figure 3, in order to highlight the relative contribution of each investigated phase.

Table 3. Characterized impacts generated from the treatment of organic waste in the baseline scenario of Fossalto, referring to the selected FU (1 ton of treated organic waste).

Impact category	*Unit*	*Collection phase*	*Transportation phase*	*Treatment phase*	*Compost recovery*	*TOTAL*
GWP	kg CO_2 eq	19.26	2739.43	56.74	-31.84	2783.58
PMFP	kg PM2.5 eq	0.04	2.51	0.19	-0.04	2.70
TAP	kg SO_2 eq	0.12	5.54	1.42	-0.16	6.92
FEP	kg P eq	0.01	0.30	3.42E-03	-0.01	0.30
MEP	kg N eq	4.87E-03	0.03	1.64E-03	-0.01	0.03
HTP_c	kg 1,4-DCB	0.70	87.50	2.22	-0.71	89.70
MRS	kg Cu eq	0.08	15.78	0.11	-0.35	15.62
FRS	kg oil eq	10.01	892.54	5.50	-4.39	903.66
WCP	m^3	0.11	5.95	0.07	-0.63	5.50

The highest contribution to all the analysed impact categories derives from the transportation phase, accounting always for more than 91.5% of total generated impacts, except for the TAP and MEP impact categories in which the transportation impacts for 78.2% and 81.5%, respectively. In deeper details, MRS, FRS and GWP are the most impacted categories, with impacts of 15.8 kg Cu eq, 893 kg oil eq and 2740 kg CO_2 eq attributable to the transportation phase. The contribution deriving from the collection phase is relevant only in the MEP impact category, in which it amounts to 4.87E-3 kg N eq, corresponding to 13.8% of the total impact on marine eutrophication, whereas it is minor than 2.2% in all the remaining impact categories. In particular, the impact on the MEP impact category derives from the production of bio-based compostable bags used for collecting the organic waste. As far as the treatment phase is concerned, the most relevant impact regards the TAP impact category, with a release of 1.42 kg SO_2 eq, corresponding to 20% of the total impact on terrestrial acidification. In the remaining impact categories, the contribution of the treatment phase ranges from 0.61% in FRS to 6.92% in PMFP. The impacts generated from the recovery of compost have negative values, thus indicating that environmental benefits are gained from the production of compost and the corresponding avoided production of nitrogen, phosphate and potassium chemical fertilizers. In particular, the most relevant benefits regard the MEP and WCP impact categories, accounting for -18.3% and -10.3% respectively. Although, as expected, the environmental gains achieved by avoiding the production of chemical fertilizers are not sufficient to overcome the environmental loads generated by the management of organic waste, the contribution to make the total impacts lower is considerable.

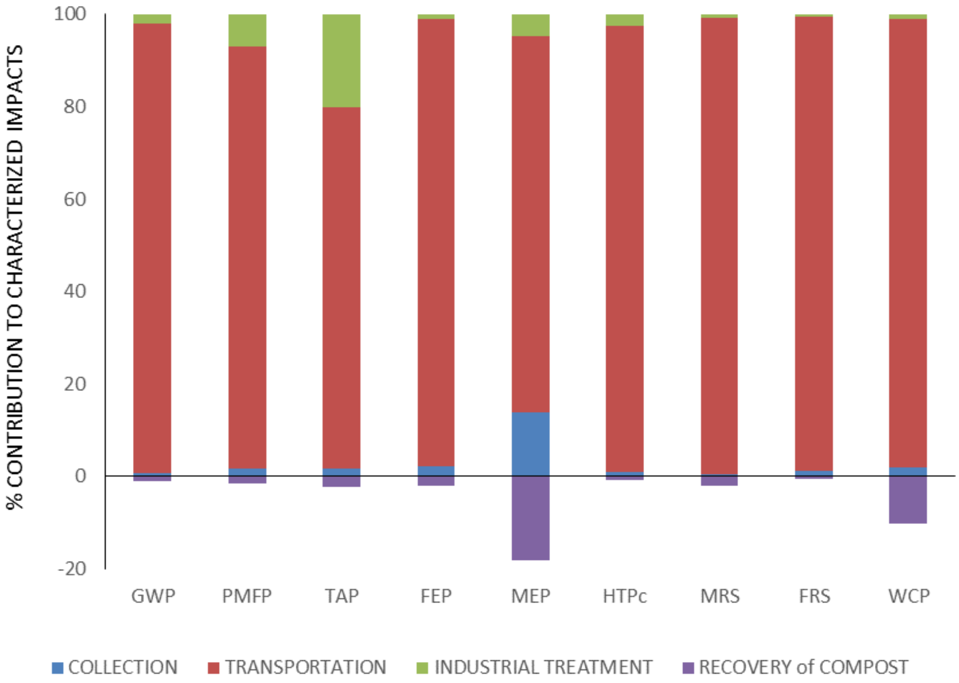

Figure 3. Percentage contribution of each phase to the total impact of each analysed impact category in the baseline scenario of Fossalto, referring to the selected FU (1 ton of treated organic waste).

The characterized results of the impact assessment of the NETWAP scenario, in which the local composting is assumed to be regularly running, are shown in Table 4 and in Figure 4, as absolute and percentage values respectively.

Table 4. Characterized impacts generated from the treatment of organic waste in the NETWAP scenario of Fossalto, referring to the selected FU (1 ton of treated organic waste).

Impact category	*Unit*	*Collection phase*	*Transportation phase*	*Treatment phase*	*Compost recovery*	*TOTAL*
GWP	kg CO_2 eq	18.52	905.72	469.18	-12.86	1380.55
PMFP	kg PM2.5 eq	0.04	0.80	0.56	-0.02	1.37
TAP	kg SO_2 eq	0.11	1.75	1.73	-0.07	3.52
FEP	kg P eq	0.01	0.09	0.09	0.00	0.18
MEP	kg N eq	0.00	0.01	0.01	0.00	0.02

HTP_c	kg 1,4-DCB	1.35	77.19	7.79	-0.92	85.40
MRS	kg Cu eq	0.06	2.51	0.24	-0.12	2.69
FRS	kg oil eq	9.90	297.20	137.84	-2.54	442.39
WCP	m^3	0.10	1.91	2090.10	-0.36	2091.75

Also in this scenario, the highest contribution to all the analysed impact categories derives from the transportation phase, with impacts ranging from 40% in MEP impact category to more than 89% in HTP_c and MRS categories. The impacts generated from the local composting in TAP and FEP impact categories are lower than those generated from transport, although very similar. The only exception is represented by the WCP impact category, where the almost totality of the impact is associated with the local composting and, in particular, with the energy requirements of the composter. The compost recovery determines some benefits (negative values of the impacts), although such a contribution does not go beyond the 19% in the MEP category.

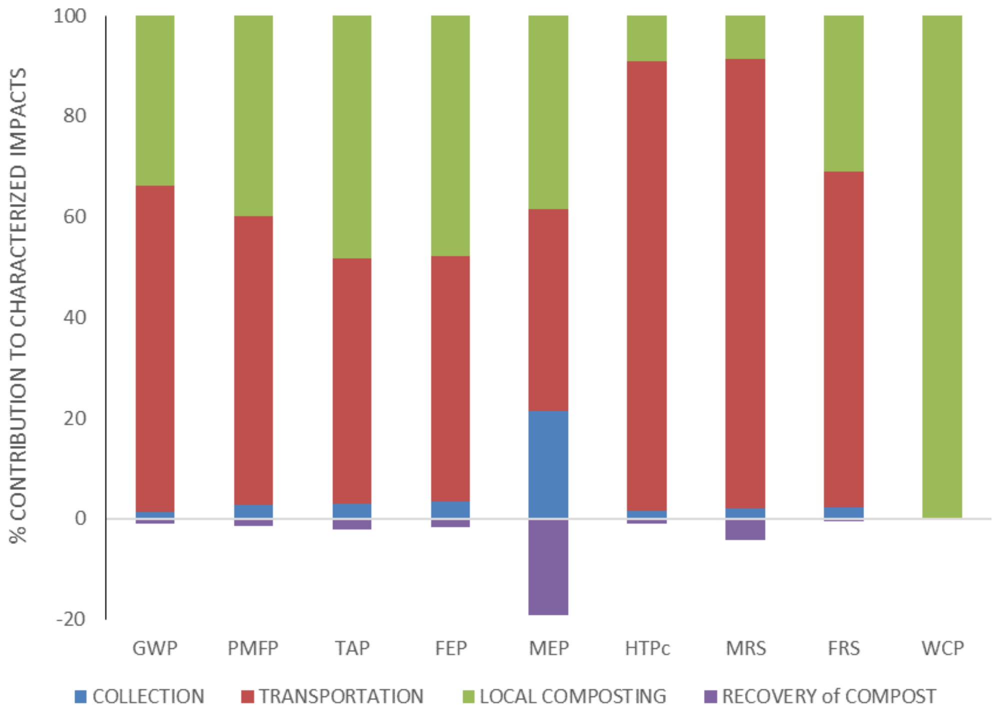

Figure 4. Percentage contribution of each phase to the total impact of each analysed impact category in the NETWAP scenario of Fossalto, referring to the selected FU (1 ton of treated organic waste).

A direct comparison of the total impacts generated in the baseline and NETWAP scenarios is shown in Table 5.

Table 5. Total impacts generated from the treatment of organic waste in the baseline scenario *versus* the NETWAP scenario of Fossalto, referring to the selected FU (1 ton of treated organic waste).

Impact category	***Unit***	***Baseline scenario***	***NETWAP scenario***
GWP	kg CO_2 eq	2783.58	1380.55
PMFP	kg PM2.5 eq	2.70	1.37
TAP	kg SO_2 eq	6.92	3.52
FEP	kg P eq	0.30	0.18
MEP	kg N eq	0.03	0.02
HTPc	kg 1,4-DCB	89.70	85.40
MRS	kg Cu eq	15.62	2.69
FRS	kg oil eq	903.66	442.39
WCP	m^3	5.50	2091.75

Except from the WCP impact category where the impact of the NETWAP scenario is three orders of magnitude higher, the NETWAP scenario generates lower impacts in all the remaining impact categories. The reductions range from 5% in HTP_c up to 83% in MRS, whereas the kg of CO_2 eq as well as the kg of oil eq are halved thanks to the local composting.

It has to be highlighted that, for conservative purposes, the Ecoinvent process “Electricity, medium voltage, production IT, at grid/IT U” was selected as reference for the electricity flow in the NETWAP scenario. Nevertheless, selecting the “Electricity, low voltage {IT}| market for | APOS, U” process in a sensitivity perspective, the WCP impact decreases to a value of 7.62 m^3, only slightly higher than in the baseline scenario, thus indicating the strong dependence of the WCP impact category on the selected electricity flow.

1.2 Ist Island pilot

The second territory selected for the pilot experience of the NETWAP project was the Dalmatian island of Ist, located in the north-central part of the Zadar archipelago. The island has an area of 9.65 km^2 and a resident population of 182 inhabitants, that strongly increases during the summertime reaching 3-4 thousands of tourists. No large touristic infrastructures (hotels, campsites, restaurants) are present in the island, but the harbor authority is well equipped to receive tourists of nautical activities. Regarding the waste management, ČISTOĆA Zadar l.t.d. is the company in charge of collecting and treating waste. Plastic packaging (CER 150102), paper and cardboard (CER 200101), bulky waste (CER 200307) and unsorted waste (CER 200301) are separately collected by means of a door-to-door system. The frequency of collection is twice per week. Collected waste is transferred to a deposit station (or reloading station) on the island where it is temporarily stored in press containers and thus prepared for transport to mainland via a ship concessionaire. The transport to the continent is planned through 11 trips per year. Detailed information about waste production and waste separate collection in Ist Island in 2018, 2019 and 2020 are reported in the Deliverable 3.2.1. In particular, it is noteworthy that organic waste is not separately collected, but included in the unsorted waste, that is finally disposed of at the Diklo landfill, about 10 km north from Zadar. However, a common practice of Ist residents is to use biowaste as food for animals. A valorization of the organic waste is thus required and the option to treat the organic waste locally is valuable to reduce the number of trips to the mainland, lowering the amount of unsorted waste to be disposed of in the landfill, with advantages from both the environmental and economic points of view. To this aim, in the framework of the NETWAP project, an electromechanical composter was installed in 2021 for treating the organic waste locally. More details about the composter can be found in the Deliverable 5.1.1.

1.2.1 Goal and scope definition

Also in the case of the Ist Island pilot action, the environmental impacts of different management strategies for the Organic Fraction (OF) of Municipal Solid Waste (MSW) were assessed by means of LCA. In particular, the baseline scenario of organic waste treatment in the island was evaluated and compared to the scenario implemented within the framework of the NETWAP project. As for Fossalto, the results may provide a basis for making decisions about the future management of organic waste in small islands with features similar to Ist, thus the target audience is represented by all the interested stakeholders and decision-makers, such as the public administration and the waste management companies. In fact, this study is aimed at providing involved stakeholders with potentially useful recommendations for local waste management planning.

The same approach described for the assessment of the Fossalto baseline scenario was used also for Ist, in order to allow a comparison of the achieved results. Therefore, in agreement with the ILCD Handbook, in the investigated system, the attributional modelling principle was chosen (Situation A in the ILCD Handbook) and a gate-to-cradle approach was applied, when considering the production of a composted soil improver in the NETWAP scenario. The functional unit (FU) chosen for this assessment is the treatment of 1 ton of organic waste produced in Ist Island: all materials, emissions, cost, energy consumption, and recovery levels are referred to the selected FU. Since the organic fraction is not separately collected, it was assumed that an amount of 20.28 ton of kitchen waste is produced yearly, based on the estimated composition of mixed waste (namely, 30.9% according to the Croatian Agency for the Environment and Nature) and considering an average amount of mixed municipal solid waste of 65.62 ton collected between 2018 and 2020.

Also in this case, the boundaries of the investigated system go beyond the physical and geographical boundaries of Ist pilot, in order to include the whole organic waste chain: from the generation of waste (a zero burden approach was assumed, not including the generation of waste or the life cycle of the products before they became waste) to the disposal in the Diklo landfill in Zadar or the treatment in the NETWAP electromechanical composter, through the collection and transportation, up to the final disposal of residual waste, if any (i.e., in the case of NETWAP scenario, waste deriving from the composting treatment that does not undergo further treatment and is landfilled).

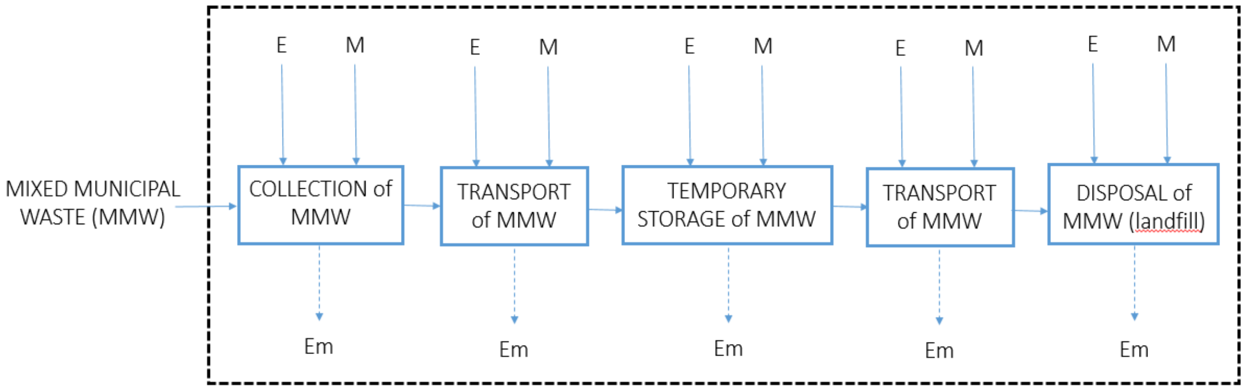

Figure 5. System boundary of the baseline scenario of Ist Island pilot action.

The relevant processes included within the boundary of the investigated system, relatively to the baseline scenario of Ist Island pilot action, are shown in Figure 5:

- Collection of the mixed municipal waste in the island, including containers, bins and bags;
- Transportation (by truck) of mixed municipal waste, including (i) the transportation within the island, with trucks running an average distance of 10 km from the collection points to the deposit station, and (ii) the transportation on the mainland from the port to the landfill (20 km, roundtrip);
- Temporary storage of mixed municipal waste in the deposit station on the island, including press containers and the containers lifter;
- Transportation (by ship) of mixed municipal waste from the island to the mainland by ship trips of 65 nautical miles per trip;
- Landfill disposal of mixed municipal waste.

In the case of the NETWAP scenario, the system boundary is the same as shown in Figure 2 and the same system expansion applied in the assessment of Fossalto scenarios can be performed to account for the benefits deriving from the production of compost and the consequently avoided production of chemical fertilizers.

As for Fossalto, timeframe of this study is limited to one-year data to generate the results, but time series data would strengthen results and allow bolder scenarios. Furthermore, even though the achieved results are greatly dependent on the features of the investigated system, this study can be helpful for other small islands where waste treatment plants are not present.

1.2.2 Life Cycle Inventory

In this study, data from different sources have been used. Foreground data, i.e. specific information about material and energy flows related to the collection, temporary storage, transportation and landfilling of mixed municipal waste, were provided by Ist Municipality. When direct measurements were not available, estimations were made based on the information collected locally and their consistency was verified in scientific literature. As already specified for the Fossalto pilot territory, only preliminary experimental data from the local composting activities were provided also in the case of Ist Island. For this reason, the analysis of the NETWAP scenario was modelled with reference to a previous composting campaign, based on an electromechanical composter similar to the one installed in Ist, in terms of energy and material requirements, emissions and compost production. For background data, the EcoInvent v.3.5 database (allocation at point of substitution, dataset of unit processes) was chosen, since it includes average European data for most existing materials and energy supply processes and/or services. Data regarding the landfilling of organic waste were derived from the Ecoinvent database, including the airborne and waterborne emissions. The environmental impacts generated from capital goods and infrastructures were also included in the analysis, as well as the transport costs related to waste transported by truck and by ship. All the values were referred to the functional unit, as defined earlier. Table 6 lists the main foreground input and output flows involved in the organic waste collection, storage, transportation and treatment steps, together with the main sources of the reported data, for both the investigated scenarios (baseline *versus* NETWAP).

Table 6. Life Cycle Inventory for the organic waste fraction in the baseline scenario of Ist Island. Values refer to the total amount of organic waste estimated in the average amount of mixed municipal solid waste of 65.62 ton, collected between 2018 and 2020.

Estimated Organic Fraction in Mixed Municipal Waste in Ist Island (total amount 20.28 ton, out of 65.62 ton of mixed municipal waste)			
Inputs	**Unit**	**Value**	**Reference**
Collection phase			
Container number (HDPE)	#	2.39	Our assumption (considering the volume of mixed waste collected per collection event)
Container volume	l/item	80 - 120 - 240	Ist Municipality
Estimated lifetime	yrs	7	[12]
Compostable bags number	#	2932.41	Our assumption (considering the collection events in 1 year and families composed of 2 people)
Compostable bags weight	kg/item	0.013	https://www.ekoe.org/sacchetti-shopper-media-biodegradabili-e-compostabili-cm-3018x53-13gr/
Transportation phase (by truck)			
Average distance (island)	km/trip	10	Ist Municipality (distance run within the island)
Total run distance (island)	km/yr	1042.9	Ist Municipality
Average distance (mainland)	km/trip	20	Ist Municipality (distance run from the port to the landfill, roundtrip)
Total run distance (mainland)	km/yr	220	Ist Municipality
Temporary storage			
Retractable container number	#	0.93	Ist Municipality
Retractable container volume	l/item	30000	Ist Municipality
Compression container number	#	0.62	Ist Municipality
Compression container volume	l/item	20000	Ist Municipality

Metallic container number		0.93	Ist Municipality
Metallic container volume		7000	Ist Municipality
Containers' estimated lifetime	yrs	8	Ist Municipality
Hookloader (load capacity)	kg	26000	Ist Municipality
Container lifter (capacity)	kg	18000	Ist Municipality
Transportation phase (by ship)			
Average distance	km/trip	120.4	Ist Municipality
Total sailed distance	km/yr	1324.2	Ist Municipality
Landfill disposal			
Treatment of biowaste in sanitary landfill	ton	20.28	EcoInvent v.3.5
NETWAP composter			
Electricity requirement	kWh	6757.8	Our assumption (based on a previous composting campaign)
CO_2 emissions	kg	351.02	Our assumption (based on a previous composting campaign)
NH_3 emissions	kg	10451.61	Our assumption (based on a previous composting campaign)
Produced compost	kg	1148.68	Our assumption (based on a previous composting campaign)
Avoided N-fertilizer	kg	26.42	[8]
Avoided P_2O_5-fertilizer	kg	10.91	[8]
Avoided K_2O-fertilizer	kg	10.34	[8]

1.2.3 Life Cycle Impact Assessment

The professional software SimaPro v.9.0.0.48 (Pre-Consultants), coupled with the EcoInvent v.3.5 database, was used to set up the LCA model and implement the impact assessment calculations also for the Ist Island system. As for the Fossalto pilot action, among the impact assessment methods, the ReCiPe Midpoint (H) (http://www.lcia-recipe.net/) was preferred, since it provides a common framework in which midpoint impact categories can be investigated [13]. The same impact categories analysed for Fossalto were investigated also for Ist (namely, the impact categories reported in Table 2), in order to allow a comparison between the pilot actions.

1.2.4 Interpretation

The baseline scenario of organic waste management was firstly assessed in order to model physical flows, resources consumption and emissions to the environment, with reference to the treatment of 1 ton of organic waste yearly produced in Ist Island (as average value between 2018 and 2020). The characterized results of the impact assessment of this scenario are summarized in Table 7. Hereby all LCA results are disaggregated to visualize the contributions of each investigated phase (collection, transportation by truck, temporary storage, transportation by ship and landfilling phases) to the environmental loads. The % values are also displayed in Figure 6, in order to highlight the relative contribution of each investigated phase.

Table 7. Characterized impacts generated from the treatment of organic waste in the baseline scenario of Ist Island, referring to the selected FU (1 ton of treated organic waste).

Impact category	*Unit*	*Collection*	*Transportation by truck*	*Temporary storage*	*Transportation by ship*	*Landfilling*	*TOTAL*
GWP	kg CO_2 eq	4.36	679.50	119.71	12.47	759.53	1575.56
PMFP	kg PM2.5 eq	0.01	0.62	0.24	0.08	0.02	0.97
TAP	kg SO_2 eq	0.03	1.37	0.40	0.26	0.05	2.11
FEP	kg P eq	1.54E-03	0.07	0.06	4.63E-04	0.09	0.23
MEP	kg N eq	1.10E-03	7.14E-03	0.01	5.12E-05	1.13	1.15
HTP_c	kg 1,4-DCB	0.16	21.70	52.48	0.28	1.14	75.76
MRS	kg Cu eq	0.02	3.92	14.44	0.03	0	18.40
FRS	kg oil eq	2.27	221.39	27.38	3.66	0	254.69
WCP	m^3	0.02	1.48	1.23	0.01	0	2.74

The highest contributions to the analysed impact categories derive from the transportation by truck and from the landfilling. In particular, transportation by truck generates 86.9% of the total impacts on FRS and around 65% of the total impacts on PMFP and TAP. The main impact generated by landfilling concerns the MEP impact category, amounting to 98.5% of the total releases of kg N eq. Also the emissions of CO_2 eq coming from landfilling are considerable, with a total amount of 760 kg CO_2 eq (corresponding to 48% of the total impacts on GWP, while 43.1% is caused by transportation by truck). Temporary storage of organic waste in the deposit station mainly impacts on HTP_c and MRS, respectively with 52.5 kg 1,4-DCB (69.3% of the total impact) and 14.4 kg Cu eq (78.5% of the total impact). The impacts of the collection phase range from 0.10% on the MEP and MRS impact categories to 1.29% on the TAP category and can be considered negligible. On the contrary, the contributions from the transportation by ship are relevant on PMFP and TAP impact categories, amounting to 8.5% and 12.2% respectively.

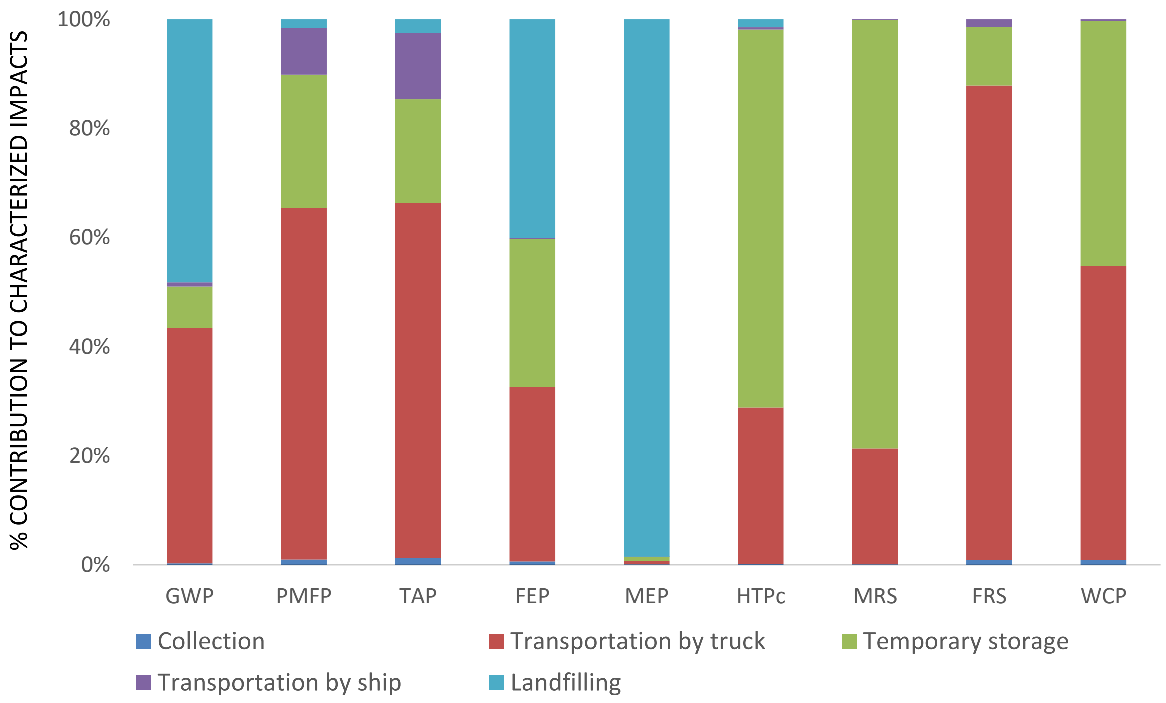

Figure 6. Percentage contribution of each phase to the total impact of each analysed impact category in the baseline scenario of Ist Island, referring to the selected FU (1 ton of treated organic waste).

The characterized impacts of the NETWAP scenario, in which the local composting is assumed to be regularly running, are shown in Table 8, whereas Figure 7 displays the relative contribution of each investigated phase to the total impacts as percentage value.

Table 8. Characterized impacts generated from the treatment of organic waste in the NETWAP scenario of Ist Island, referring to the selected FU (1 ton of treated organic waste).

Impact category	*Unit*	*Collection phase*	*Transportation phase*	*Treatment phase*	*Compost recovery*	*TOTAL*
GWP	kg CO_2 eq	4.36	561.13	118.53	-17.82	666.20
PMFP	kg PM2.5 eq	0.01	0.51	0.18	-0.03	0.68
TAP	kg SO_2 eq	0.03	1.13	0.58	-0.09	1.65
FEP	kg P eq	0.00	0.06	0.02	0.00	0.08
MEP	kg N eq	1.10E-03	5.90E-03	2.13E-03	-4.40E-03	4.73E-03
HTP_c	kg 1,4-DCB	0.16	17.92	2.74	-0.39	20.43
MRS	kg Cu eq	0.02	3.23	0.15	-0.19	3.21
FRS	kg oil eq	2.27	182.82	34.06	-2.39	216.76
WCP	m^3	0.02	1.22	1494.85	-0.38	1495.72

The contribution of the transport phase, that includes the transport of waste by truck within the island, ranges from 65% in MEP up to 95% in MRS, representing the main responsible for all the investigated impact categories, except for the WCP. As already highlighted for the Fossalto pilot, the almost totality of the impact in WCP is associated with the local composting and, in particular, with the energy requirements of the composter. The local composting generates relevant impacts also in the TAP and PMFP categories (33% and 26%, respectively). The environmental benefits of the compost recovery (negative values of the impacts) do not overcome the loads generated by the collection, transport and treatment phases. Nonetheless, the contribution to reduce the total impact in the MEP category is quite relevant (48%).

Figure 7. Percentage contribution of each phase to the total impact of each analysed impact category in the NETWAP scenario of Ist Island, referring to the selected FU (1 ton of treated organic waste).

If compared to the baseline scenario, the NETWAP scenario results much less impactful in all the investigated impact categories other than WCP (see Table 9).

Table 9. Total impacts generated from the treatment of organic waste in the baseline scenario *versus* the NETWAP scenario of Ist Island, referring to the selected FU (1 ton of treated organic waste).

Impact category	***Unit***	***Baseline scenario***	***NETWAP scenario***
GWP	kg CO_2 eq	1575.56	666.20
PMFP	kg PM2.5 eq	0.97	0.68
TAP	kg SO_2 eq	2.11	1.65
FEP	kg P eq	0.23	0.08
MEP	kg N eq	1.15	0.00

HTPc	kg 1,4-DCB	75.76	20.43
MRS	kg Cu eq	18.40	3.21
FRS	kg oil eq	254.69	216.76
WCP	m^3	2.74	1495.72

The impact on MEP category is almost totally cancelled, while the impacts on MRS and HTP_c are reduced by 83% and 73%, respectively. Also the GWP category is advantaged with a reduction of the CO_2 emissions from 1575.56 to 666.20 kg of CO_2 eq. As observed for the pilot in Fossalto, the impact on the WCP category is enormously higher, mainly depending on the electricity consumption in the local composting. Also in this case, however, this impact is strongly affected in sensitivity terms by the selection of the electricity flow.

2. Life Cycle Costing (LCC)

Life Cycle Costing (LCC) is applied as an assessment tool to estimate the entire cost of the system under investigation, during its whole life cycle. As a cost-oriented approach, LCC focuses on all resources consumed by the product or process system, during its lifetime. Through LCC, these resources are quantified as costs [14] including the current costs related to the initial investment, operating and maintenance costs, replacement costs and disposal costs [15].

Three levels of assessments can be distinguished in the literature: conventional LCC (cLCC), environmental LCC (eLCC) and social LCC (sLCC). Conventional LCC (cLCC) can be defined as the sum of all funds expended in support of an item from its conception and fabrication through its operation and the end of its useful life [16]. These funds are also referred to as internal costs. Environmental LCC (eLCC) expands cLCC by including also the external costs of environmental impacts (also known as externalities or environmental costs) [17]. In particular, environmental externalities arise from climate change and from other changes in air or in water and soil quality, inducing impacts on human health, the developed environment and ecosystems [18]. Social LCC (sLCC), in addition to the costs taken into account by cLCC and eLCC, assesses all costs associated with the life cycle of a product or service that are borne by anyone in the society (macro-economic level), whether today or in the future [19]. Therefore, eLCC and sLCC are built-on and expand the scope and boundaries of cLCC, as shown in the Figure 8.

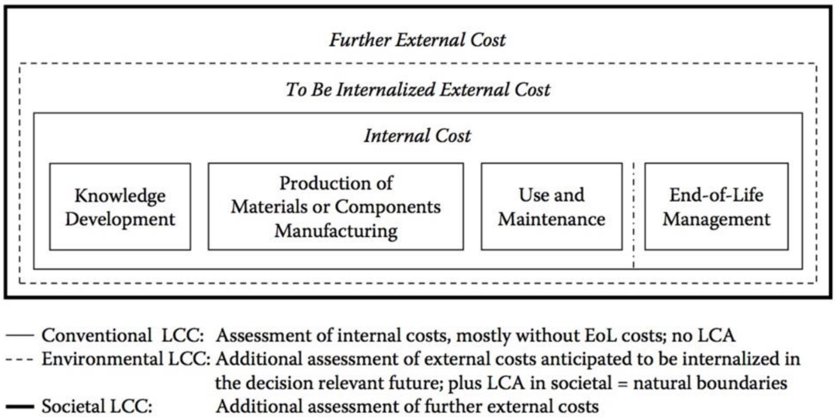

Figure 8. Boundaries of conventional, environmental and social LCC.

In this study, the eLCC (i.e. internal costs + externalities) was carried out to provide a comprehensive combination of both environmental and economic performance of the NETWAP pilot areas, in order to support technological and management decisions of businesses.

In this study, the eLCC is consistent with the performed LCA and follows a steady-state modelling approach, which lacks any temporal specification, assuming all technologies will remain constant in time. The Environmental Priority Strategies (EPS) approach (version 2015dx [20]) was applied for the calculation of the externalities. The EPS method follows the LCA methodology, according to the ISO standards 14040-44/2006 [21]. Impacts from emissions and use of resources, which cause significant changes in any of the safeguard subjects (i.e. areas of protection: Ecosystem Services – ES, Access to Water – AW, Abiotic Resources – AR, Human Health – HH, BioDiversity – BD), are investigated.

The results of the EPS impact assessment method are monetary values (monetarization) of environmental impacts from emissions and use of resources. They are indicated as damage costs and are expressed as ELU (Environmental Load Units). One ELU represents an externality corresponding to 1 Euro environmental damage cost. The cost or a "price" can be developed from individuals' "Willingness to pay (WTP)". WTP represents the value that an average OECD-inhabitant, having the impacts on her/himself, is willing to pay to avoid environmental damage [21]. Global average damage costs are estimated for emissions and resources, and the reference is the present state of environment (business as usual), in the year 2015. Therefore, the basic idea of EPS is to make a list of environmental damage costs available to the analyst, in the same way as ordinary costs are available for materials, processes and parts. Damage costs for an emission or used resource are determined as the sum of damage costs caused by the emission or resource use on the safeguard subject, via different mechanisms (pathways).

2.1 Fossalto pilot

This eLCC analysis was conducted from the perspective of the entrepreneur/decision maker who wants to invest in the waste management system developed within the NETWAP project. Therefore, the objective of this study is to provide decision makers with information useful for evaluating the economic convenience of the investment and for identifying the aspects that can be improved to increase profitability. Both internal costs and externalities were accounted for.

Concerning the system boundaries, the studied system, its boundaries and the related assumptions were the same as defined for the LCA study (for deeper details, see Section 2.1.1). In order to make the results comparable, also the functional unit of the investigated system was the same for both LCA and eLCC. Emissions, material and energy consumptions as well as financial costs related to the system were all referred to the same FU (namely, the treatment of 1 ton of organic waste produced in Fossalto in 2020). Moreover, in order to match eLCC with LCA, the same time boundaries were chosen. Since the time boundaries for LCA analysis were 1 year (2020), it was not necessary to discount the costs to present values.

2.1.1 Internal costs

Internal costs were split into collection, transportation and treatment phases, analogously to the environmental impacts assessment.
The internal costs referring to the baseline scenario were mostly provided by the Fossalto Municipality. When primary data were not available, price estimates were retrieved from specialized websites. The internal costs for the baseline scenario of Fossalto pilot, included in the eLCC analysis and referring to the selected FU (1 ton of treated organic waste), are reported in Table 10.

Table 10. Internal costs for the baseline scenario in Fossalto, referring to the selected FU (1 ton of treated organic waste).

Organic Fraction of Municipal Solid Waste in Fossalto (CB) (total amount 43,14 t; reference year 2020)			
Internal costs	**Unit**	**Value**	**Reference**
Collection phase			
Cost of personnel for MSW	€/yr	23738	Fossalto Municipality (yearly cost of

collection/transportation*			personnel for MSW collection)
Cost of containers	€/item	7	Fossalto Municipality (as average value)
Containers estimated lifetime	yrs	7	[12]
Cost of compostable bags	€/item	0.1104	https://www.amazon.it/SACCHETTI-COMPOSTABILI-BIODEGRADABILI-RACCOLTA-UMIDO-ORGANICO/dp/B01EVBZJFE
Transportation phase			
Cost of each roundtrip	€/day	10	Fossalto Municipality
Cost of lorry	€	31000	https://www.isuzu.it/it/truck/35-ton/serie-blue/l35
Lorry estimated lifetime	km/item	540000	EcoInvent v.3.5
Treatment phase			
Montagano facility			
Cost of treatment	€/ton	80	Fossalto Municipality
Income from compost	€/ton	25	https://agronotizie.imagelinenetwork.com/fertilizzanti/2017/09/11/compost-consigli-pratici-per-l-acquisto-e-utilizzo/55336

* The costs of personnel were equally distributed between collection and transportation phases.

The total internal costs of the Fossalto baseline scenario amount to 270.89 €/FU. The highest costs sustained for the treatment of organic waste are related to the collection costs, totalling around 118 €/FU (44% of the total costs), 60% of which are spent for the compostable bags and 36% as personnel costs. The treatment costs follow, amounting to 80 €/FU. Transportation costs amount to 75 €/FU, including 42.10 €/FU dedicated to the personnel in charge of the transportation, while the income deriving from the production of compost is limited to 2.63 €/FU.

Therefore, if transportation represents the main hotspot from the environmental point of view, the cost of collecting organic waste by means of compostable bags is a crucial expenditure that should be reduced, by lowering the collection events for example.

Experimental data concerning the operational costs of the electromechanical composter installed in the pilot territory can be gathered only when the plant is regularly running for some time. Therefore, due to the lack of updated data, only estimates can be done for evaluating the internal costs. It can be assumed that the internal costs of the NETWAP scenario essentially differ from the baseline scenario (i) for the transportation phase, that is reduced to the distances run within Fossalto (only 15 km out of 45 km), and (ii) for the treatment in the Montagano facility. Also the income deriving from the production of compost is different (totalling 1.42 €/FU), due to the lower amount of produced compost, while the costs of the collection phase, that are the highest in determining the total internal costs, are unchanged. As far as the treatment phase is concerned, a conservative perspective can be applied, considering no significant change in the costs (although it is likely to foresee a reduction of costs). Based on these assumptions, the total internal costs of the Fossalto NETWAP scenario are reduced by 18%, amounting to 222.03 €/FU.

2.1.2 Externalities

The environmental damage costs of the studied process, for each investigated safeguard subject, are reported in Table 11.

Table 11. Environmental damage costs for the baseline scenario in Fossalto, referring to the selected FU (1 ton of treated organic waste).

Safeguard subject	*Unit*	*Collection phase*	*Transportation phase*	*Treatment phase*	*Compost recovery*	*Total*
Ecosystem services	ELU	6.81E-02	10.63	-0.11	-0.11	10.47
Access to water	ELU	4.29E-03	0.65	0.01	-0.01	0.65
Biodiversity	ELU	2.68E-04	0.03	1.74E-03	-4.50E-04	0.04
Human health	ELU	3.92	470.46	4.02	-5.03	473.36
Abiotic resources	ELU	24.16	5531.71	18.13	-211.84	5362.15

The total environmental damage cost for the baseline scenario in Fossalto amounts to about 5847 €/FU, with a dominant contribution (higher than 90%) deriving from the Abiotic resources safeguard subject. In particular, the factor that mostly affects the environmental costs of Abiotic resources is associated to the transportation phase and the related consumption of fossil fuels. The transportation phase is also prevailing in the Human health safeguard subject, that contributes to the total environmental damage cost for 8.10%. Indeed, for Access to Water, Ecosystem Services and Biodiversity, no significant environmental costs were registered. The savings in the environmental costs due to the avoided production of chemical soil improvers, substituted by the produced compost, are not very relevant, being lower than 4% of the damage cost in each safeguard subject.

Analogous results are achieved for the NETWAP scenario, as shown in Table 12.

Table 12. Environmental damage costs for the NETWAP scenario in Fossalto, referring to the selected FU (1 ton of treated organic waste).

Safeguard subject	*Unit*	*Collection phase*	*Transportation phase*	*Treatment phase*	*Compost recovery*	*Total*
Ecosystem services	ELU	0.07	3.51	1.89	-0.04	5.42
Access to water	ELU	4.11E-03	0.22	0.11	-2.88E-03	0.33
Biodiversity	ELU	2.56E-04	0.01	0.01	-1.93E-04	0.02
Human health	ELU	3.79	153.96	66.50	-2.13	222.12
Abiotic resources	ELU	23.43	623.44	27.50	-25.17	649.21

The total environmental damage cost for the NETWAP scenario in Fossalto drastically drops to 877.10 €/FU. The contribution of the different phases to the safeguard subjects does not differ from the baseline scenario, with around 90% of the costs deriving from the Abiotic resources safeguard subject. Also in this case, the transportation phase and the related consumption of fossil fuels determine the main environmental costs of Abiotic resources and Human health (96% and 69% respectively). Similarly, the treatment phase, generating the 11% of the total environmental damage cost, affects Human health and Abiotic resources at an extent of 66,5% and 27,5% respectively.

2.2 Ist Island pilot

Analogously to the case of Fossalto pilot action, for Ist Island the eLCC analysis was conducted from the perspective of the entrepreneur/decision maker who wants to invest in the waste management system developed within the NETWAP project. Therefore, the objective of this study is to provide decision makers with information useful for evaluating the economic convenience of the investment and for identifying the aspects that can be improved to increase profitability. Both internal costs and externalities were accounted for.

Concerning the system boundaries, the studied system, its boundaries and the related assumptions were the same as defined for the LCA study (for deeper details, see Section 2.2.1). In order to make the results comparable, also the functional unit of the investigated system was the same for both LCA and eLCC. Emissions, material and energy consumptions as well as financial costs related to the system were all referred to the same FU (namely, the treatment of 1 ton of organic waste produced in Ist Island). Moreover, in order to match eLCC with LCA, the same time boundaries were chosen. Since the time boundaries for LCA analysis were 1 year, as average value between 2018 and 2020, it was not necessary to discount the costs to present values.

2.2.1 Internal costs

In Ist Island, waste collection is a fully public service. According to the primary aggregated data provided by the Ist Municipality, the internal costs for the baseline scenario, included in the eLCC analysis and referring to the selected FU (1 ton of treated organic waste), are reported in Table 13.

Table 13. Internal costs for the baseline scenario in Ist Island, referring to the selected FU (1 ton of treated organic waste).

Organic Fraction of Municipal Solid Waste in Ist Island (total amount 20.28 t, out of 65.62 ton of mixed municipal waste)			
Internal costs	**Unit**	**Value**	**Reference**
Cost of MSW collection	€/yr	26000	Ist Municipality
Maintenance of vehicles	€/yr	3900	Ist Municipality
Personnel cost	€/yr	11050	Ist Municipality

The total internal costs of the baseline scenario in Ist Island amount to 2019.23 €/FU, which appears very high for such a small island without industrial activities. The highest costs sustained for the treatment of organic waste are related to the collection costs, totalling around 1280 €/FU (63% of the total costs). These costs include the transportation (by ship) of waste to the mainland. Moreover, it has to be considered that the yearly costs are determined by the amount of mixed municipal waste that have to be disposed of and that there is no income, due to the lack of valorisation treatments.

In the case of the NETWAP scenario, the internal costs are drastically reduced thanks to the local composting and the avoided transportation by ship. Considering the same assumptions made for the Fossalto pilot, the estimate of the total internal costs is in all respects similar to the Fossalto NETWAP scenario. Only slight differences can be highlighted due to a lower distance run per FU in Fossalto (39 km/FU in Fossalto *versus* 51,4 km/FU in Ist Island).

2.2.2 Externalities

The environmental damage costs of the investigated scenario of organic waste management in Ist Island, for each investigated safeguard subject, are reported in Table 14.

Table 14. Environmental damage costs for the baseline scenario in Ist Island, referring to the selected FU (1 ton of treated organic waste).

Impact category	*Unit*	*Collection*	*Transportation by truck*	*Temporary storage*	*Transportation by ship*	*Landfilling*	*TOTAL*
Ecosystem services	ELU	0.02	2.18	0.42	0.06	0.01	2.68
Access to water	ELU	9.71E-04	0.13	0.02	2.86E-03	0	0.16
Biodiversity	ELU	6.06E-05	0.01	1.42E-03	2.10E-04	3.57E-03	0.01
Human health	ELU	0.89	96.37	32.32	2.58	0.39	132.54
Abiotic resources	ELU	5.47	1133.08	6364.12	6.50	0	7509.17

The total environmental damage cost for the baseline scenario in Ist Island amounts to about 7644.57 €/FU. As already observed for Fossalto, the Abiotic resources safeguard subject determines almost the totality of the environmental damage, with a contribution of 98%, whereas the remaining 2% is due to Human health safeguard subject. In particular, the temporary storage of waste in the deposit station mostly affects the environmental costs of Abiotic resources with 6364 €/FU, corresponding to 85% of the total damage cost on the safeguard subject. The remaining 15% (1133 €/FU) is associated to the transportation phase and the related consumption of fossil fuels. In the Human health safeguard subject, the transportation phase is prevailing (73%), but the temporary storage also gives a relevant damage (24%). Indeed, for Access to Water, Ecosystem Services and Biodiversity, no significant environmental costs were registered.

Table 15 shows the externalities of the NETWAP scenario in Ist Island. The total environmental damage cost amounts to 1147.05 €/FU, considerably lower than in the baseline scenario. As for the other investigated scenarios, the Abiotic resources safeguard subject is responsible for the 90% of total external costs, with a predominant contribution from the transportation phase, that also in the Human health category plays a relevant role (with a contribution of 86%). A saving of 116.83 €/FU is determined in the Abiotic resources safeguard subject thanks to the recovery of compost.

Table 15. Environmental damage costs for the NETWAP scenario in Ist Island, referring to the selected FU (1 ton of treated organic waste).

Safeguard subject	*Unit*	*Collection phase*	*Transportation phase*	*Treatment phase*	*Compost recovery*	*Total*
Ecosystem services	ELU	0,02	2,18	0,47	-0,06	2,60
Access to water	ELU	9,71E-04	0,13	0,03	-3,93E-03	0,16
Biodiversity	ELU	6,06E-05	0,01	0,00	-2,55E-04	0,01
Human health	ELU	0,89	96,37	17,06	-2,80	111,51
Abiotic resources	ELU	5,47	1133,08	11,06	-116,83	1032,78

3. Social Life Cycle Assessment (s-LCA)

3.1 Methodological approach

The Social LCA (hereinafter S-LCA) is a methodology that aims to assess the potential social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle, including those stages in which companies do not have a direct control. With S-LCA it is possible to evaluate social risks, effects, performances and impacts. *Social impacts* are consequences of positive or negative pressures on social areas of protection (i.e., well-being of stakeholders), which can be caused by e.g., a specific behaviour of one or more stakeholders, which for example causes effects related to changes in life expectancy, health, social status. Social effects measure the effect of an activity on stakeholders but an intermediate level, as the entire causal relationship is not identified. Social performances are neither social effects nor social impacts of changes, but "[…] features of a situation in a relevant organization (or features of the value chain of organizations shaping the life cycle), referring more or less to social issues” [22]. Finally, a *social risk* measures the likelihood of negative effects only (damage, injury, loss) that may be avoided through preventive actions [23].

The S-LCA methodology is formalized within the Social LCA Guidelines framework, published by the UNEP/SETAC Life Cycle Initiative [24]. Since its first edition in 2009, the practice of S-LCA has evolved from a small circle of academic practitioners to one that now includes stakeholders from industry, policy makers, and business. Because different S-LCA methods have different applications and objectives, the last version of Guidelines aims to explain the strengths and challenges of different approaches to target multiple questions. Each section defines the main steps, provides examples, and directs the user to additional resources and references. The assessment framework is based on the ISO 14040, as for LCA: thus, goal and scope, inventory, impact assessment and interpretation stages.

A key step of any S-LCA study is the materiality assessment, i.e., the identification of stakeholder and social topic relevant for the product system at hand. Given that the S-LCA Guidelines do not provide any guidance on how to do materiality assessment, for this purpose within the NETWAP project, also the Handbook for product social impact assessment [25] has been considered. The Handbook for Product Social Impact Assessment (PSIA) – (“the Handbook”) builds on the UNEP 2009 S-LCA Guidelines and the Methodological Sheets [26] to present a method with a specific set of indicators that can be applied to assess social impacts at the product level. It describes a consensus-based methodology to assess positive and negative social impacts of products and services on four stakeholder groups: workers, local communities, small-scale entrepreneurs and users. Uniquely, the methodology focuses on assessing social impacts of products and services. The PSIA method outlined in the Handbook consists of four key components:

- Stakeholder groups
- Social topics
- Performance indicators
- Reference scales to assess impact

Figure represents the relationship between these elements.

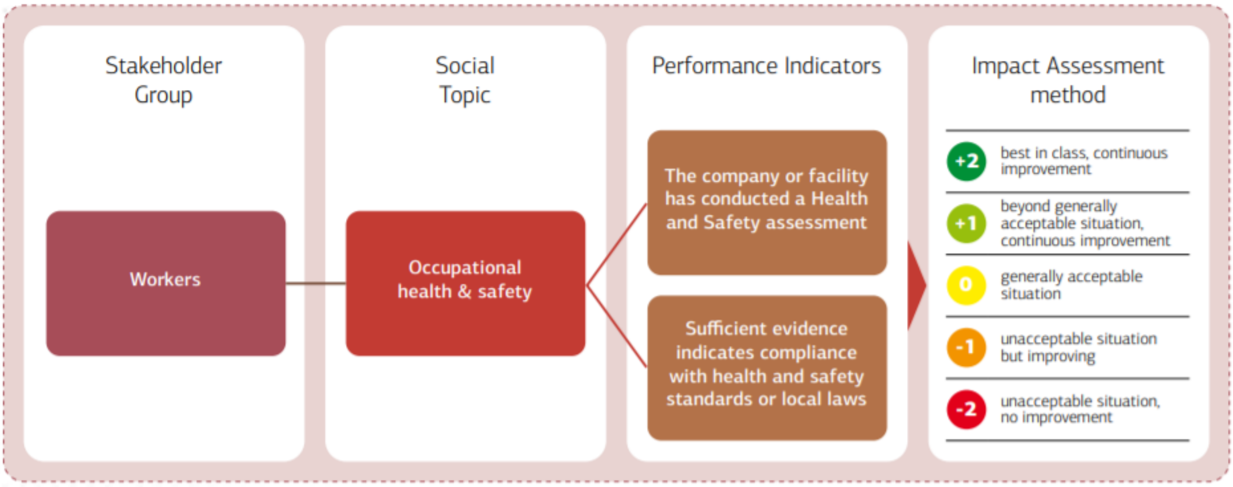

Figure 9. Key components of PSIA methods and their relations.

The social topics are based on the analysis of the interaction between companies and society. They are dependent on the way society functions (social dependencies) and they affect the way society functions (social impacts). The handbook suggests the following list of 25 social topics (Figure 10) to be considered for the materiality assessment with the purpose of pre-selecting the relevant ones.

Social topics for workers	Social topics for local communities
1.1 Occupational health and safety 1.2 Remuneration 1.3 Child labour 1.4 Forced labour 1.5 Discrimination 1.6 Freedom of association and collective bargaining 1.7 Work-life balance	3.1 Health and safety 3.2 Access to material and immaterial resources 3.3 Community engagement 3.4 Skill development 3.5 Contribution to economic development
Social topics for users	**Social topics for small-scale entrepreneurs**
2.1 Health and safety 2.2 Responsible communication 2.3 Privacy 2.4 Affordability 2.5 Accessability 2.6 Effectiveness and comfort	4.1 Meeting basic needs 4.2 Access to services and inputs 4.3 Women's empowerment 4.4 Child labour 4.5 Health and safety 4.6 Land rights 4.7 Fair trading relationships

Figure 10. Social topics of PSIA method for the four stakeholder groups.

According to the Handbook, relevance can have two meanings:

- A topic is more material if a product and its life-cycle is likely to have a high positive or negative impact on the stakeholders and thus the business (e.g. it is well known that recycling of electronics can create very serious health damages to the workers or small-scale entrepreneurs involved in waste processing, so workers' health is a good candidate for a relevant social topic).
- A topic is more material if the intended audience finds a topic very relevant and desires to have information on it (e.g. in Europe people are very concerned with women's rights therefore customers want to see that information on whether a particular product has good or bad impacts for women's rights).

To assess materiality and estimate the potential impacts, some form of expert judgement is needed. Whether an audience considers a social topic important depends of course on the goal of the analysis and on which audience the assessment decides to focus on. If the study results are supposed to be used by or (directly or indirectly) reported to the general public, public perception of the topics is important. This perception may be quite different in different regions and cultures; for instance, child labour is seen as a much higher priority in the West than in other cultures. If the study is to be used by a more specifically

defined smaller group (for instance, when a product is marketed to very young or very old customers or other specific subsets of society), the perception of this group must be used.
This means that unique and fixed results in terms of materiality do not exist and even the materiality assessment could be reviewed during the S-LCA, since the verdict on what is material and what is not may change when more information is gathered.
Within the NETWAP project, the Social LCA evaluation is characterised by the following aspects:

- Objects of the assessment are two pilot cases of local organic waste management through composting; the technology, quite simple and installed in two small villages located in Italy and Croatia, is still in the initial operation phase;
- The potential socio-economic impacts are limited to the reference geographic area (Ist island and Fossalto village);
- The two villages differ in terms of geographic and socio-economic contexts and motivations for the implementation of the new technology; however, potential benefits from the new system are expected, and no relevant differences in terms of social risks in both situations.

It is important to highlight that social impacts and/or performances are the results of actions undertaken by stakeholders, driven by production and consumption activities throughout the life cycle. As such, a product system is a "system of interacting organisations whose social behaviour depends on the existence of the product studies and causes social effects" [22]. The product, service, or organisation does not cause social impacts, but it is human action that creates them; moreover, human activities that produce goods are structured into organisations. Thus, organisations are the reference units for a social life cycle: social impacts/performances are not directly related to process flows and to the function(s) delivered by a given product, service, or organisation, but rather to the way a particular company interacts with its stakeholders.

Therefore, considering the main characteristics of the pilot case of NETWAP reported above, and the lack of direct information on the composting operational phase and of use of compost in local farming activities, **the S-LCA methodology was applied to map potential social issues of concern that, currently, cannot be quantified but evaluate at qualitative level** with the following purposes:

- The definition of the social materiality for the new organic waste treatment via local composting in the two pilot cases – Fossalto (Italy) and Ist island (Croatia);
- The definition of indicators for measuring and monitoring the potential social issues that might arise when the two composters will be up and running;
- A first evaluation of the social effects of the new organic waste treatment, via local composting, compared to the current situation in the two pilot cases – Fossalto (Italy) and Ist Island (Croatia).

In this regard, the technical report does not follow the structure of the S-LCA phases, but it is organised according to the main goals defined above.

3.2 Goal and scope

3.2.1 Objective of the S-LCA study

The goal of the social assessment is threefold:

- to define the most relevant social aspects related to the introduction of organic waste collection and treatment via local composting in the two pilot cases – Fossalto (Italy) and Ist island (Croatia);
- to define social indicators for monitoring potential social issues that might arise when the two composters will be up and running;
- to provide a preliminary overview of the potential benefits related to the new organic waste management system in the two pilot cases – Fossalto (Italy) and Ist island (Croatia).

3.2.2 Description of the analysed systems in Fossalto

The service object of the study is depicted in Figure for Fossalto pilot case.

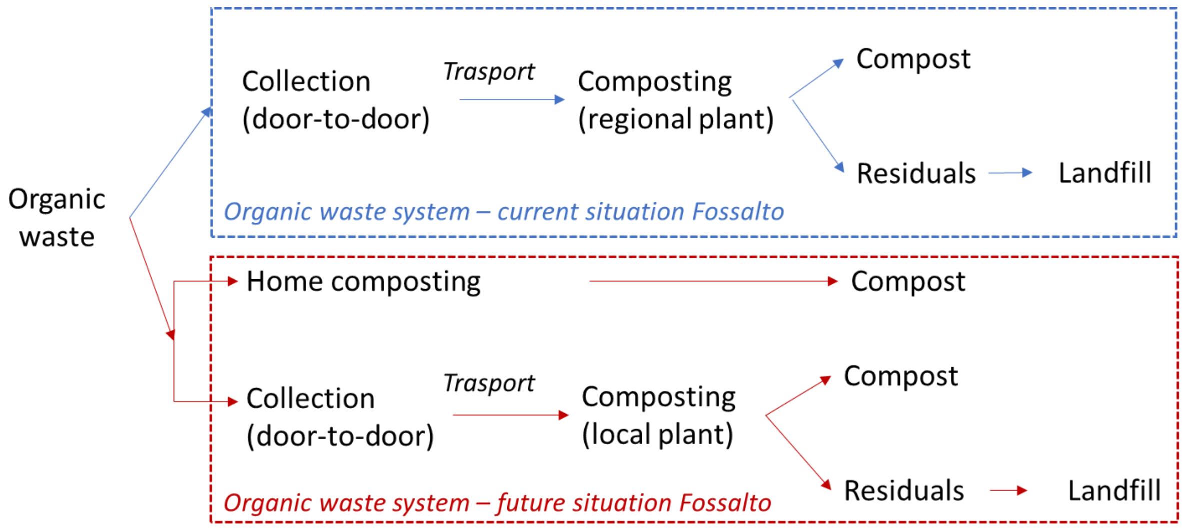

Figure 11. System description of Fossalto organic waste management.

Currently, the sorted collection of organic waste is already in place with a door-to-door collection system; wastes are so collected and transported to a composting facility located far from the village and managed by the regional company. Compost is produced for further application in agriculture and residuals are landfilled. The new organic waste management system, developed within NETWAP project, consists in the introduction of a formal list of citizens who will manage organic waste directly in their home composting and the introduction of the composting plant located in the village and managed directly by the local authority. The new system will produce a reduction of costs and impacts related to the organic waste transport from Fossalto to the regional composting plant, and this in turn results in the reduction of waste disposal fee for citizens and the municipality.

At this moment, the local composting plant has received a positive opinion from the Regional Environmental Protection Agency (Arpa Molise), therefore installation and start-up phase are expected soon.

The main differences between the current and future systems are listed in Table 6.

Table 16. Main aspects of the waste management systems – current and future – analysed for Fossalto pilot case.

	Current system	**Future system (proposed in NETWAP project)**
Organic waste separate collection	Present	Present
Collection system	Door-to-door	Door-to-door
Waste transport	Via lorry	Not necessary
Type of waste treatment	Composting	Composting
Management of waste treatment	Molise regional authority	Municipal authority

3.2.3 Description of the analysed systems in Ist island

As for the Ist island, the service object of the study is depicted in Figure 12.

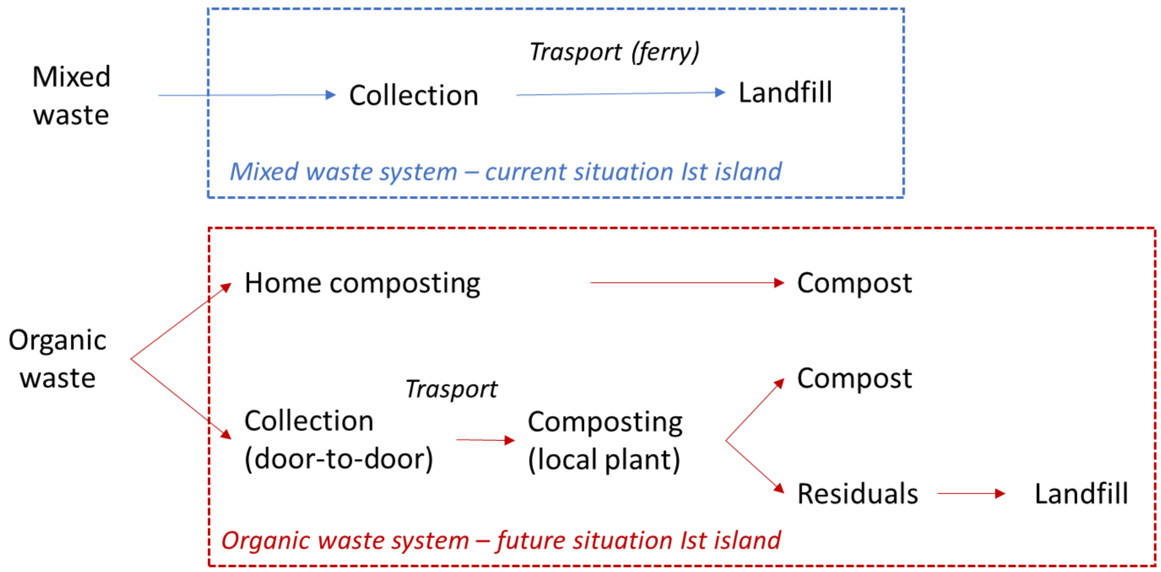

Figure 12. System description of Isl Island waste management system.

Currently, organic fraction is not separately collected on the island, therefore it is collected, transported and treated together with mixed waste. Only few cases of home composting are present on the island. Transport of waste by ferry is necessary because waste treatment plants are not present on the island and so they need to be transported near Zadar, where mixed waste are landfilled. The new organic waste management system will first introduce sorted organic waste, which will be collected by means of door-to-door system. Thus, the new waste system will consist in the introduction of a formal list of citizens who will manage organic waste directly in their home composting and the introduction of the composting plant located in the village and managed directly by the local authority. The main advantages are the reduction of costs and impacts of waste transport by ferry, and the consequence of waste rate for citizens and the municipality, but also the production of compost that could be applied by the local farms, substituting soil improvers which are necessarily ferried from the coast.

At this moment, after several issues related to location and electricity supply, the pilot phase is on-going; the waste input to the composting plant is still not as large as the season is starting slower than usual but and also sorted collection is in the polit phase since people are still adjusting to waste separation.

The main differences between the current and future systems are listed in Table 17.

Table 17. Main aspects of the waste management systems – current and future – analysed for Ist Island pilot case.

	Current system	**Future system (proposed in Netwap project)**
Organic waste separate collection	Not present	Present
Collection system	Door-to-door	Door-to-door
Waste transport	Via ferry	Not necessary
Type of waste treatment	Landfill	Composting (and compost production)
Management of waste treatment	Zadar regional authority	Municipal authority

3.2.4 Description of the context

The first pilot case involves the municipality of Fossalto located in the Molise region of Italy. Fossalto is a very small village (1258 inhabitants) with high average age and suffering from depopulation. It is located in an agricultural area with no touristic development; therefore, few businesses exist in terms of restaurants and bar, and no hotels are present. Some of the inhabitant live in the country area and already carry out informal home composting; moreover, the presence of small size farm activities represents an opportunity for the direct use of compost. Few other examples of local composting exist in the reference region (Molise), therefore Fossalto pilot case represents one of the first examples. The level of awareness in terms of potential benefits from the different organic waste management is not completely developed; in this sense the information and sensibilization activities already in place will be fundamental.

Ist is a very small island of the Dalmatian coast of Croatia. The closest city to Ist is Zadar. The island has an area of 9.65 km^2 and it has a permanent population of 182 inhabitants. During the past 50 years it has witnessed a slow depopulation which has halved its number of inhabitants. The Croatian Government is attempting to attract people to the island through its National Programme of Islands' Development. Recently the island has benefited from the development of tourism and the Covid emergency have produced a repopulation with young families moving there. The island is mainly tourist area; therefore, some touristic facilities are present during all the year (restaurants, cafes, bed&breakfast) and the port authority is also involved in the waste management system because directly inform and manage waste produced by touristic ships. Also, small farms exist, producing fruits and vegetables which are directly sold in the local market and consumed on the island. The high demand for more sustainable tourism (eco-tourism) is one of the main drivers for technological improvements; this process is involving many islands of the Dalmatian coast, in the region of Zadar. In this sense, there is a good level of awareness in terms of potential benefits from the new organic waste management since it is a concrete action to be in step with the current national programme of islands' sustainability.

3.2.5 System boundaries

The system boundaries are defined at two levels. The first concern the life cycle stages from a technological point of view and include all the activities belonging to the waste management system, from the waste collection, through their transportation, treatment via composting and compost production. Landfill disposal is excluded because it does not vary from the current and the future situations in a significant way; moreover, it is out of the scope of the project.

The second level concerns the stakeholder groups which are directly and indirectly affected by the waste system. In this project, the groups suggested by the handbook – workers, local communities, users and small-scale entrepreneurs – are considered as a starting point. The relations between stakeholders and life cycle stages are reported in Figure and Figure 14. In particular, for both Fossalto and Ist Island pilot case, the following groups are considered:

- group of "users", that is waste producers, are people involved in the waste production and sorting, both households and commercial facilities (e.g., touristic facilities);
- group of "workers" involved in the waste collection, transport and treatment by means of composting;
- group of "local communities" involved along the whole waste management system, from the collection to the composting treatment, excluding landfill disposal;
- group of "small-scale entrepreneurs" involved in the compost use for different applications especially local farming.

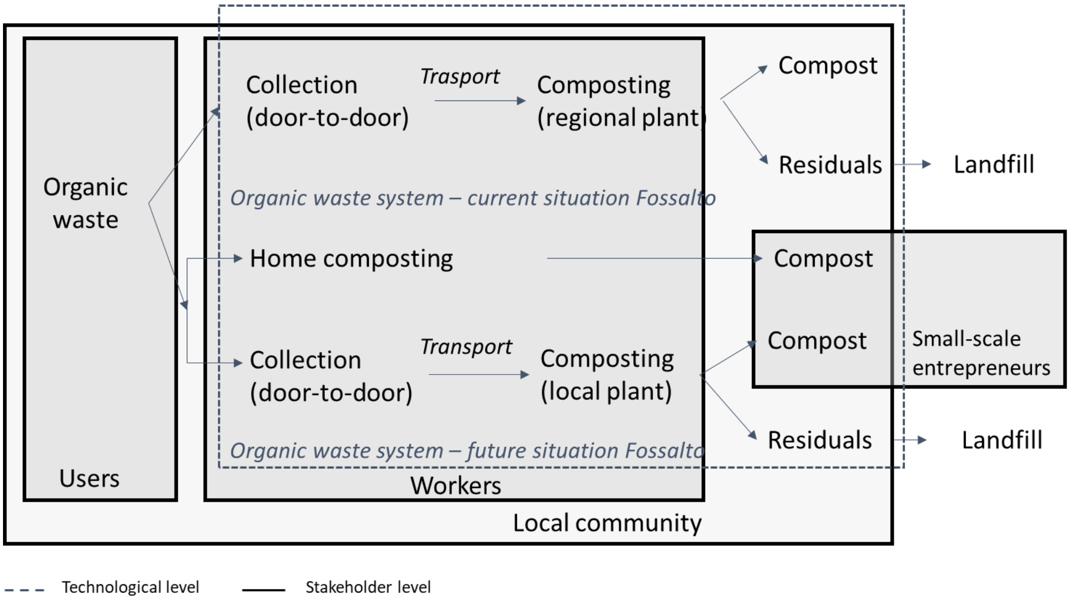

Figure 13. S-LCA system boundaries – Fossalto pilot case.

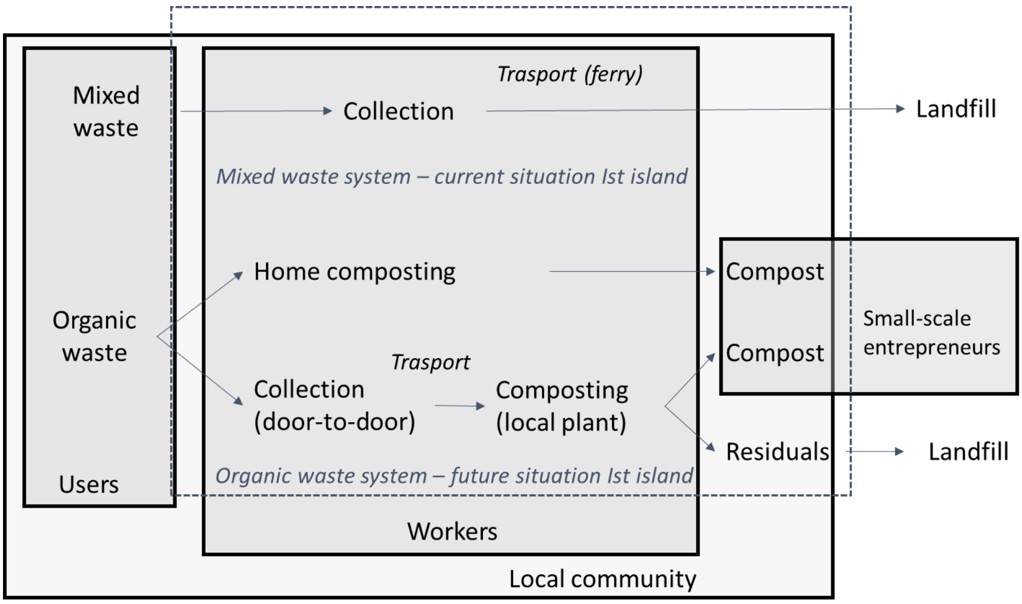

Figure 14. S-LCA system boundaries – Ist Island pilot case.

3.3 Definition of materiality

3.3.1 Approach

According to Mirdar Harijani et al. [27], waste management systems are usually optimised by taking the economic perspective into account, along with the environmental one, but generally leave aside the social point of view [28]. Specific guidelines targeted to the sector about social themes or indicators are not available yet in literature. Thus, for the definition of the materiality, a three-steps approach was applied, consisting in the identification of the method and suggested social topics, a desk research target to the sector, and interviews to partners, as depicted in Figure 15.

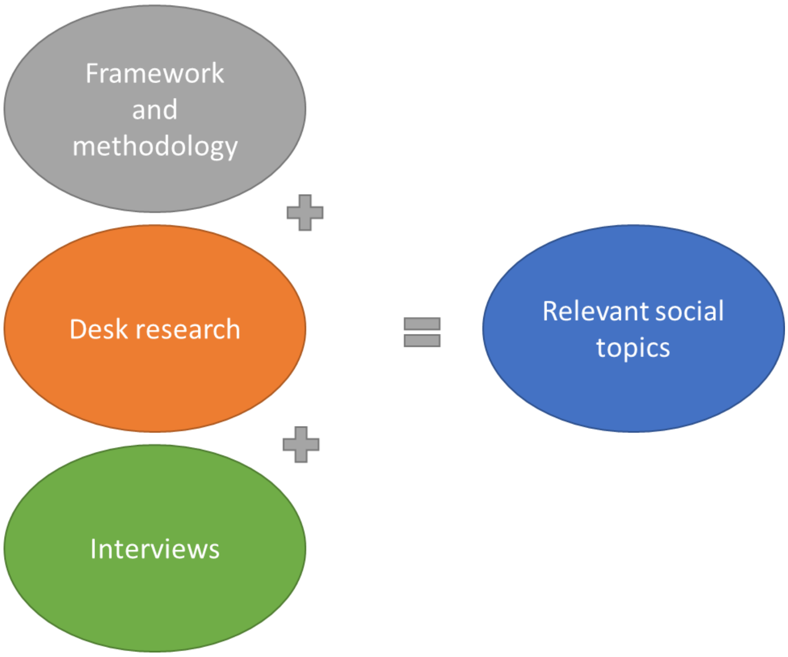

Figure 15. Three-steps approach for materiality analysis.

The analysis of the materiality started out with the identification of the social topics relevant for the four groups of stakeholders identified in the system boundaries: workers, local communities, users and small-scale entrepreneurs. They are four groups suggested by the Handbook and represent the starting point to be further validated by literature and partners. Table shows the social topics accounted for by the

Handbook, independently from the application considered, to be considered for the materiality assessment with the purpose of pre-selecting the relevant ones (an extended definition is reported in Annex).

Table 18. Social topics for the stakeholder groups suggested in the Handbook.

Stakeholder	**Social topics**
Workers	Occupational health and safety Remuneration Child labour Forced labour Discrimination Freedom of Association and Collective Bargaining Work-life balance
Users	Health and Safety Responsible communication Privacy Affordability Accessibility Effectiveness and comfort
Local communities	Health and safety Access to material and immaterial resources Community engagement Skill development Contribution to economic development
Small-scale entrepreneurs	Meeting basic needs Access to service and inputs Women's empowerment Child labour Heal and safety Land rights Fair trading relationships

As a second step, a desk research was carried out to review the current knowledge about relevant social aspects related to the waste management systems. The review was structured as follows:

- Both general waste management systems and those target to specific waste fractions (e.g organic, plastics) were included in the review, developed both in Europe and extra European countries;
- The following keywords were used: Social life cycle assessment AND SLCA AND social assessment AND social sustainability AND waste management AND recycling AND waste collection;
- The review was carried out by means of google, ResearchGate, science direct, and it included mainly scientific paper in the field of both Social LCA and waste management.

As a third step, interviews directly done to project partners' were carried out during two online meetings. The results from the literature analysis and the interviews are described in the following sections.

3.3.2 Results from literature

The literature review has been carried out to identify stakeholders and social aspects considered relevant by the papers related to the waste management system and with a focus on the organic fraction.
As many authors pointed out [29] [28], no consensus has been reached for the impact categories to be used, and not even for the stakeholders to be considered, when assessing the social impact caused by waste management systems. Therefore, the proposal and definition of social impact categories, indicators and metrics seem crucial to facilitate the social assessment of MSW management systems.
In recent years some case studies have analysed social performance of waste management systems by means of S-LCA methodology; most of them focused on applications in developing countries: Menikpura et al. [30], Aparcana and Salhofer [31] and Ak and Braida [32] for municipal solid waste (MSW) in Thailand and Turkey, respectively, and Lu et al. [33] for waste-to-energy incineration in Taiwan, among others. Ibáñez-Forés [28] specifically addressed the social performance of municipal solid waste (MSW) management systems in developing countries by taking into account a pilot case in Brazil where a selective MSW collection has been implemented with the collaboration of previous informal waste pickers, who have been reorganised into associations or cooperatives of collectors of recyclable materials (formal sector). It is evident that some of the relevant social topics coming out from these papers are not applicable in those socio-economic contexts where a formal waste management system is carried out according to specific regional or national legislation as in the case of European countries. For this reason, the literature review has been broadened to include also papers that dealt with social analysis of waste management even if not specifically developed according to the S-LCA methodology. As a result, seven papers were identified in addition.
Table 19.19 reports the results of reviewed papers in which different waste management systems were analysed. The following issues were identified for each study: the country where the case study was applied (geographical context) and the functional unit. 9 papers referred to developing countries (extra-Europe) and 7 studies to European countries. Most of the analysed studies are applied to MSW and focus

on all domestic waste fractions as a whole, or on the management of some specific fractions, mainly packaging waste. The remaining analysed studies focused on construction and demolition waste or industrial waste [34] or used cooking oil [35]. No papers were found about social analysis on organic waste fraction, apart from Martínez-Blanco [36] who addressed the application of S-LCA to compost production, among other types of traditional soil improvers.

Table 19. Reviewed papers about social assessment of solid waste management.

Sources	**Journal**	**Geographical context**	**Objective**	**Functional unit**
Aparcana and Salhofer [31]	International Journal of Life Cycle Assessment	Low income countries / Perù	To assess the social impact of formalised recycling systems and to determine the feasibility of applying S-LCA to three Peruvian recycling systems based on two formalisation approaches.	Amount of household recyclable waste collected by one house during 1 year. For Perù, 60 kg/inhabitant-year of collected recyclable household waste.
Aparcana and Salhofer [37]	International Journal of Life Cycle Assessment	Perù		Amount of household recyclable waste collected by one house during 1 year. (For Perù 60 kg/inhabitant-year of collected recyclable household waste)
Foolmaun and Ramjeeawon [38]	International Journal of Life Cycle Assessment	Mauritius Island	To investigate and compared the environmental and social impacts of four selected disposal alternatives of used PET bottles.	The disposal of 1 tonne of used PET bottles to the respective disposal facilities
Ibáñez-Forés et al. [28]	Ecological indicators	Districts of Joao Pessoa (Brasil)	To identify indicators to measure social performance of municipal solid waste management systems in developing countries.	Solid waste management
Lu et al. [33]	Sustainability	Taiwan	This study utilizes inventory analysis and S-LCA approach on GHG management of Waste-to-Energy incineration plants in Taiwan to systematically identify materiality issues to be promoted.	Not expressed
Menikpura et al. [30]	Waste management & research	Nonthaburi municipality (Thailand)	To identify a set of endpoint composite indicators able to consider the most critical ultimate damages/effects of MSW management on the environment, the economy and society in Thailand.	Not expressed

Prakash et al. [39]	Publisher Oko-Institut e.V.	Ghana	To identify improvement potentials for the Ghanaian e-waste management capacities through better recycling technologies by considering socio-economic assessment of the informal refurbishing and e-waste recycling sector in Ghana.	Not expressed
Umair et al. [40]	Resources, Conservation and Recycling	Pakistan	To assess the social impacts, by means of S.LCA, of informal e-waste recycling in Pakistan using data obtained in a detailed on-site inventory of the processes directly involved in informal e-waste recycling.	Not expressed
Yildiz-Geyhan et al. [29]	Resources, Conservation and Recycling	Istanbul (Turkey)	To analyse the social impacts of different packaging waste management systems, both formal and informal collection scenarios, in Istanbul, Turkey.	Collection of 1 ton packaging waste
Chifari et al. [41]	Ecological indicators	Italy/Naples	To develop an holistic framework to organize and integrate quantitative information characterizing the performance of Urban Waste Management Systems (UWMS) across dimensions and scales. Theoretical considerations are illustrated with preliminary data from a case study on the Metropolitan Area of Naples, Italy.	Not expressed
Ferrão et al. [42]	Resources, Conservation and Recycling	Portugal	To analyse the impact of the management of packaging waste on the environment, economic growth and job creation in Portugal.	Total packaging waste managed by the SPV under SIGRE in 2011.
Guidi et al. [43]	Chemical engineering transactions	Italy	To estimate sustainability indices, environmental, economic and social, to evaluate and compare areas for radiative waste disposal.	Not expressed
Fragkou et al. [44]	Local Environment: The International Journal of Justice and Sustainability	Spain/Barcelona	To propose indices for the evaluation of both the environmental and social performance of a system considering MSW management in Barcelona's metropolitan region.	Municipality

Hu et al. [45]	International Journal of life cycle assessment	Netherland	To propose an approach to put the LCSA framework into practice. This approach is illustrated with an on-going case study on concrete recycling.	The disposal of x ton of materials from the EOL building.
Lehmann et al. [46]	Sustainability	Spain and Portugal	The paper discusses the selection of social impacts and indicators from S-LCA and Social Impact Assessment (SIA) for two case studies: Integrated Water Resources Management in Indonesia and Integrated Packaging Waste Management in Spain and Portugal.	Not expressed
Martínez-Blanco et al. [36]	Journal of Cleaner production	Spain	To explain and discuss the challenges of S-LCA methodology in a case study under the framework of Life Cycle Sustainability Assessment (LCSA). The environmental, economic and social aspects related to two mineral fertilizers and one industrial compost were assessed.	To fulfil nitrogen fertilization demand for the production.
Vinyes et al. [35]	International Journal of life cycle assessment	Spain	To compare the sustainability of three domestic Used Cooking Oil (UCO) collection systems, by means of LCSA, to determine which systems should be promoted for the collection of UCO in cities in Mediterranean countries	To collect the used cooking oil generated in a neighbourhood of 10,000 inhabitants for 1 year in the city of Barcelona considering the efficiency of the each collection system.

The following tables show the stakeholder groups (Table 20), social impact categories (Table 21) and the social impact subcategories/topics (Table 22) considered in the reviewed literature.

Overall, the results indicate that no consensus has been reached on either the impact or stakeholder categories. However, in relation to the stakeholder categories applied in most of the reviewed studies, nine different categories were identified, five of which match those proposed by UNEP (2020) and/or Handbook. Workers (considered in 75% of the reviewed studies) and local communities (considered in 66%) are the groups generally considered, followed by citizens/consumers/users, corresponding to the waste producers (58%) and society (58%). Value chain actors and municipality/public administration are contemplated only in three and four papers out of twelve, respectively.

Table 20. Stakeholder groups considered in the reviewed papers (those studies where stakeholder groups are not reported have been excluded).

	Developing countries								European countries			
	Aparcana and Salhofer [31]	Aparcana and Salhofer [37]	Foolmaun et al. [38]	Ibanez-Fores et al. [28]	Lu et al. [33]	Prakash et al. [39]	Umair et al. [40]	Yildiz-Geyhan et al. [29]	Chifari et al. [41]	Lehmann et al. [46]	Martinez-Blanco et al. [36]	Vinyes et al. [35]
Municipality / Public administration	X	X		X					X			
Informal recyclers	X											
Waste disposal companies / Recycling companies / Formal recyclers	X	X							X			X
Citizens / Consumers/ Users	X			X	X			X	X		X	X
NGOs		X							X			
Workers			X	X	X	X	X	X		X	X	X
Society			X		X	X	X	X			X	X
Local Community			X		X	X	X	X		X	X	X
Value chain actors					X		X					X

Some studies have followed the UNEP-SETAC guidelines (e.g. [46] [36] [35]) to select the social impact categories and indicators, while others have used their own criteria/guidelines (e.g. [41] [43]); no studies have considered the Handbook, this probably because of its recent publication and applications. Eight impact categories are identified in the reviewed papers; the more frequent considered social impact categories are: Socio-economic repercussions (82% of the studies), working conditions (65% of the studies), Human rights (59%), Health and safety (35% of the studies) and governance (35%) (Table 21).

Table 22 indicates the social aspects/topics/subcategories that are considered in the reviewed papers and grouped according to the impact categories.

Table 21. Impact categories considered in the reviewed papers.

	Aparcana and Salhofer [31]	Aparcana and Salhofer [37]	Foolmaun and Ramjeeawon [38]	Ibanez-Fores et al. [28]	Lu et al. [33]	Menikpura et al. [30]	Prakash et al. [39]	Umair et al. [40]	Yildiz-Geyhan et al. [29]	Chifari et al. [41]	Ferrao et al. [42]	Guidi et al. [43]	Fragkoua, et al. [44]	Hu et al. [45]	Lehmann et al. [46]	Martinez-Blanco et al. [36]	Vinyes et al. [35]
Human rights	X	X	X	X			X	X	X						X	X	X
Working Conditions	X	X	X	X			X	X	X					X	X	X	X
Socio-economic repercussions	X	X	X	X	X			X	X	X	X	X	X		X	X	X
Damage to human-health (DALY)						X											
Income-based community well-being			X		X	X											
Health and safety			X	X				X	X			X				X	
Cultural heritage												X				X	
Governance					X		X	X	X							X	X

Table 22. Social aspects/topics/subcategories considered in the reviewed papers.

Source	**Human rights**	**Working Conditions**	**Socio-economic repercussions**	**Damage to human-health (DALY)**	**Income-based community well-being**	**Health and safety**	**Cultural heritage**	**Governance**
Aparcana and	Child labour Discrimination	Freedom of association	Education	---	---	---	---	---

Salhofer [31][37]	Education	and collective bargaining Working hours Minimum income Fair income Recognised employment relationship and fulfilment of legal social benefits Physical working conditions (health, security, working equipment) Psychological working conditions							
Foolmaun and Ramjeeawon [38]	Child labour Discrimination	Fair salary Forced labour Health and safety	Community engagement	---	Contribution to economic development	Health and safety	---	---	

		Social benefits/social security						
Ibanez-Fores et al. [28]	Equal opportunities (discrimination)	Working rights Quality of job positions (working conditions) Professional development	Socio-economic conditions Community satisfaction & participation	---	Local development	Health and safety	---	Governance
Lu et al. [33]	---	---	Promoting social responsibility Social benefit/social security Community engagement Access to immaterial resources Access to material resources	---	---	---	---	Public commitment to sustainability issues Contribution to economic development Technology
Prakash et al. [39]	Forced labour, Child labour	Safe & healthy	Safe & healthy living	---	Employment creation	---	---	Unjustifiable risks

		working conditions Freedom of association and right to collective bargaining Equality of opportunity and treatment and fair interaction Remuneration Working hours Employment security Social Security Professional development Job satisfaction	conditions Human rights and indigenous rights Socioeconomic opportunities Community engagement					Contribution to national economy and contribution to national budget Impacts on conflicts
Umair et al. [40]	Child labour Equal opportunies/discrimination	Working hours Health and safety (work	Promote social responsibility	---	Local Employment Contribution to economi	Health and safety (living environment &	---	Public contribution to sustainable issues

		environment) Social security Forced labour Wages Freedom of association	Fair Competition Community engagement		c development	workers)			
Yildiz-Geyhan et al. [29]	Forced labour Child labour Discrimination	Health and safe working conditions Job satisfaction and engagement Working hours Wage Social benefits/Security Freedom of association and collective bargaining	Secure living conditions Social acceptability Service satisfaction	---	Employment Contribution to economic development	Health and safe working & living conditions	---	---	---
Chifari et al. [41]	---	---	---	---	Jobs created	---	---	---	---

Ferrao et al. [42]	---	---	---	---	Jobs created	---	---	---
Guidi et al. [43]	---	---	Social acceptability Demography	---	---	Community health	Social structure Community character	---
Fragkoua et al. [44]	---	---	Environmental justice Average socioeconomic status Unemployment rate Average studies level Post-compulsory education	---	---	---	---	---
Hu et al. [45]	---	Person per hour employed	---	---	---	---	---	---
Lehmann et al. [46]	Equal opportunities	Hours of Work	---	---	Local Employment	Health and safety	---	---
Martinez-Blanco, et al. [36]	Child labour Forced labour Equal opportunities/Discrimination	Freedom of association and collective bargaining	Safe and healthy living conditions	---	Local employment Contribution to economi	Health and safety	Education and responsibility Comfort and	Corruption Public commitment to sustaina

		Fair salary Working hours	Access to material resources Community engagement		c development		collecting effort for citizens Acceptance and willingness to collect organic waste	bility issues Prevention and mitigation of armed conflicts Feedback mechanism Product application Transparency
Vinyes et al. [35]	Equal opportunies (Sex) Equal opportunities (degree of disability) *(INDICATORS)*	Total employees Total working hours Employees with disabilities Employees with higher education Employees with basic education *(INDICATORS)*	Children's environmental education	---	Local employment Contribution to economic development	---	---	Public committment to sustainability issues

Table 21 indicates that human rights, working conditions, socio-economic repercussions and income-based community well-being are the most used social impact categories and at least three

subcategories/topics are analysed per each of them. Among the most widely used subcategories, there are those related to working conditions (e.g. fair salary, freedom of association, working hours, forced labour, health & safety) and those belonging to socio-economic repercussions (e.g. community engagement, social acceptability, safe health and living conditions) and income-based community well-being (e.g. local employment, local economic development). Moreover, also the governance impact category is considered in terms of public commitment to sustainability issues.
A summary of literature review in terms of relevant stakeholder groups and subcategories is proposed in Table 23; subcategories are classified according to UNEP/SETAC nomenclatures as much as possible, while asterisk is used to indicate additional themes or stakeholder groups (derived from different sources).

Table 23. Relevant stakeholders and social subcategories derived from the literature review (*categories outside UNEP/SETAC guidelines).

Stakeholder group	Social subcategories from literature
Users (Citizens/Consumers)	Health and safety Feedback mechanism Transparency Citizen’s satisfaction* Citizen participation* Development of environmental awareness & responsibility*
Workers	Freedom of association and collective bargaining Child labour Fair salary Working hours Equal opportunities / discrimination Health and safety Forced labour Social benefits / social security Degree of environmental worker awareness* Level of education* Local labour integration of formal worker from informal worker*
Society	Public commitments to sustainability issues Contribution to economic development Social acceptability*
Local Community	Community engagement Access to immaterial resources Access to material resources Safe & healthy living conditions Respect of indigenous rights Local Employment
Municipal authorities*	Public commitments to sustainability issues Maturity/existence of the informal WM system's regulation*

3.3.3 Results from the interviews

The Interviews to the project partners were carried out during 2 online meetings, and they were aimed at:

- Validating stakeholders affected/involved by the current and the new waste management system for organic fraction;
- Identifying socio-economic aspects related to the introduction of organic waste collection and local composting treatment;
- Collecting feedback about effects – positive and negative – the new waste management system could have if compared to the current situation.

The interviews were organised as follows: after a short description about the methodology and the goal of the social analysis, the different social topics proposed by the Handbook were presented to identify their relevance in the given pilot case. During the online meetings, social topics from the handbook were proposed to provide as a starting point for the materiality assessment; however, interviewed were asked to propose and discuss also additional ones.

The interviews were structured in two parts. In the first part, partners were asked to validate and described types and relevance of the stakeholder groups proposed by the Handbook. They were asked to answer the following questions:

- Which are the stakeholder groups affected by the waste management system?
- Are the group "workers/users/local communities/small-scale entrepreneurs" affected, positively or negatively, by the new organic waste treatment?
- Are there additional stakeholders to be included?

In the second part, they were asked to answer the following questions for each social topic:

- Does the organic waste collection and local composting treatment have an effect on the identified social topics? Possible answer: YES, NO, I DON'T KNOW.
- Which type of effect? Possible answer: POSITIVE, NEGATIVE, NEUTRAL
- Provide examples of effects, also based on the comparison among scenarios (current situation vs installation of composters).

The outcomes from interviews are reported in the following sections for the two pilot cases.

3.3.3.1 Fossalto pilot case

Starting from the system boundaries described in section 4.2.3 (Figure 13 and Figure 14), stakeholder groups were validated and also a more precise definition was reached according to the specific pilot case context (Table 24).

Table 24. Stakeholder groups identified for Fossalto pilot case.

Stakeholder group*	**Fossalto**
Workers	Workers of local company dedicated to waste management system (current situation) Workers involved in the local composting plant (future situation)
Users	Citizens
Local communities	Not relevant
Small-scale entrepreneurs	Small local farms (compost users)

*According to the Handbook structure

In terms of relevance of social topics, both general feedbacks and more specific ones related to the proposed social topics are here summarized.

General feedbacks are:

- Few other examples of local composting exist in the reference region (Molise), therefore Fossalto pilot case represents one of the first examples;
- Overall citizens expectations are high and positive toward the new organic waste treatment, also thanks to training and awareness-raising activities developed during the project and already on-going;
- Both benefits and potential risks are expected if compared to the current situation;
- The main positive effects expected in a short term are waste management rate reduction and the increase of environmental sustainability awareness; while, the activation of a path of improvement on the environmental sustainability of the area is expected in the mid- and long term;
- The main risk associated to the local composting plants are expected to be management difficulties, costs and odours;

- Possibilities for the application and use of compost from the composting plant are directly in the local small farms, which could be interested in applying compost as soil improver and explore more sustainable agricultural techniques;
- Public commitment to sustainability issues is generally high, in fact the municipal administration is particularly engaged and it directly promotes the new waste system;
- Overall, it is premature to imagine additional long-term effects, both positive and negative, related to the new organic waste system.
- It is not possible to identify specific health and safety risks/benefits derived from the new organic waste treatment since it is not already in the operation phase, however risks in terms of odours are expected.

Specific feedbacks have been collected about each social topic proposed by the Handbook; they are summarized in Table 25.

Table 25. Feedbacks from interviews on Fossalto pilot case (*additional social topic proposed during interviews).

Stakeholder	Social topics	Does the organic waste collection and local composting treatment have an affect?	Which type of effect?	Provide examples or comments
Workers	Occupational health and safety	Yes	Neutral	No differences are expected from the current situation
	Remuneration	Yes	Neutral	No differences are expected from the current situation
	Child labour	Not relevant	---	---
	Forced labour	Not relevant	---	---
	Discrimination	I don't know		---
	Freedom of Association and Collective Bargaining	I don't know		---
	Work-life balance	Yes	Neutral	No differences are expected from the current situation
Users	Health and Safety	Yes	Neutral	No differences are expected from the current situation
	Responsible communication	Yes	Positive	---
	Privacy	Not relevant	---	---
	Affordability	Yes	Positive	Low tariff for waste management is expected for citizens

	Accessibility	Yes	Neutral	The same waste collection will be applied (door-to-door)
	Effectiveness and comfort	Yes	Positive	---
	Level of acceptance*	Yes	Positive	Local community is engaged and supportive of any positive development
Local communities	Health and safety	Yes	Negative	One expected risk is the odour
	Access to material and immaterial resources	I don't know		---
	Community engagement	Yes	Positive	The new waste management system will increase awareness in terms of environmental sustainability of the area
	Skill development	I don't know		---
	Contribution to economic development	I don't know		---
Small-scale entrepreneurs	Meeting basic needs	Not relevant	---	---
	Access to service and inputs	Yes	Positive	Compost as a soil improver
	Women's empowerment	I don't know		---
	Child labour	Not relevant	---	---
	Health and safety	I don't know		---
	Land rights	Not relevant	---	---
	Fair trading relationships	I don't know		---

Legend	
(red)	Negative effect
(yellow)	Neutral effect
(green)	Positive effect
(grey)	Don't know

3.3.3.2 Ist Island pilot case

Starting from the system boundaries described in section 4.2.3 (Figure 12), stakeholder groups were validated and also a more precise definition was reached according to the specific pilot case context (Table).

Table 26. Stakeholder groups identified for Ist Island pilot case.

Stakeholder group*	**Ist island**
Workers	Workers of local company dedicated to waste management system (current situation) Workers involved in the local composting plant (future situation)
Users	Citizens Touristic facilities
Local communities	Tourists Touristic facilities
Small-scale entrepreneurs	Small local farms (compost users)

*According to Handbook structure

In terms of relevance of social topics, both general feedbacks and more specific ones related to the proposed social topics are here summarized.

General feedbacks are:

- The high demand for more sustainable tourism (eco-tourism) is one of the main drivers for technological improvements; this process is involving many islands of the Dalmatian coast, in the region of Zadar. In this sense, one of the main reasons for the implementation of the organic waste collection in Ist Island is to be in step with the current national programme of islands' sustainability.
- Overall citizens expectations are high and positive toward the new organic waste treatment, also thanks to training and awareness-raising activities developed during the project and already on-going;
- The current situation, where mixed waste are collected and organic fraction is not sorted, is generally considered efficient and problems in terms of public health and hygiene are not present. However, short-term positive effects generally expected are waste management rate reduction and the increase of environmental sustainability awareness and sense of responsibility;
- Possibilities for the application and use of compost from the composting plant are directly in the local small farms, which could be interested in applying compost as soil improver, thus avoiding fertilizers transport via ferry, and explore more sustainable agricultural techniques;
- Public commitment to sustainability issues is generally high, in fact the municipal administration is particularly engaged, and it directly promotes the new waste system;

- Possible follow up projects, involving near islands, are also imagined in order to improve waste management systems and the treatment of the organic fraction.

Specific feedbacks have been collected about each social topic proposed by the Handbook; they are summarized in Table .

Table 27. Feedbacks from interviews on Ist Island pilot case (*additional social topic proposed during interviews).

Stakeholder	Social topics	Does the organic waste collection and local composting treatment have an affect?	Which type of effect?	Provide examples or comments
Workers	Occupational health and safety	I don't know		---
	Remuneration	I don't know		In the long term, to copy this WMS, workload and responsibilities of a worker should be broaden to make the salary more justifiable. Even if the new worker has to travel, expenses still might be less than before, depending on the frequency of neccesity for garbage trucks that go to the temporary storage place etc. As Čistoća as a public institution (in any region, or a county to be precise) maintains all the logistic data for WMS, this can be dully calculated.
	Child labour	Not relevant	---	---
	Forced labour	Not relevant	---	---
	Discrimination	I don't know		---
	Freedom of Association and Collective Bargaining	I don't know		This is hard to define in Croatia. As the waste management is under a public institution, it means any activity done by the institution should be done in the best interest of the public. However, by being a public institution, it's also under the jurisdiction of local, regional and national authorities, meaning that politics and internal relationships have the last word over any public interest. To minimize the effect of political relationships, local initiatives have to push their own agenda and work with unaffiliated experts to further elaborate their cause, and can still fail to do any meaningful change. Cooperation with experts is a huge necessity for any sort of inclusivity in my opinion, as they can articulate the problems the local community faces and propose new solutions; issues and potential resolutions proposed in that way might have a higher chance to both affect the problem and resonate with the local community. Another issue is that local communities, even if they can articulate the problem, lack the power to make any change, as seen by the electricity problem on Ist island. This all in turn hinders the freedom of association and makes the local community (and workers) dependant on the public institution, which can act unrelated to public interest.
	Work-life balance	I don't know	Positive	As mentioned, hired worker is from the local community, so for anyone who wishes to stay in a remote area, a work opportunity like this is of great interest. Specifically, Ist island is 2 hours away by public transport, so most of the Ist

				residents stay in Zadar over the week and return to Ist on weekend. These kinds of opportunities can be beneficial for the local communities.
Users	Health and Safety	Yes	Neutral	In the long term by plastic waste reduction this might come to have a bigger impact, but we cannot say that community composting has an effect on this category
	Responsible communication	Yes	Positive	- Education and good communication will encourage people to put more effort in the separate waste collection. Users are more willing to separate waste if they have reliable information what is happening with that waste latter one. - Population of the Ist island is engaged in maintaining the island as clean as possible, so having activities and a tangible commodity such as a composter motivates further developments.
	Not relevant	---	---	Not relevant
	Affordability	Yes	Positive	The community composting does not cost additional money, so it is affordable to everyone. Moreover, they may benefit from the compost and/or reduction of waste management fee.
			Negative	In the long term, this is yet to be determined. The issue is that Ist island is a remote place with not as much inhabitants, so connecting the WMS (composter specifically and the workload on it) with several smaller islands in proximity would be better for the composting process and affordability in general. As the Croatian waste management is under a public institution, this issue can be calculated quite precisely.
	Accessibility	Yes	Neutral	As majority of the workload (carrying the waste to the composter) is done by a Čistoća worker, we cannot say there is any change in this specific aspect, other that the hired worker is from the local community which is a plus.
	Effectiveness and comfort	Yes	Positive	The effect will be positive, because community composting requires less effort from the users than home composting.
		I don't know		This development still needs some work. The touristic season is only starting now, so major organic waste producers (restaurants) are also affected by it. In the long term, tourists (from incoming boats, yachts etc) should be supported and pushed to separete waste material.
		Yes	Neutral	As the collection of the organic waste is done by a worker, the comfort level has remained the same, except if we can detect any positive relationship related to more eco-friendly service.
	Level of acceptance*	Yes	Positive	Local community is engaged and supportive of any positive development, and this innovative approach has their interest.
Local communities	Health and safety	I don't know		---
	Access to material and immaterial resources	Yes	Positive	This initiative was one of several ideas the local residents had in mind when thinking about their island preservation, so if anything, it supports new initiatives and opens up communication (as in networking) with other interested parties, stakeholders or institutions.
	Community	Yes	Positive	As there is a noticeable discrepancy between the tourists and the local community, especially related to waste disposal, these sorts of activities support engagement

	engagement			because they indicate some positive changes can be done, especially when related to the public institution.
	Skill development	Yes	Positive	---
	Contribution to economic development	Yes	Positive	This is one aspect that has an immediate effect. To be precise, a worker from the local community is hired to maintain the composter, so it creates an on-site development. Especially for remote island communities, this can provide mutual interest between several locations.
Small-scale entrepreneurs	Meeting basic needs	Not relevant	---	---
	Access to service and inputs	Yes	Positive	Compost as a soil improver
	Women's empowerment	I don't know		---
	Child labour	Not relevant	---	---
	Health and safety	I don't know		---
	Land rights	Not relevant	---	If anything, this can improve the current waste management system, but it would require a lot of effort to make the public institutions fully transparent about the funding and resources used in any region. Ist island example is just one of many, as for example Croatia has 428 municipalities alone, which have a saying on public decisions, then there are Cities, then there are public authorities, then there are national authorities and between all that private interests and global trends. So having a calculable methodology with transparent input/output data would be a good public utility in the long term to make any claims about the WMS in any region. Disseminating this utility and making it interesting to public, let alone utilizing it would be a whole another issue, but in my opinion, it wouldn't start from a high political dialogue but through enabling experts to engage the interest of local communities (if successful, that would make a claim legitimate as well, making it a stronger case for the high level political dialogue).
	Fair trading relationships	I don't know		---

Legend	
	Negative effect

	Neutral effect
	Positive effect
	Don't know

3.3.4 Summary of material social topics for the pilot cases

Specific guidelines targeted to the sector about social themes or indicators are not available yet in literature, therefore a three-steps approach was applied to identify material social topics related to the waste management system, and in particular to the introduction of organic waste collection and treatment via local composting in the two pilot cases. The first step allowed identifying a starting list of stakeholders and social subcategories/topics for further pre-selection; in particular, UNEP guidelines and Handbook for Product Social Impact Assessment were considered. The second step aimed at collecting information from literature on social sustainability in the waste management systems and so extracting stakeholders and social topics generally considered relevant in the sector. Most of the literature about S-LCA applied to the waste management system dealt with developing countries and context where both formal and informal management systems coexist; overall, stakeholder groups and social subcategories are derived from UNEP Guidelines and own sources. The last step, interviews to partners, were used to validate stakeholders relevant for the two case studies and the related social topics. Moreover, also examples of expected benefits/risks were collected.

Outcomes from the three steps were integrated toward a clear and comprehensive list of stakeholders and social topics that could be considered to evaluate social impacts of the new waste systems if compared to the current one (Table 28). In terms of relevance, both case studies identified the same social topics. In the case of Fossalto, the relevance of local community is not evident for the moment as in the case of Ist Island where local community is represented by actors of tourism sectors. However, as the level of awareness increases, this topic is likely to become important also in Fossalto case study.

Interviews also suggested the nature of effects – positive or negative - that is expected concerning the social topics. In this case, the two pilots provided different answers which are summarized in Table 29. In some case, it is still not possible to identify the effect that will be produced by the new organic waste management system.

Table 28. Summary of material stakeholders and social topics for waste management systems of the two pilot cases.

Stakeholder group	Social subcategories/topics	Source
Workers	Occupational health and safety	Handbook and UNEP Guidelines
	Remuneration	Handbook and UNEP Guidelines
	Discrimination	Handbook and UNEP Guidelines
	Freedom of Association and Collective Bargaining	Handbook and UNEP Guidelines
	Work-life balance	Handbook
Users (Citizens/Waste producers)	Health and safety	Handbook and UNEP Guidelines
	Feedback mechanism*	UNEP Guidelines
	Responsible communication**	Handbook
	Affordability	Handbook
	Accessibility	Handbook
	Effectiveness and comfort	Handbook
Society	Public commitments to sustainability issues	UNEP Guidelines
Local Community	Health and safety	Handbook and UNEP Guidelines
	Access to material and immaterial resources	Handbook and UNEP Guidelines
	Community engagement	Handbook and UNEP Guidelines
	Skill development	Handbook
	Contribution to economic development	Handbook and UNEP Guidelines
Small-scale entrepreneurs	Access to service and inputs	Handbook
	Women's empowerment	Handbook
	Health and safety	Handbook
	Fair trading relationships	Handbook

*this social subcategory includes the concepts of "customer satisfaction" and "level of acceptance" that arose during literature review and interviews.

**this social subcategory includes the concept of “development of environmental awareness &responsibility” that arose during literature review.

Table 29. Summary of expected effects produced by the new organic waste management systems in the two pilot cases.

Stakeholder group	**Social subcategories/topics**	**Fossalto pilot case**	**Ist Island pilot case**
Workers	Occupational health and safety		
	Remuneration		
	Discrimination		
	Freedom of Association and Collective Bargaining		
	Work-life balance		
Users (Citizens/Waste producers)	Health and safety		
	Feedback mechanism		
	Responsible communication		
	Affordability		
	Accessibility		
	Effectiveness and comfort		
Society	Public commitments to sustainability issues		
Local Community	Health and safety		
	Access to material and immaterial resources		
	Community engagement		
	Skill development		
	Contribution to economic development		
Small-scale entrepreneurs	Access to service and inputs		
	Women’s empowerment		
	Health and safety		
	Fair trading relationships		

Legend	
	Negative effect
	Neutral effect
	Positive effect
	Don't know

3.4 Definition of indicators for measuring the social materiality

The selection of indicators to monitor potential social issues that might arise when the two composters will be up and running has been carried out considering indicators suggested by the Handbook for products social impact assessment (PRè Sustainability, 2018) and the Methodological Sheets for subcategories in s-LCA [26].

The Handbook provides a list of Performance Indicators corresponding to quantitative and qualitative markers of performance for each of the social topics. Performance indicators reflect both positive and negative impacts of the assessed product or service system. Methodological sheets present a definition for each subcategory identified in the S-LCA Guidelines and contain tables with suggested inventory indicators (metrics) for both generic (hotspot) and specific analysis. The tables also note whether data are available in quantitative, semi-quantitative and/or qualitative form and provide data sources for each indicator. The site-specific and generic indicators and data examples do not constitute a complete list of the best indicators to use in a study; but they only would provide suggestions. In addition to the Performance Indicators lists, the Handbook also indicates the assessment method based on a 5-point reference scale for each indicator to assess social performance. Each position on the scale is a performance reference point, assigned a score ranging from -2 to +2. Figure 16 shows the generic principles followed to develop references scales for social topics.

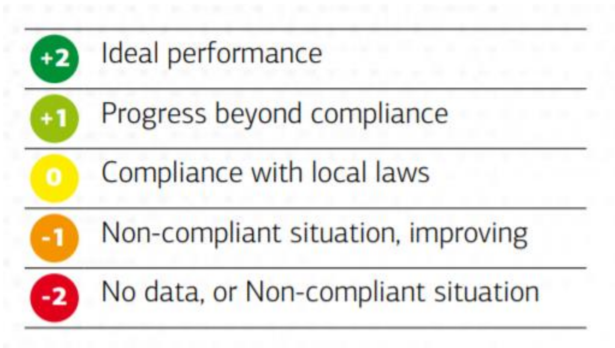

Figure 16. General principles used to establish reference scales for each social topic.

As for the Methodological sheets, tables contain examples of assessment methods but a specific one is not proposed since out of the scope of the document. At this regard, the last version of the UNEP guidelines proposes two main social impact approaches: the Reference Scale Assessment and the Impact

Pathway Assessment [24]. These two approaches differ significantly in the way they approach s-LCA and in what they aim to assess. The Reference Scale Assessment is focussed on assessing social performances or social risks in the life cycle, while the Impact Pathway Assessment aims at assessing the (potential) social *impact* that arises from the product system under study, following cause-and-effect relations through quantified characterization models. The method proposed by the Handbook (5-point reference scale) belongs to the first group (Reference scale).

In order to reach the objective of S-LCA in NETWAP project, the selection of indicators was guided by the following aspects:

- Both for social topics included in the Handbook and for those ones in common between Handbook and UNEP guidelines, the Performance Indicators suggested by the Handbook were selected.
- For those social topics derived exclusively from the UNEP guidelines or from other sources, the indicators were selected from the ones suggested by the Methodological Sheets.

The comprehensive list of social topics and related indicators is provided as excel worksheet named “SOCIAL INDICATORS FOR NETWAP PROJECT”.

Figure 17 shows the example of the social topic “Health and safety” of the Workers stakeholder group; the social topic is linked to the relevant performance indicators to achieve a certain score (ranging from -2 to +2). Typically, performance indicators have a Yes/No format, where the affirmative answer counts as positive. To receive a higher score, a company is required to comply with all the requirements of the levels below as well. For those indicators out of the Handbook, the same reference scale was applied.

Reference scale for Health and Safety

	Definition of the scale level	Performance Indicators
+2	There is solid science-based evidence that normal use of the product can contribute very significantly to a better health and safety AND the product or service is marketed and managed in such a way that it does reach the most vulnerable groups who would benefit most from this product and service.	• The evidence must contain two parts: o Scientific evidence or opinions from independent experts or independent organisations that are specialised in this area, confirming the product has properties that can significantly improve the health and safety of users o Opinions from independent experts who confirm that the product indeed is marketed and managed in such a way that it reaches the most vulnerable groups • In a B2B situation a description of the efforts to design components and/or support the design of the final product that contributes to this achievement[15]
+1	The company has a dossier or other evidence that shows how the product or service has been successfully designed to create a maximum contribution to health and safety of the user and that the recommended use of the product contributes to a better health and safety for the intended users[16].	• A dossier or evidence that contains elements such as: o The company has assessed how the product can optimise or harm the health and safety of the user; for instance, through reduction of salt, saturated fats or calories, or significantly improved ergonomics. o The product developers have a verifiable audit trail on the efforts and decisions to optimise the health and safety of the user. • In a B2B situation a description of the efforts to design components and/or support the design of the final product that contributes to this achievement
0	The normal use product and the way it is marketed and managed does not have any significant detrimental effect on the health and safety of the user.	• Absence of verifiable claims by authorities, consumer organisations and user groups that there is a significant detrimental health and safety impact (for B2B and B2C situations). • Reports from authoritative sources that confirm there is no or a negligible health impact, in the way the product is used (for B2B and B2C situations)
-1	The normal use of the product has negative health or safety impacts, but the producer has developed a corrective action plan to improve the product and to influence the way the product is used in order to significantly reduce the negative impacts.	• Verifiable information that the health and safety issue is recognised by the company and that the product and the way it is managed and marketed is being improved with a clear and credible timeline • In a B2B context: verifiable information that the health and safety issue is recognised and that the component or ingredient and the way it is applied is being improved with a clear and credible timeline.
-2	Any use of the product has direct negative health or safety impacts on short or long term.	• Reports from consumer organisations, NGOs, watchdogs and authorities that describe the negative impacts • The product does not conform to the legal requirements and is not approved by the authorities.

Figure 17. Performance indicators and reference scale for the social topic “health and safety” for “Workers” stakeholder group.

4. Concluding remarks

In recent years, local communities have been showing an increasing amount of attention to decentralized composting because it can overcome limitations of centralized waste treatment facilities such as high transportation, operation and maintenance costs, high degree of specialized skills and advanced technology required, large facilities and low quality of compost. The NETWAP project perfectly fits this trend towards improved sustainability. In fact, the sustainability assessment of the baseline scenarios of the selected pilot actions shows that the improvement potentialities are high, especially in terms of environmental impacts and externalities. The assessment of the organic waste management system implemented in the framework of the NETWAP project will be crucial in indicating if local composting is a sustainable solution. The environmental and economic impacts generated by transportation, as highlighted by LCA and LCC for both the baseline scenarios of Fossalto and Ist Island, will be likely overcome as well as the impacts generated by the temporary storage in the deposit station in the case of Ist Island. Moreover, LCA and LCC showed the environmental and economic benefits of recovering compost at industrial scale in the case of Fossalto pilot. The local recovering of compost will generate further environmental gains. This study confirms that Life Cycle-based evaluations are very valuable tools for decision-makers to complement monetary evaluations, for a better understanding of benefits and costs of waste management policies.

5. References

[1]. European Parliament and Council, 2008. In: Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives (Waste Framework. LexUriServ) do 3-30. doi:2008/98/EC.;32008L0098.

[2]. ISO 14040 (2006). ISO, International Standard. Environmental Management and Life Cycle Assessment and Principles and Framework. International Organization for Standardization, Geneva, Switzerland.

[3]. ISO 14044 (2006). ISO, International Standard. Environmental Management - Life Cycle Assessment - Requirements and Guidelines. International Organization for Standardization, Geneva, Switzerland.

[4]. ILCD Handbook (2010). European Commission - Joint Research Centre - Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. First edition March 2010. EUR 24708 EN. Luxembourg. Publications Office of the European Union; 2010.

[5]. Laurent, A., Bakas, I., Clavreul, J., Bernstad, A., Niero, M., Gentil, E., Hauschild, M.Z., Christensen, T.H., 2014. Review of LCA studies of solid waste management systems e Part I: lessons learned and perspectives. Waste Management 34, 573-588. http://dx.doi.org/10.1016/j.wasman.2013.10.045.

[6]. Rigamonti, L., Falbo, A., Grosso, M., 2013. Improvement actions in waste management systems at the provincial scale based on a life cycle assessment evaluation. Waste Management 33, 2568-2578. http://dx.doi.org/10.1016/j.wasman.2013.07.016.

[7]. Fiorentino, G., Ripa, M., Protano, G., Hornsby, C., Ulgiati, S., 2015. Life cycle assessment of mixed municipal solid waste: multi-input versus multi-output perspective. Waste Management 46, 599-611. http://dx.doi.org/10.1016/j.wasman.2015.07.048.

[8]. Ripa, M., Fiorentino, G., Vacca, V., Ulgiati, S., 2017. The relevance of site-specific data in Life Cycle Assessment (LCA). The case of the municipal solid waste management in the metropolitan city of Naples (Italy). Journal of Cleaner Production 142, 445–460. https://doi.org/10.1016/j.jclepro.2016.09.149.

[9]. Keng, Z.X., Chong, S., Ng, C.G., Ridzuan, N.I., Hanson, S., Pan, G., Lau, P.L., Supramaniam, C.V., Singh, A., Chin, C.F., Lam, H.L., 2020. Community-scale composting for food waste: A life-cycle assessment supported case study. Journal of Cleaner Production 261, 121220. https://doi.org/10.1016/j.jclepro.2020.121220.

[10]. Rapporto annuale del Polo impiantistico in Loc. Colle Santo Ianni in agro di Montagano (CB). Anno 2019.

[11]. Ekvall, T., Assefa, G., Björklund, A., Eriksson, O., Finnveden, G., 2007. What life-cycle assessment does and does not do in assessments of waste management. Waste Management 27, 989-996. http://dx.doi.org/10.1016/j.wasman.2007.02.015.

[12]. Iriarte, A., Gabarrell, X., Rieradevall, J., 2009. LCA of selective waste collection systems in dense urban areas. Waste Management 29, 903-914. http://dx.doi.org/10.1016/j.wasman.2008.06.002.

[13]. Goedkoop, M., Heijungs, R., Huijbregts, M., DeSchryver, A., Struijs, J., VanZelm, R., 2009. ReCiPe 2008 — a life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. Report I: Characterisation. Den Haag. https://doi.org/10.13140/RG.2.1.4872.6640.

[14]. Bagg, M., 2013. Save cash and energy costs via an LCC model. World Pumps 12, 26-27.

[15]. Hin, J., Zmeureanu, R., 2014. Optimization of a residential solar combisystem for minimum life cycle cost, energy use and exergy destroyed. Solar Energy 100, 102-113.

[16]. White G., Ostwald, P., 1976. Life cycle costing. Manag. Account. 15, 335–344.

[17]. Bierer, A., Götze, U., Meynerts, L., Sygulla, R., 2015. Integrating life cycle costing and life cycle assessment using extended material flow cost accounting. Journal of Cleaner Production 108, 1289–1301. https://doi.org/10.1016/j.jclepro.2014.08.036.

[18]. Stern, N.H., 2006. The Economics of Climate Change: the Stern Review, Cambridge University Press.

[19]. Hunkeler, D., Lichtenvort, K., Rebitzer, G., 2008. Environmental Life Cycle Costing. SETAC press, 2008. Available at: http://lifecyclecenter.se.

[20]. Steen, B., 1999. A Systematic Approach to Environmental Priority Strategies in Product Development (EPS) Version 2000 – General System Characteristics. CPM report 4, 1999.

[21]. Baumann, H., Tillman, A.-M., 2004. A Hitch Hikers guide to LCA- An orientation in life cycle assessment methodology and application. Edition 1:3. Lund: Studentlitteratur AB.

[22]. Macombe, C., Leskinen, P., Feschet, P., Antikainen, R., 2013. Social life cycle assessment of biodiesel production at three levels: a literature review and development needs. Journal of Cleaner Production 52, 205–216.

[23]. Zamagni, A., Pauline, F., De Luca, A.M., Ioida, N., Buttol, P., 2015. Social Life Cycle Assessment: methodologies and practice. In: Dewulf, J., De Meester, S., Alvarenga, R. (eds). Sustainability Assessment of Renewables-Based Products: Methods and Case Studies. John Wiley & Sons ISBN 9781 118933947.

[24]. UNEP, 2020. Guidelines for Social Life Cycle Assessment of Products and Organizations 2020. Benoît Norris, C., Traverso, M., Neugebauer, S., Ekener, E., Schaubroeck, T., Russo Garrido, S., Berger, M., Valdivia, S., Lehmann, A., Finkbeiner, M., Arcese, G. (eds). United Nations Environment Programme (UNEP).

[25]. Goedkoop, M.J., de Beer, I.M., Harmens, R., Saling, P., Morris, D., Florea, A., Hettinger, A.L., Indrane, D., Visser, D., Morao, A., Musoke-Flores, E., Alvarado, C., Rawat, I., Schenker, U., Head, M., Collotta, M., Andro, T., Viot, J.-F., Whatelet, A., 2020. Product social impact assessment Handbook – 2020.

[26]. Benoit-Norris, C., 2013. The Methodological Sheets for Sub-Categories in Social Life Cycle Assessment (S-LCA). Pre Publication- Version. The Methodological Sheets for Subcategories in Social Life Cicle Assessment (S-LCA). https://doi.org/10.1007/978-1-4419-8825-6.

[27]. Harijani, M., Mansour, A., Karimi, S., Lee, C.G., 2017. Multi-period sustainable and integrated recycling network for municipal solid waste – a case study in Tehran. Journal of Cleaner Production 151, 96–108.

[28]. Ibáñez-Forésa, V., Bovea, M.D., Coutinho-Nóbrega, C., de Medeiros, H.R., 2019. Assessing the social performance of municipal solid waste management systems in developing countries: Proposal of indicators and a case study. Ecological Indicators 98, 164–178.

[29]. Yıldız-Geyhan, E., Altun-Çiftçioğlu, G.A., Kadırgan, M.A.N., 2017. Social life cycle assessment of different packaging waste collection system. Resources, Conservation & Recycling 124, 1–12.

[30]. Menikpura, S.N.M., Gheewala, S.H., Bonnet, S., 2012. Framework for life cycle sustainability assessment of municipal solid waste management systems with an application to a case study in Thailand. Waste Management & Research 30, 708–719.

[31]. Aparcana, S., Salhofer, S., 2013a. Application of a methodology for the social life cycle assessment of recycling systems in low income countries: three Peruvian case studies. International Journal of Life Cycle Assessment 18(5), 1116-1128.

[32]. Ak, H., Braida, W., 2015. Sustainable municipal solid waste management decision making: development and implementation of a single score sustainability index. Management of Environmental Quality 26, 909–928.

[33]. Lu, Y.T., Lee, Y.M., Hong, C.Y., 2017. Inventory analysis and social life cycle assessment of greenhouse gas emissions from waste-to-energy incineration in Taiwan. Sustainability 9.

[34]. Klang, A., Vikman, P.-Å., Brattebø, H., 2003. Sustainable management of demolition waste—an integrated model for the evaluation of environmental, economic and social aspects. Resources, Conservation & Recycling 38, 317–334.

[35]. Vinyes, E., Oliver-Solà, J., Ugaya, C., Rieradevall, J., Gasol, C.M., 2013. Application of LCSA to used cooking oil waste management. International Journal of Life Cycle Assessment 18, 445–455.

[36]. Martínez-Blanco, J., Lehmann, A., Muñoz, P., Antón, A., Traverso, M., Rieradevall, J., Finkbeiner, M., 2014. Application challenges for the social Life Cycle Assessment of fertilizers within life cycle sustainability assessment. Journal of Cleaner Production 69, 34–48.

[37]. Aparcana, S., Salhofer, S., 2013b. Development of a social impact assessment methodology for recycling systems in low-income countries. International Journal of Life Cycle Assessment 18, 1–10.
[38]. Foolmaun, R.K., Ramjeawon, T., 2013. Life cycle sustainability assessments (LCSA) of four disposal scenarios for used polyethylene terephthalate (PET) bottles in Mauritius. Environment, Development and Sustainability 15, 783–806.
[39]. Prakash S, Manhart A, 2010. Socio-economic assessment and feasibility study on sustainable e-waste management in Ghana. Publisher Oko-Institut e.V.
[40]. Umair, S., Björklund, A., Petersen, E.E., 2015. Social impact assessment of informal recycling of electronic ICT waste in Pakistan using UNEP SETAC guidelines. Resources, Conservation & Recycling 95, 46–57.
[41]. Chifari, R., Renner, A., Lo Piano, S., Ripa, M., Bukkens, S.G.F., Giampietro, M., 2017. Development of a municipal solid waste management decision support tool for Naples, Italy. Journal of Cleaner Production 161, 1032-1043.
[42]. Ferrão, P., Ribeiro, P., Rodrigues, J., Marques, A., Preto, M., Amaral, M., Domingos, T., Lopes, A., Costa, E.I., 2014. Environmental, economic and social costs and benefits of a packaging waste management system: a Portuguese case study. Resources, Conservation & Recycling 85, 67–78.
[43]. Guidi, G., Gugliermetti, F., Astiaso Garcia, D., Violante, A.C., 2009. Influence of environmental, economic and social factors on a site selection index methodology for a technological centre for radioactive waste management. Chemical Engineering Transactions 18, 505–510.
[44]. Fragkou, M.C., Salinas Roca, L., Espluga, J., Gabarrell, X., 2014. Metabolisms of injustice: municipal solid-waste management and environmental equity in Barcelona's Metropolitan Region. Local Environment 19, 731–747.
[45]. Hu, M., Kleijn, R., Bozhilova-Kisheva, K.P., Di Maio, F., 2013. An approach to LCSA: the case of concrete recycling. International Journal of Life Cycle Assessment 18, 1793–1803.
[46]. Lehmann, A., Russi, D., Bala, A., Finkbeiner, M., Fullana-I-Palmer, P., 2011. Integration of social aspects in decision support, based on life cycle thinking. Sustainability 3, 562–577.

6. Annex

In this Annex a short definition of relevant social topics selected for the NETWAP project pilot cases is provided. A more extensive definition and specific examples can be found in the Handbook, in particular the document "Social Topics Report" (2020 version 1.0 - November 2020) available at https://product-social-impact-assessment.com/ and in the Methodological Sheet [26].

Stakeholder group	**Social subcategories/topics**	**Definition**

Workers	Occupational health and safety	The extent to which the management maintains or improves the safety and overall health status of the workers. The term health, in relation to work, indicates not merely the absence of disease or infirmity, but also includes the physical and mental elements affecting health, which are directly related to safety and hygiene at work. This social topic assesses both the rate of incidents and the status of prevention measures and management practices.
	Remuneration	The extent to which the management compensate the workers. This social topic assesses the combination of wages and social benefits received by workers.
	Discrimination	The extent to which a company is engaged in preventing discrimination and pro-actively promoting nondiscrimination at the workplace. Discrimination refers to any distinction, exclusion or preference which has the effect of nullifying or impairing equality of opportunity or treatment.
	Freedom of Association and Collective Bargaining	The extent to which workers have the right to establish and to join organisations of their choice without prior authorisation, to promote and defend their interests, and to negotiate collectively with other parties. They should be able to do this freely, without interference by other parties or the state, and should not be discriminated against as a result of union membership. The right to organise includes the right of workers to strike and the rights of organisations to draw up constitutions and rules, to freely elect representatives, to organise activities without restriction and to formulate programmes.
	Work-life balance	The extent to which a company enables workers to have choices over when, where and how they work and encourages healthy work-life balance.
Users (Citizens/Waste producers)	Health and safety	The extent to which the product, under defined conditions (target market, intake) maintains or improves the health and safety status of the users in the target market, supported by scientific or market research based on health and nutrition and health economics science. The extent to which the product, under defined circumstances (target market, intake) contributes to measurable reduction of the risk of disease, related to defined markers of health (Daily Adjusted Life Years (DALYs) as defined by WHO, defined diseases), based on scientific health impact research. Products should not cause diseases or disabilities when used normally (in accordance with manufacturer guidance and recommendations).
	Feedback mechanism	Feedback mechanisms are paths by which consumers communicate with organizations, such as surveys, return policies, quality assurances, guarantees, warranties, etc. These mechanisms help reveal consumer satisfaction related to the consumption and use of the product or service.

	Responsible communication	The extent to which an organisational transparency enables users to make informed choices. There are certification standards, labels and special indices that may be used to provide information about performance regarding social responsibility. This enables users, especially consumers, to develop a (more) sustainable lifestyle.
	Affordability	The extent to which the organization and marketing affect affordability of the service to poor or otherwise under-privileged people.
	Accessibility	The extent to which the organization affect accessibility of the service to different groups of people, e.g. disabled persons, the elderly, persons with low income, etc. Accessibility mainly relates to people with some sort of handicap.
	Effectiveness and comfort	The extent to which the offered products or services affect the efficiency and comfort of users. User comfort is related to the sensory indicators of taste, touch, sound, smell and vision. Effectiveness compares the effort required to achieve the same result as with an alternative solution: the less effort required, the more effective the product/solution.
Society	Public commitments to sustainability issues	A public commitment is a promise or agreement made by an organization, or a group of organizations, to its customers, employees, shareholders, local community or the general public whose fulfilment can be evidenced in a transparent and open way. Typically this will take the form of performance improvement targets with defined dates for achievement and public reporting of progress. The promise or agreement is disseminated through the organization's website, promotional materials or other means. These commitments relate to the contribution of organizations to the sustainable development of the community or society as the reduction of impacts from their activities.
Local Community	Health and safety	The extent to which the company or facility works to prevent and mitigate adverse impacts or enhance positive impacts on the health and safety of the local community, with particular attention to vulnerable groups such as indigenous peoples and women.
	Access to material and immaterial resources	The extent to which the company or facility works to prevent and mitigate adverse impacts on local communities or to restore and improve community access to tangible resources (natural and man-made) and infrastructure. It also includes respect for indigenous peoples' and women's land rights and tangible forms of cultural heritage.
	Community engagement	The extent to which the company or facility engages with community stakeholders through ongoing open dialogue and responds to their concerns and inquiries fairly and promptly, to continuously foster greater trust and relationship with the local community. Particular attention needs to be paid to engaging representatives of vulnerable groups such as indigenous peoples and women.s

	Skill development	The extent to which the organization contributes to skill development for the community at large and new jobs creation. Skill development for the community at large creates a more resilient and healthy community, and potentially creates a resource for companies that look for new staff when needed.
	Contribution to economic development	The extent to which the company or facility contributes to the economic development of the local community. Although there are several definitions of economic development, we define this as: Economic development is the cultivation of activities that create a net gain of money into the community.
Small-scale entrepreneurs	Access to service and inputs	The extent to which companies contribute to access to inputs such as credit, banking or a secure method for storing and saving money, good-quality seeds, water, medicine, fertilizer and services such as ICT, legal support, electricity and infrastructure (e.g. roads, bridges, schools). This topic has many similarities to the Access to material and immaterial resources for local communities, but here we focus on the needs that small-scale entrepreneurs have, to run and further develop their business.
	Women's empowerment	The extent to which a company sourcing from a community of small-scale entrepreneurs is contributing to the empowerment of female small-scale entrepreneurs and the woman (spouses, daughters etc.) related to male small-scale entrepreneurs.
	Health and safety	The extent to which a company that sources form small-scale entrepreneurs contributes to the improvement of health and safe working conditions and other measures to improve health and safety in this community of suppliers, by engaging small-scale entrepreneurs in training programmes, awareness raising events, etc.
	Fair trading relationships	The extent to which a company sourcing from small-scale entrepreneurs contributes to fair trading terms. The International Fair Trade Centre defines fair trading terms in its charter as follows: *Trading terms offered by Fair Trade buyers seek to enable producers and workers to maintain a sustainable livelihood; that meets day-to-day needs for economic, social and environmental well-being and that allows to improve conditions over time. There is a commitment to a long-term trading partnership that enables both sides to co-operate and grow through information sharing and joint planning.*