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ASSESSING FOOD WASTE THROUGH LIFE CYCLE THINKING METHODS: LIMITS AND POTENTIALITIES

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ABSTRACT (English)

Food waste is receiving growing attention by scientific communities, governments, institutions and businesses, due to its environmental, economic and social impacts. Considering the Climate Change, that represents the emissions of greenhouse gasses to air expressed as kg of Carbon Dioxide equivalent (CO_2eq), the food waste produced during the production phase contributes for about 2.2 Gt CO_2eq. Furthermore, the costs related to food waste is about 140 billion Euro per year in EU-28. The food waste can also contribute to negative social impacts since it can be seen as a cause, on the one hand, of the reduction of food, on the other, of the problem of feeding the growing world's population. In this context, sustainable food waste management strategies need to be evaluated and achieved. The object of this PhD thesis is to provide a general state of the art and a critical point of view related to the application of the Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Social Life Cycle Assessment (S-LCA) in the specific context of food waste management, with the aim of highlighting limits and potentialities in using Life Cycle Thinking methods for assessing this particular sector. The main scope is to understand if LCA, LCC and S-LCA methods are suitable for assessing sustainable strategies in food waste management. Regarding the first life cycle method, the results underscore that LCA can be considered as an appropriate method for evaluating the environmental sustainability of food waste management. Despite this, its suitability is strongly connected to the practitioner's choices and to the specific analysis context. The LCC method still presents methodological and applicative issues and needs to be improved and better evaluated. In addition, the lack of information specifically related to the application of this tool in food waste management underscores that we are in an early stage for providing detailed information on its suitability. Nevertheless, the LCC can be seen as a useful and important method for evaluating economic impacts considering a life cycle perspective. Lastly, the results related to the S-LCA highlighted that, due to important methodological issues, we are still far from defining the method as a suitable method for assessing the social impacts connected to the food waste management, despite this it is the only one that allows evaluating social aspects from life cycle perspective. According to the author's knowledge, this is the first study in which methodological aspects related to the life cycle thinking tools are linked to the evaluation of the sustainable performances of food waste management systems. Further future analyses should focus in finding solutions for improving the suitability of the assessed methods in food waste management assessment, considering in particular LCC and S-LCA.

ABSTRACT (Italiano)

Comunità scientifiche, governi, istituzioni ed imprese hanno mostrato un crescente interesse nell’ambito degli sprechi alimentari (food waste). Tale interesse è principalmente volto agli impatti ambientali, economiche e sociali causati dai rifiuti alimentare. Considerando, per esempio, l’effetto sul cambiamento climatico gli impatti ambientali in termini di cambiamento climatico, la produzione di derrate alimentari in eccesso può produrre emissioni di gas serra pari a circa 2,2 Gt di anidride carbonica equivalente (CO_2 eq). Inoltre, i costi associati allo spreco alimentare in Europa causano annualmente ingenti perdite economiche pari a circa 140 miliardi di euro. Da un punto di vista sociale, lo spreco alimentare può causare impatti sociali negativi dato che può sia portare ad una riduzione nella quantità sia avere ripercussioni negative nella crescente richiesta di cibo da parte della popolazione mondiale. In questo contesto, strategie sostenibili connesse alla gestione degli sprechi alimentari devono essere valutate ed applicate. L'obiettivo di questa tesi di Dottorato di Ricerca è quello di fornire uno stato dell'arte ed un’analisi critica relativa all'applicazione dei metodi di Life Cycle Thinking nel contesto specifico della gestione degli sprechi alimentari. Tale obiettivo ha lo scopo di evidenziare limiti e potenzialità nell'utilizzo della Life Cycle Assessment (LCA), della Life Cycle Costing (LCC) e della Social Life Cycle Assessment (S-LCA) per valutare questo particolare settore. Il punto cardine dello studio è capire se i metodi LCA, LCC e S-LCA sono adatti per valutare strategie sostenibili nella gestione degli sprechi alimentari. Per quanto riguarda il primo strumento, i risultati hanno sottolineato che la LCA può essere considerata un metodo appropriato per valutare la sostenibilità ambientale della gestione dei rifiuti alimentari. La sua applicabilità è comunque fortemente connessa alle scelte del professionista che la applica e al contesto di analisi specifico. Da un punto di vista economico, il metodo LCC presenta ancora problemi metodologici e applicativi e deve essere sottoposto a specifiche valutazioni in grado di migliorarne le caratteristiche procedurali. Inoltre, la mancanza di informazioni correlate all'applicazione di questo metodo nella gestione dei rifiuti alimentari sottolinea che siamo ancora in una fase iniziale per fornire informazioni dettagliate sulla sua idoneità. Nonostante ciò, la LCC può essere vista come una metodologia utile ed importante per valutare gli impatti economici considerando una prospettiva di ciclo di vita. I risultati relativi alla S-LCA evidenziano che, a causa di importanti problemi metodologici, siamo ancora lontani dal definire il metodo come uno strumento idoneo a valutare gli impatti sociali connessi alla gestione dei rifiuti alimentari, nonostante la S-LCA sia l'unico metodo che consente di valutare gli aspetti sociali con un’ottica di ciclo di vita. Il presente studio rappresenta la prima analisi effettuata nell’ambito della valutazione degli aspetti metodologici legati agli strumenti di Life Cycle Thinking ed alla valutazione della sostenibilità dei sistemi di gestione degli sprechi alimentari. È importante sottolineare la necessità di svolgere ulteriori approfondimenti, in un prossimo futuro, al fine di trovare proposte per migliorare l´applicabilità, nell’ambito della gestione dei rifiuti alimentari, delle metodologie qui analizzate, con particolare attenzione per la LCC e la S-LCA.

1. INTRODUCTION

In the “new era” in which the concepts of sustainability and sustainable development became the basis for the human life, the problem connected with food waste production and management is continuously discussed. It has been confirmed that food waste causes environmental, economic and social impacts. Due to this, finding strategies and solutions for preventing, reducing or better managing food waste has become a priority for governments, institutions, businesses and scientific communities. Recently, the concept of food waste and the related problems have been drawn close the concept of Life Cycle Thinking and related methods, with the scope of evaluating the performance of such strategies and solutions in an environmental, economic and social context. Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Social Life Cycle Assessment (S-LCA) may provide useful information related to the actual situation and, at the same time, may allow in taking decisions that may help in reducing food waste production or in improving its management, considering the three pillars of sustainability. In this context, the object of this PhD thesis is to provide a general state of the art by means of an analysis of the international scientific literature, and a critical point of view related to the application of the LCA, LCC and S-LCA in the specific context of food waste management, with the aim of highlighting limits and potentialities in using Life Cycle Thinking tools for assessing this particular sector. The main scope consists in replying to the research question based on understanding if LCA, LCC and S-LCA methods are suitable for assessing strategies for a sustainable food waste management.

Figure 1 shows the conceptual framework of the study here presented. The thesis is structured by firstly providing a detailed introduction on waste and food waste sector as well as on Life Cycle Thinking methods. Secondly, the three method applied in the specific context of food waste management will be analysed by means of a literature analysis in three different papers. The literature analysis will be mainly focused on the papers presenting specific characteristics that are able to satisfy the scope of the thesis. In this context, LCA (Paper 1), LCC (Paper2) and S-LCA (paper 3) will be analysed in depth by highlighting limits and potentialities. Lastly, the conclusions will summarise the main findings from the three papers and provide an overview on the suitability (or not-suitability) of the Life Cycle Thinking methods for assessing the food waste management sector.

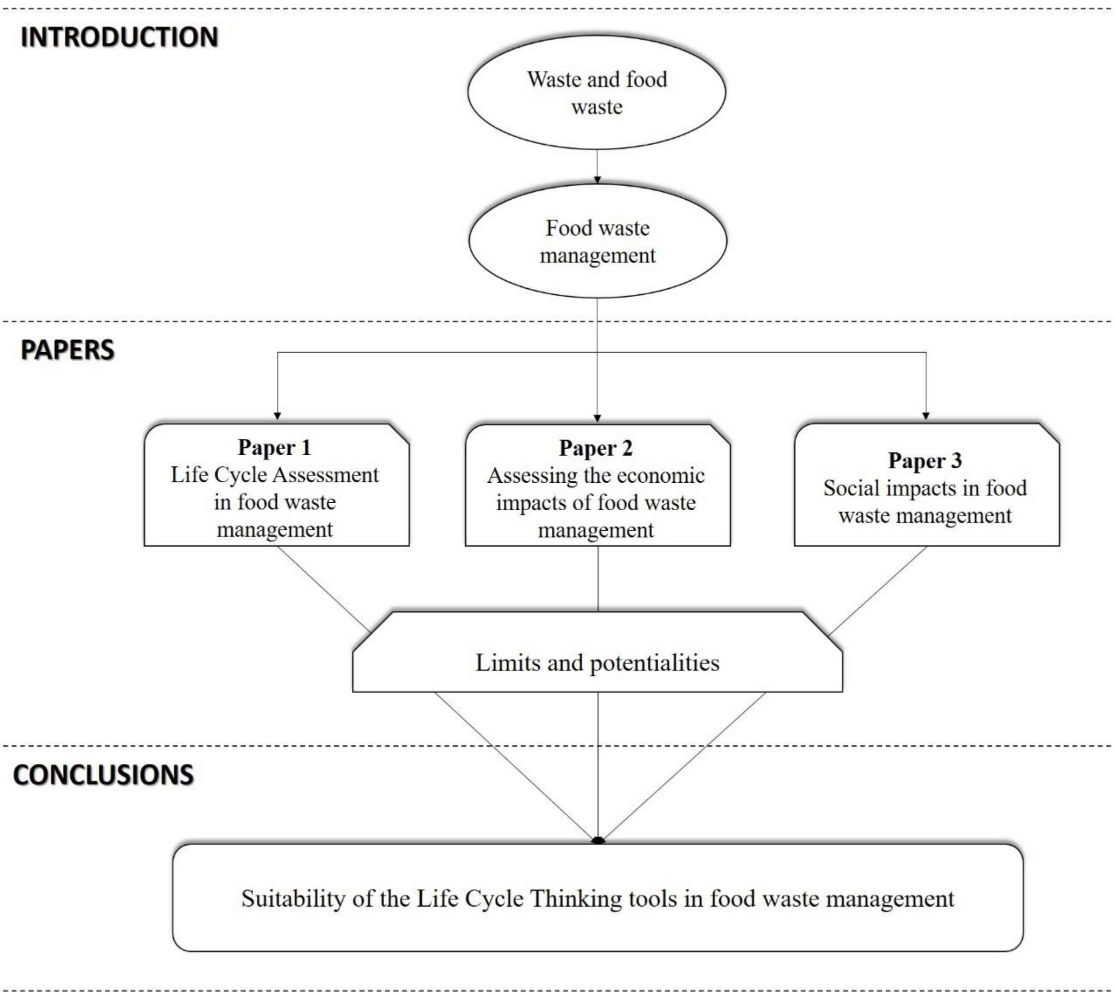


Figure 1. Diagram of the conceptual framework used in this PhD thesis.

The three years of this PhD have been focused on studying and analysing food waste and the related management activities, considering a life cycle perspective. In particular, my studies focused on both, methodological and applicative aspects. In this context, during my PhD, in addition to the methodological analysis that I'm going to present in this PhD thesis, I also performed two studies directly related to the application of the LCA tool in food waste management (Mondello et al., 2017; Salomone et al., 2017). Both the studies were carried out thank to a cooperation between the two research groups of the University of Messina and University of Roma Tre in which I worked, and were published in international scientific journals:

- Salomone, R., Saija, G., Mondello, G., Giannetto, A., Fasulo, S., Savastano, D. (2017). Environmental impact of food waste bioconversion by insects: application of life cycle assessment to process using Hermetia illucens. Journal of Cleaner Production, 140, 890-905.
- Mondello, G., Salomone, R., Ioppolo, G., Saija, G., Sparacia, S., Lucchetti, M.C. (2017). Comparative LCA of Alternative Scenarios for Waste Treatment: The Case of Food Waste Production by the Mass-Retail Sector. Sustainability, 9(5), 827.

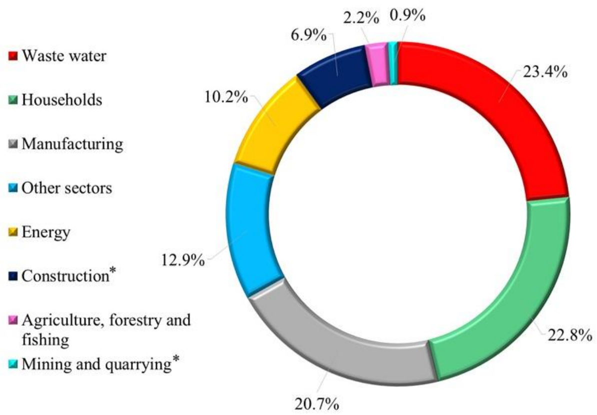
Furthermore, the critical aspects related to the Social LCA that will be presented in the Paper 3, emerged during a six months visiting period that I carried out at the Institute of Environmental Sciences (CML) - Department of Industrial Ecology, Leiden University (NL).

1.1 Waste: terms, definition and data

The Waste Framework Directive (WFD) included in the Directive 2008/98/EC of the European Parliament and of the Council, defines the term ‘waste’ as “any substance or object which the holder discards or intends or is required to discard” (EC, 2008). This definition describes a waste as a “product that reaches its end of life and needs to be disposed”, highlighting the need for appropriate mechanisms that allow such process of waste discarding as well as appropriate waste management systems. In this context, the concept of “waste management” includes all the processes related to the collection, transport, recovery and disposal of waste that should be achieved by adopting the best available techniques (EC, 2008).

Worldwide, existing data related to waste generation are mainly referred to the municipal solid waste (MSW) or household waste production (UNEP, 2015). In particular, 2 billion tonnes of MSW were produced in 2016, and a production per person per day ranging from 0.11 kg to 4.54 kg, (average of 0.74 kg per person) was accounted considering low-, medium- and high-income countries. Despite the amount of waste annually produced is quite high, it is supposed that the MSW production will increase to 3.4 billion tonnes in 2050 (about 70% more than 2016), in accordance with the world population growth (The World Bank, 2018). Furthermore, while developed countries are responsible for about 50% of total waste produced worldwide, the waste management system, in developing countries, is still affected by many issues connected, in particular, to the collection process and to uncontrolled waste dumping and burning, causing environmental, economic and social impacts (UNEP, 2015).

Regarding the European context, the total amount of waste generated by the 28 Member States of the European Union (EU-28) accounted for about 891 million tonnes (excluding the mineral wastes produced by the construction and mining and quarrying sectors), and the average production per capita was about 4.9 tonnes, in 2014 (Eurostat, 2017). Analysing in depth the economic activities and household, and considering the waste generated from both production and consumption (figure 2), the highest contribution is connected to the waste water (208 million tonnes), followed by the household waste (203.5 million tonnes), while the lowest waste production is related to the mining and quarrying for which the waste produced was about 7.9 million tonnes (EEA, 2017).



Economic activity	Waste (million tonnes)
Waste water	208
Households	203.5
Manufacturing	184.1
Other sectors	115
Energy	90.7
Construction*	61.8
Agriculture, forestry and fishing	19.7
Mining and quarrying*	7.9

*excluding mineral wastes

Figure 2. Waste generation in EU-28 by economic activities and households in 2014

The European Commission is working hard in order to improve the waste management activities. Despite this, many issues related to waste treatment are still occurring due to obsolete management systems or inappropriate countries' legislation and control. For example, only 40% of household waste is reused or recycled, and some countries still dispose about 80% of such waste through landfill instead of recycling plant (EC, 2018a). In this context, the 7th Environment Action Programme, proposed by the European Commission, also contains some priorities with the scope of optimising the waste management among all the Member States by 2050. These priorities include waste reduction, improving recycling and re-use processes, adopting incineration only for non-recyclable waste, avoiding the landfilling and implementing the EU waste management policies and legislations (EC, 2013).

The data and information reported above underscore as waste production and management is an issue that urgently needs solutions. Following this idea, the governments are moving towards approaches that should improve the environmental, economic and social aspects connected to the waste sector.

1.2 Food waste: what are we talking about?

During the recent years, food waste became one of the most important problems discussed by the governments at global and country level and it has been highly investigated by the international scientific community, considering the specific context of waste management (Mondello et al., 2017). In accordance with the Food and Agriculture Organization of the United Nations (FAO), the term "food waste" refers to good quality food for human consumption that, due to choice or negligence by the actor, is discarded or left to spoil. Food waste is an important part of "food loss" which represents the portion of food that is spilled or spoiled or shows a low quality before to reach the consumer. Food loss is mainly due to a not well-functional production system or to a not appropriate institutional framework (FAO, 1981; FAO, 2014). Food waste and food loss occur at different levels and activities along the Food Supply Chain (FSC) (figure 3). In particular, food waste is mainly produced at the retail and consumer level, while food loss is mainly caused during the agricultural, manufacturing and distribution processes (Lipinski et al., 2013; Gustavsson et al., 2011; Parfitt et al., 2010).

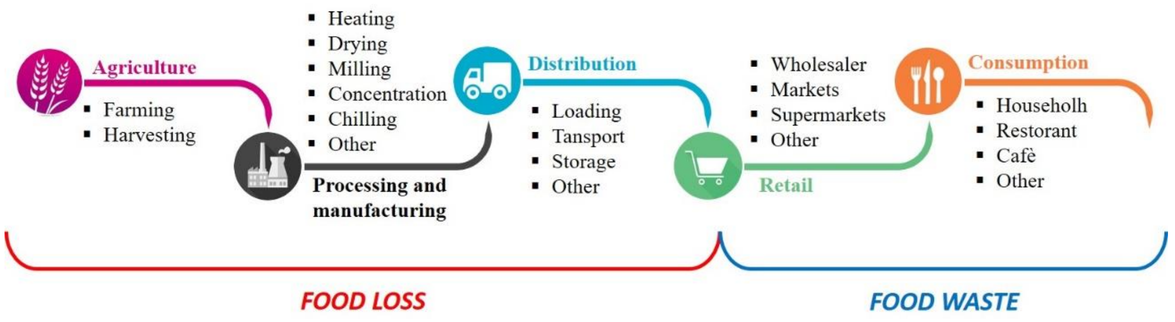


Figure 3. Food Supply Chain (FSC) levels in which food loss and food waste are generated

In accordance with Papargyropoulou et al. (2014), in addition to the FAO's definition, two more explanations of "what the food waste is" can be found in the international scientific literature. Stuart (2009) claimed that food waste also includes the part of food, with good quality for human consumption, which is used for feeding animals or is obtained as by-product from the food production process. Instead, Smil (2004) added to the other definitions that food waste also cover the surplus of food consumed by a person, over the energy value needed.

The amount of food waste globally produced is about 1.3 billion tonnes per year, representing one-third of the edible food produced for human consumption and causing an economic loss for about 1 trillion US dollar (Gustavsson et al., 2011). Data from FAO related to the amount of food waste produced per person underscores that its production mainly occurs among industrialised areas instead of developing countries. Indeed, considering food waste at the consumer level, the amount produced per capita is between 95 and 115 kg per year in Europe and North America, while, the amount produced is much lower (6-11 kg per year) in sub-Saharan Africa, south and south-eastern Asia (FAO, 2018).

Food waste also obtained growing attention by the European Commission. Between 2012 and 2106, the European Commission Framework Programme 7 carried out a four years' project called FUSIONS (Food Use for Social Innovation by Optimising Waste Prevention Strategies) which represented a real "milestone for food waste accounting" in Europe (Corrado and Sala, 2018). The project had the scope of improving the resource efficiency in Europe by reducing the food waste and allowed to collect important data and to find strategies for its prevention (FUSIONS, 2016). Across the FSC, the amount of food annually wasted is about 88 million tonnes in EU-28, corresponding to about 173 kg per person (20% of the total amount of food produced in Europe) (Stenmarck et al., 2016). The FUSIONS Project also allowed estimating the contribution to food waste production by activities and sectors (figure 4). In particular, the highest contribution is connected to the households sector, producing about 47 million tonnes of food waste, followed by the processing sector (17 million tonnes), while the lowest food waste production is due to to the wholesale and retail sector, contributing for about 4.6 million tonnes (Stenmarck et al., 2016).

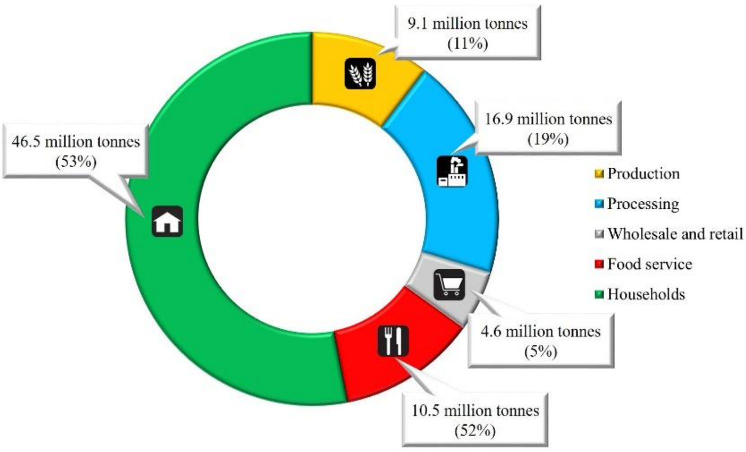


Figure 4. Sectors contribution to food waste production in EU-28

The greater amount of food is wasted at the household level because of many causes connected in particular to the consumer's negligence. William et al. (2012) highlighted that the main reasons for which food is thrown are due to excess in food purchased or cooked compared to the real needs of the consumer, or due to passing of the expiration date. In addition, the highest amount of household food waste consists of fruit and vegetables (about 50% of wasted food) representing the food whit higher perishable characteristics and with the lowest cost (De Laurentis et al., 2018). Despite the lowest contribution, the wholesale and retail sector plays an important role in food waste generation, since it is responsible for the highest production in terms of edible food waste, contributing for about 83% (Stenmarck et al., 2016). Furthermore, this sector is directly connected to household sector and the related consumer, which represents the last step and highest contributor in the FSC (Mondello et al., 2017).

It is evident that the problem related to food waste requests the highest level of attention by authorities, government and business. In particular, specific actions must be oriented to food waste prevention or treatment by adopting the best available practices and moving towards innovative systems.

1.3 Sustainability and food waste hierarchy: prevention, management and treatment

The concept of sustainability and sustainable development has been introduced, for the first time, by the Brundtland Report (World Commission on Environment and Development) from the United Nations, in 1987. The definition claims sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). The concept of sustainable development can be also seen as the integration between three main sustainability's pillars: environment, economy and society. Therefore, safeguard the development of future generations means ensure strategies and solutions for the present that are able to reduce (or better avoid) environmental, economic and social impacts.

In 2015, the United Nations Member States proposed a set of 17 goals, called "Sustainable Development Goals" (SDG) containing 164 different targets. The goals aim to guide the international development during the period 2015-2030, considering different aspects such as, poverty, inequality climate, environmental degradation, prosperity, peace and justice (UN, 2015a). The goal 12 "Responsible production and consumption", target 3 claims "By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses". (UN, 2015b) The goal 12.3 highlights how the problem connect to food waste is a priority that urgently needs solutions. It is evident that food waste causes environmental, economic and social impacts. For example, considering the Global Warming, that represents the emissions of greenhouse gasses to air expressed as kg of Carbon Dioxide equivalent (CO_2 eq), the food waste produced during the production phase contributes for about 2.2 Gt CO_2 eq (Porter et al., 2016). Furthermore, the costs related to food waste is about 140 billion Euro per year in EU-28 (Stenmarck et al., 2016). Regarding the last pillar, the society context can be considered as the most difficult to be assessed since the social situation can totally change moving between different countries or cities. Anyhow, the food waste can contribute to negative social impacts since it can be seen as a cause, on the one hand, of the reduction of food, on the other, of the problem of feeding the growing world's population (Stancu et al., 2016). Therefore, it is compulsory moving towards a food waste prevention or management that can reduce (or not make worse) the environmental, economic, and social impacts. In this context, starting from the waste management hierarchy introduced by the WFD (EC, 2008), Papargyropoulou et al. (2014) proposed the so called "food waste hierarchy" (figure 5).

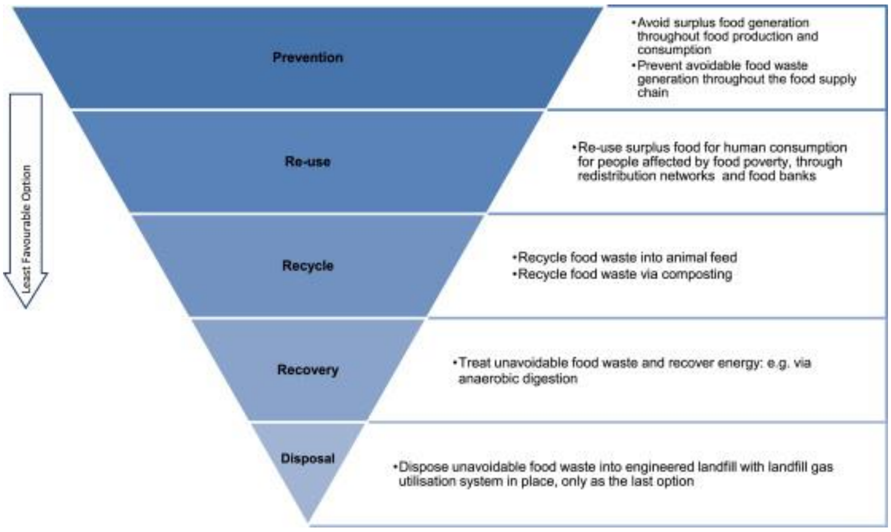


Figure 5. Food waste hierarchy (source: Papargyropoulou et al., 2014).

The food waste hierarchy is organised by proposing the best available practices for a sustainable food waste management. Moving towards the FSC, Papargyropoulou et al. (2014) proposed five different solutions for reducing food waste, starting from the most favourable option to the least favourable one:

- *prevention* should represent the first action to carry out in order to avoid food waste generation. This solution can be achieved by avoiding the surplus of food produced at the agricultural and processing levels or by preventing the avoidable production of food waste along the FSC;
- *re-use* represents the second best solution for avoiding food waste and it includes any operation that allows using again a product. In this context, the redistribution of the surplus of food produced would be a good strategy for avoiding food waste and reducing food poverty;
- *recycling* process represents the most preferable treatment strategy, when food waste generation cannot be avoided. In accordance with the WFD, the term recycle "means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or

other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations" (EC, 2008). Some examples of food waste recycling are represented by the composting process or by the treatment that converts food waste in animal feed.

- *recovery* is another process by which it is possible to obtain "a product", in particular energy, by adopting specific food waste's treatment process. In particular, the main processes are represented by the anaerobic digestion and incineration;
- *disposal* represents the last and least preferable solution proposed by the food waste hierarchy. This management strategy should be avoided or adopted only when all the former strategies described above are not available or cannot be applied. This solution consists in disposing food waste by means of landfill, preferring plants with gas utilisation.

The strategies proposed by the food waste hierarchy should allow achieving the most sustainable food waste management system by reducing the environmental, economic and social impacts. Despite this, not all of the most "preferable" solutions can simultaneously improve the environmental, economic and social aspects. Many studies underscored that recycling and energy recovery causes less environmental impacts than landfilling (i.e. Arena et al., 2003; Eriksson et al., 2005; Salomone et al., 2017; Mondello et al., 2017), but it is not clear which is the best solution when recycling and recovery are compared (Bassi et al., 2017). Regarding the economic context, sometimes, solutions that allows a reduction of the environmental impacts could cause economic impacts due to technological innovation that would require a rising in the costs. Concerning the social context, the technological innovation food waste management system can cause, on the one hand, positive social impacts connected, for example, to the improvement of the working conditions (at local level) or healthy conditions (at regional or global level), on the other, negative social impacts directly caused by the economic impacts.

1.4 Measuring sustainability in food waste management with a life cycle perspective

The previous paragraph highlighted the importance in reaching the sustainability in food waste management along the food waste hierarchy. Nevertheless, the key issue regards how the sustainability performance and the related environmental, economic and social aspects of a food waste management systems can be measured. Food waste can be generated at different levels of the FSC, thus it is fundamental analysing the sustainability performance by considering the whole life cycle. In this context, the Life Cycle Thinking (LCT) approach can help in having a point of view that does not focus on a specific process, but allows extending the analysis on all the life cycle. LCT is a “conceptual approach” that allows assessing the environmental, economic and social sustainability of a product or service considering its whole life cycle, from raw materials extraction to the end-of-life, in order to identify improvement solutions for reducing the related impacts. Its assignment is “to develop and disseminate practical tools for evaluating the opportunities, risks, and trade-offs associated with products and services over their entire life cycle to achieve sustainable development”. LCT is made operational through Life Cycle Management (LCM) which is “a management approach that puts the tools and methodologies in the LCT basket into practice”. LCM is a scheme that help companies to reduce the environmental and social “obligations” connected with their product along its whole life cycle (UNEP/SETAC, 2018).

Regarding the waste (and food waste) management, the WFD suggests that the best strategy can be also reached by considering potential deviation from the priority order of the waste hierarchy, and that this deviation can be justified by the LCT (EC, 2008). In this context, LCT can help to evaluate the environmental, economic and social impacts or benefits connected to different options proposed by the waste hierarchy (EC, 2011). Among all the tools and the technics included in the LCM approach, the Life Cycle Assessment (LCA), the Life Cycle Costing (LCC) and the Social Life Cycle Assessment (SLCA) are undoubtedly considered the most appreciated for assessing the environmental, economic and social impacts and helping companies in decision-making process (UNEP/SETAC, 2018).

1.4.1 Life Cycle Assessment (LCA)

The Life Cycle Assessment (LCA) is a standardized tool that allows the assessment of the potential environmental impact associated with a product, process, or service throughout its entire life cycle, from raw material extraction and processing, through manufacturing, transport, use and disposal (Guinée, 2002).

In accordance with the International Organization for Standardization (ISO), and in particular with the ISO 14040:2006 and ISO 14044:2006, the LCA method is structured of four iterative phases (figure 6) (ISO 2006a, ISO 2006b):

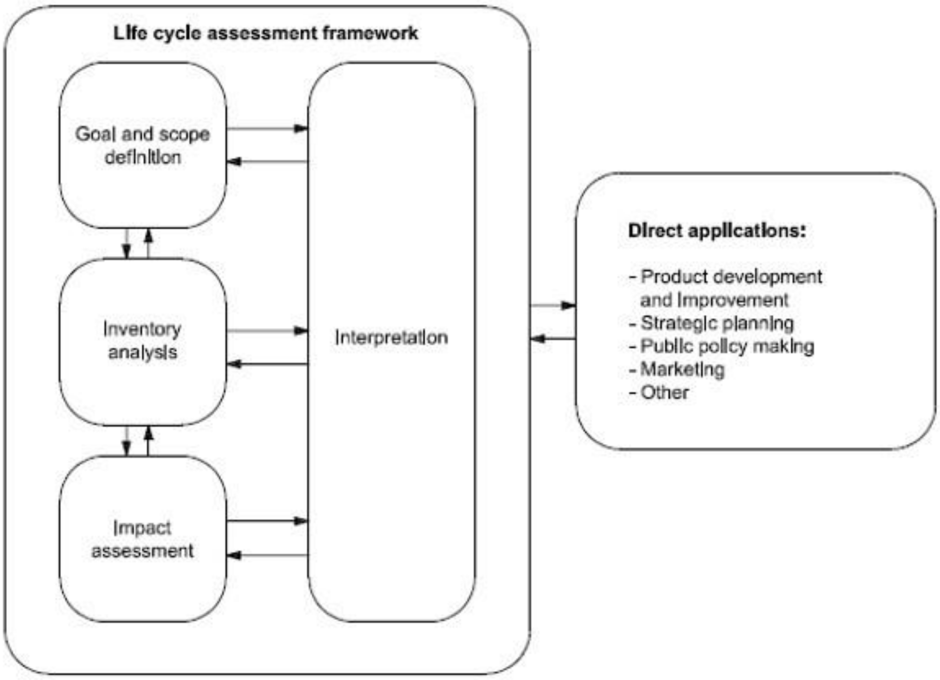


Figure 6. Phases of the Life Cycle Assessment method (source: ISO, 2006a)

1. Goal and scope definition – the first phase of an LCA study consists in defining all the general decisions used for carrying out the analysis. In particular, this phase allows defining, the goal of the analysis, the intended audience, the investigated product, process or service, the functional unit, the system boundaries, the assumptions and limits of the study, the data requirements and the impact assessment method adopted. The functional unit and system boundaries represent two fundamental key parameters defined in the goal and scope definition phase. In particular, the functional unit represents the reference to which the input and output data related to the system under investigation are normalised. The functional unit has to be clearly defined and measurable, allowing the comparison between different systems. The system boundaries allow defining which life cycle stages and processes are included in the LCA study and which one are excluded from the analysis, representing

the so called cut-off. In relation to the life cycle stages considered in the study, the system boundaries can follow different approaches, such as "cradle to grave", "cradle to gate" or "gate to gate".

2. Inventory analysis – this is the longest phase of an LCA study. In particular, it consists in defining all the flows of matter and energy connected to each processes included in the system boundaries. The main procedures carried out during this phase are, the collection of the data related to the flows, the data calculation and the normalisation of the data to the functional unit.

3. Impact assessment – this is the phase in which the data obtained from the inventory analysis are converted in potential environmental impacts. It consists of mandatory (classification and characterisation) and optional (normalisation, grouping, weighting and analysis of data quality) elements. The *classification* represents the qualitative relationship between the inventory data and the impact categories selected for performing the impact assessment. The *characterisation* consists in the quantification of the qualitative relationship between the inventory data and impact categories. The *normalisation* allows to measure the magnitude of the impact categories, in relation to a specific reference information, in order to understand which contribution is more relevant. The *grouping* allows ranking the impact categories by considering different parameters that are previously defined in the goal and scope definition phase. The *weighting* consists in converting indicator results of different impact categories by using numerical factors and can include aggregation of the weighted indicator results. The *analysis of data quality* allows to add

important information to the impact assessment, such as the significance, the uncertainty and the sensitivity of the results.

4. Interpretation – the last phase of an LCA study consists in the discussion of the results obtained from the inventory analysis and the impact assessment phases. In addition, it allows to include recommendation, limits and conclusions related to the analysis.

In the specific context of food waste management, the LCA method is of relevant importance for finding the processes along the FSC, which causes the highest environmental impacts (hot-spots analysis) or for comparing different food waste management solutions with the scope to define the best strategy along the waste hierarchy.

1.4.2 Life Cycle Costing

The Life Cycle Costing (LCC) is a tool for the evaluation of all costs, in monetary terms, related to a product throughout its life cycle, considering not only the purchase price but also the cost of production, maintenance, use and disposal. Therefore, LCC allows assisting decision makers in their choices regarding the advisability of investing in a process (Rebitzer and Seuring, 2003). Instead of LCA, LCC method is not specifically standardised, except for the building sector. Indeed, the ISO 15686-2017 (Part 5) provides the guidelines for performing a LCC related to building and construction sector (ISO, 2017).

According to the “SETAC-Europe Working Group on Life Cycle Costing” three different types of LCC have been defined, Conventional LCC, Environmental LCC and Societal LCC (figure 7) (Hunkeler et al., 2008).

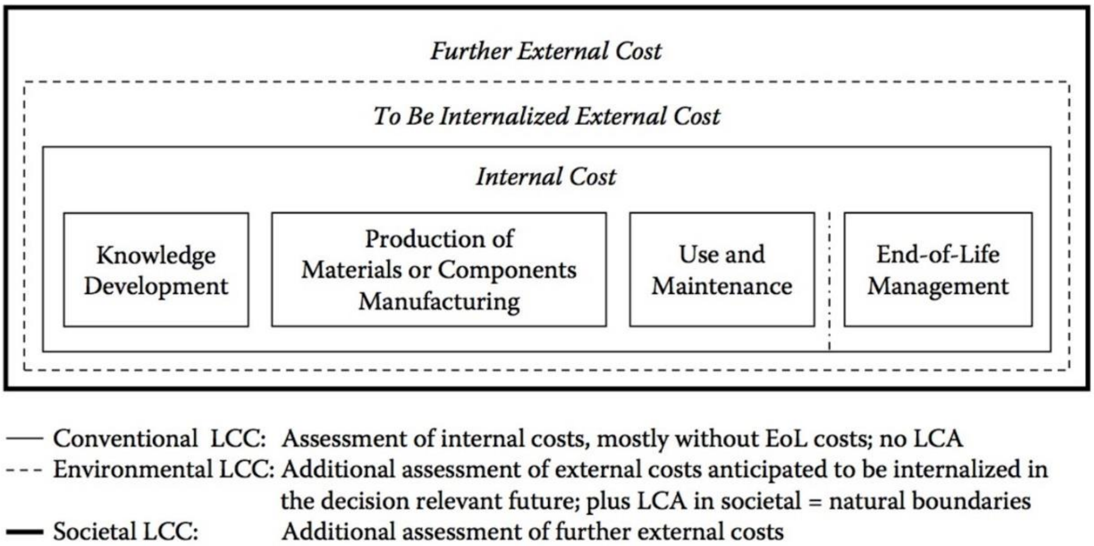


Figure 7. Types of Life Cycle Costing (source: Hunkeler et al., 2008).

The Conventional LCC refers to the "assessment of all costs associated with the life cycle of a product that are directly covered by the main producer or user in the product life cycle". In particular, this type of LCC allows to consider the internal costs but not to include the End of Life or use phases into the life cycle, since these could not be connected to the main actor. The Conventional LCC is strongly related to two traditional approaches, the total cost of ownership (TCO) and the activity-based costing (ABC). The TCO allows assessing the total costs caused by the use of a product, considering the consumer and enterprise manager point of view. The ABC helps the company to evaluate the costs of a product considering general, direct and indirect costs.

The Environmental LCC allows the assessment of all the costs connected to the whole life cycle, including research and development, production of materials or components, manufacturing, use and maintenance, and End of Life, and considering one or more actors who take part into the product life cycle. The Environmental LCC requires the internalisation of the costs, considering also the anticipated costs, along the life cycle, as well as to be related to "not-monetized" LCA results. Therefore, Environmental LCC is a tool that provides a combination of both environmental and economic performance of a product, process or activity, optimizing trade-offs between environmental view and economic and business view (Swarr et al., 2011). Furthermore, the Environmental LCC allows including two different costs in the assessment, internal costs (also assessed through the Conventional LCC) and external costs or externalities that are anticipated to be internalised for helping in "the decision-relevant future" (Rebitzer and Hunkeler, 2003).

The Societal LCC assesses all the costs connected to the life cycle of product, considering a society perspective, including governments. As shown in figure 7, the method allows including the evaluation of further external costs in addition the all the internal and external costs considered in the Environmental LCC. In particular, these added external costs refers to the externalities that cannot be monetized and that need a qualitative evaluation (such as social well-being, job quality, etc.). The main scope of the Societal LCC is to quantify the environmental consequences on the society considering a monetary point of view

According to the so called "Code of practice" proposed by SETAC Working Group on Life Cycle Costing, the operational framework of a LCC, and, in particular, of an Environmental LCC is characterised by four different steps (Swarr et al., 2011): 1) Goal and Scope definition; 2) Economic life cycle inventory; 3) Interpretation; 4) Reporting and review. These steps present a similar structure of the LCA's phases because Environmental LCC should be seen as a complementary assessment to the LCA, as suggested by Hunkeler et al. (2008). Despite this, the specific Environmental LCC phases can be directly related to the case study and can change from case to case (Hunkeler et al., 2008).

1.4.3 Social Life Cycle Assessment

The Social Life Cycle Assessment (S-LCA) is the youngest LCT tool. The first discussion about how to include the social aspects in Life Cycle Assessment was proposed by Fava et al. (1993) in the SETAC Workshop Report entitled "A conceptual framework for Life Cycle Impact Assessment. According to the UNEP/SETAC publication, which proposed the so called "Guidelines for Social Life Cycle Assessment of a product", in 2009, the S-LCA is a method that allow assessing the social and socio-economic performance of a product along its whole life cycle, considering both positive and negative impacts (UNEP/SETAC, 2009). The aspects assessed with this tool can be connected to the behaviour of enterprises, the socio-economic processes or impacts on social capital. Therefore, Social LCA provides information on the social aspects useful for decision making, with a view in improving the performance of organizations as well as the well-being of stakeholders (UNEP/SETAC, 2009). In particular, five main stakeholder categories that could be impacted by the life cycle of a product are identified: workers, local community, society, consumers and value chain actors (not including consumers). Stakeholders provide a basis for the definition of subcategories, which are defined according to specific international agreements (table 1) (UNEP/SETAC, 2009; UNEP/SETAC 2013). The subcategories are socially relevant topics or qualities which include human rights, work conditions, cultural heritage, poverty, disease, and political conflict (Hosseinijouet al., 2014).

Table 1. Stakeholders and related subcategories in Social Life Cycle Assessment (source: UNEP/SETAC, 2009).

Stakeholder categories	Subcategories
Workers	Freedom of association and collective bargaining Child Labour Working hours Forced labour Equal opportunities / Discrimination Health and Safety Fair salary Social Benefit / Social security
Consumer	Health and Safety Feedback mechanism Consumer privacy Transparency End of life responsibility
Local community	Access to material resources Access to immaterial resources Delocalization and Migration Cultural Heritage Safe and Healthy living Conditions Respect of Indigenous rights Communities engagement Local Employment Secure Living Conditions
Society	Public commitments to sustainability issues Contribution to economic development Prevention & mitigation of amend conflict Technology development Corruption
Value chain actors (not including consumers)	Fair competition Promoting social responsibility Supplier relationships Respect of intellectual property rights

In addition, subcategories are divided based on stakeholder and impact categories and are evaluated by the use of inventory indicators. Stakeholders, impact categories, subcategories and inventory indicators represent the point from which starting the S-LCA assessment framework (figure 8).

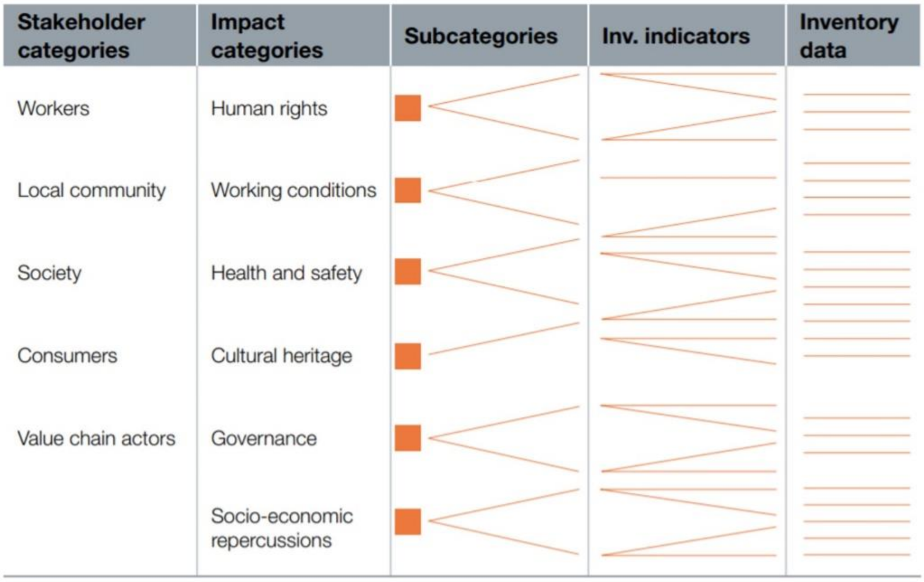


Figure 8. Assessment framework in Social Life Cycle Assessment (source: Benoit et al., 2007; UNEP/SETAC, 2009).

The operational framework of the S-LCA follows an analogous structure to that proposed by the ISO 14040/44:2006 for the common Environmental LCA (E-LCA). Indeed, it includes four main phases, goal and scope definition, life cycle inventory, life cycle impact assessment and interpretation. Despite this, there are some differences between both the methods in applying each phase (UNEP/SETAC, 2009). In particular, these differences are connected to the definition of the stakeholder categories and the related subcategories, in the goal and scope definition, that is fundamental for the next data collection in the inventory analysis phase. In this context, the categories to be assessed in S-LCA and the related social impacts obtained are directly connected to the geographic location (country or region level), while the results from an LCA study are not site-specific since the impacts cannot be differentiated between different locations (Mungkung and Gheewala, 2007). Furthermore, instead of LCA in which the life cycle inventory only refers to quantitative data, the S-LCA is applied by also adopting qualitative and semiquantitative data (Benoît-Norris et al., 2011). The differences related to kind of data collected in the inventory analysis cause difference, between E-LCA and S-LCA, in the impact assessment phase too. Such differences are mainly related to the fact that the characterisation (see section 1.3.1) does not always include mathematical operations, specifically when qualitative data have to be assessed. In particular, two different types of social and socio-economic impact categories (Type 1 and Type 2) may be adopted in S-LCA, depending on the characterisation model applied. The *Type 1* aggregate the results related to the subcategories considering a theme of interest to the stakeholder. The characterisation model is based on a performance reference point obtained from a scoring or weighting step which allows understanding the real “meaning” of the inventory data (UNEP/SETAC, 2009). The *Type 2* allow modelling the results for the subcategories considering a causal relationship defined accordingly to one specific criteria (Dreyer et al., 2006; Hunkeler, 2006; Weidema, 2006).

2. PAPER 1

LIFE CYCLE ASSESSMENT IN FOOD WASTE MANAGEMENT

2.1 Introduction

Food waste is an issue that is receiving growing attention due to its environmental, economic and social impacts (Papargyropoulou et al., 2014). Due to this, it is considered as a crucial waste management study area that needs to be assessed (Garcia-Garcia et al., 2016). Two main type of food waste can be distinguished, unavoidable and avoidable. The unavoidable waste refers to the inedible part of food produced during food preparation (e.g. peels shells etc.), while the avoidable waste refers to the food that, even though still edible, is uneaten or "left to go bad" along distribution, retailing or consumption phases in the Food Supply Chain (Bernard Saraiva Schott and Alexander, 2016). In this context, the avoidable fraction of food waste should be minimised through prevention. Despite this, when prevention cannot be achieved solutions that allow managing food waste should be applied. These solutions should move around the main stages of food waste management, including, collection, transport, pre-treatment and treatment. In particular, regarding food waste treatment, strategies as anaerobic digestion, composting, incineration or animal feed production have been widely adopted. Nevertheless, these strategies need, on the one hand, to be efficient in terms of food waste reduction, on the other, to be performed considering an environmental-friendly point of view. In addition, according to Xu et al. (2018), recovering energy and nutrients from food waste treatment allow good economic opportunity and, above all, moving towards the concept of sustainable development. Therefore, food waste management strategies need to be evaluated considering the resources efficiency and the environmental impacts. According to Notarnicola et al. (2017), Life Cycle Thinking and, in particular, Life Cycle Assessment (LCA) is able to offer an important contribution to the analysis of food waste management, allowing the proposal of environmentally-friendly solutions or improving management options along the whole FSC (Notarnicola et al., 2017).

LCA is a standardized tool that allows the assessment of the potential environmental impact associated with a product, process, or service throughout its entire life cycle, from raw material extraction and processing, through manufacturing, transport, use and disposal (Guinée, 2002).

LCA has been widely adopted for assessing food waste management solutions, by comparing different systems or analysing processes affected by higher environmental impacts. Despite many LCA studies have been performed, the need of underlining limits and potentialities related to the application and suitability of the LCA tool in the context of food waste management is required.

Starting from a literature analysis, this study aims to provide a critical analysis in order to highlight limits and potentialities connected to the application of the LCA in food waste management, with the scope of understanding the suitability of the tool. The study allows, on the one hand, to provide support for LCA practitioners in carrying out a study related to food waste, on the other to help decision-making process in understanding methodological aspects and issues related to the assessment of the environmental performance of a food waste management system.

2.2 Material and methods

The literature review was carried out by using the Scopus® databases, considered as "the largest abstract and citation database of peer-reviewed literature" (Scopus, 2018). The literature review is not comprehensive, thus including all the papers connected to the defined topic, but it is focused on specific papers considering the following criteria that allow better defining the scope of the thesis:

- comparison between different management options considering specific production sectors;
- assessment of alternative and innovative treatment technologies;
- analysis of the environmental hot-spots along a specific management system.

Furthermore, only articles written in English and published in international scientific journals within May 2018, including the key word "Life Cycle Assessment" and "food waste" in the title, abstract and keywords and following the selected criteria were considered.

The database research allows identifying all the available articles written in English and published in international scientific journals within May 2018, considering the selected keywords. In particular, 189 different articles were initially founded. The qualitative analyses considering the three criteria allowed highlighting a representative sample of 60 articles published between 2007 and 2018. Table 1 shows all the papers included in the literature review organised by considering the following information:

- year of publication, first author and title;
- type of analysis: includes the type of the LCA study performed by highlighting, comparative analyses, hot-spots analysis, assessment of alternative technologies, assessment of innovative technologies;
- level of analysis: refers to the processes included in the study are highlighted by distinguishing collection, pre-treatment and treatment;
- treatment system: includes the management processes for food waste treatment analysed in the study;

- production sector: refers to the production level of food waste along the FSC;
- functional unit: refers to the functional unit adopted for carrying out the LCA study;
- impact assessment: refers to the impact assessment method or impact categories used for performing the Life Cycle Impact Assessment (LCIA).

Table 1. Articles analysed and related methodological and applicative aspects (*Treatment system*: Aco-D – Anaerobic co-digestion; AD – Anaerobic digestion; AF – Animal feed; AnMBR – Anaerobic Membrane Bioreactor Bio – Bioconversion; Bio-gas – Bio-gasification; Bio-ref – Biorefinery process; CA – Caprodic acid production; CCo – Centralised composting; CN – Cellulose nanofiber production; Co – Composting; Con – Conversion; Don – Donation; HCo – Home composting; HTC – Hydrothermal carbonisation; IMco-D – In-sink maceration and co-digestion; In – Incineration; IS – Integrated system (AD+Py); La – Landfill; MBT – Mechanical biological treatment; Min – Minimisation; Py – Pyrolisis. *Production sector*: MSW – Municipal Solid Waste).

Year	Author	Title	Type of analysis	Level of analysis	Treatment system	Production sector	Functional unit	Impact assessment
2018	Ankathi et al.	Carbon Footprint and Energy Analysis of Bio-CH4 from a Mixture of Food Waste and Dairy Manure in Denver, Colorado	Comparative	Collection; Treatment	AD; Co; La	Food services	One day of operation of the AD facility; 1 kg of biogas produced	Global warming; Cumulative Energy Demand
2018	Moult et al.	Greenhouse gas emissions of food waste disposal options for UK retailers	Comparative	Collection; Treatment	Don; AF; AD; Co; In; La	Retail	1 MWh of electricity injected into the electricity grid	ReCiPe
2018	Pérez-Camacho et al.	Life cycle environmental impacts of substituting food wastes for traditional anaerobic digestion	Alternative technologies	Collection; Treatment	AD	NA	1 tonne of food waste	Global warming
2018	Chiu and Lo	Identifying key process parameters for uncertainty propagation in environmental life cycle assessment for sewage sludge and food waste treatment	Comparative	Treatment	La; In; AD; Aco-D ; Co	NA	105 t/d of food waste	ReCiPe
2018	Edwards et al.	Life cycle assessment to compare the environmental impact of seven contemporary food waste management systems	Comparative	Treatment	La; Aco-D; IMco-D; CCo; HCo AD; MBT	Household	One years' worth of municipal, food waste	CML-IA
2017	Chen et al.	Comprehensive evaluation of environ-economic benefits of anaerobic digestion technology in an integrated food waste-based methane plant using a fuzzy mathematical model	Hot-spots	Pre-treatment; Treatment	AD	Food services	1 tonne of food waste	Global warming; Human toxicity; Fresh water ecotoxicity; Eutrophication; Acidification
2017	Lijo et al.	The environmental effect of substituting energy crops for food waste as feedstock for biogas production	Alternative technologies	Transport; Storage; Pre-treatment; Treatment	AD	Retail	1 MWh of electricity produced	ReCiPe

2017	Opatokun et al.	Life Cycle Analysis of Energy Production from Food Waste through Anaerobic Digestion, Pyrolysis and Integrated Energy System	Comparative	Treatment	La; AD; Py; IS	From MSW	1 kg of food waste	ReCiPe
2017	Thyberg and Tonjes,	The environmental impacts of alternative food waste treatment technologies in the U.S.	Comparative	Collection; Pre-treatment; Treatment	In; Co; AD	Household	1 tonne of residential residual MSW collected	Climate change; Eutrophication; Acidification; Resource depletion; Stratospheric ozone depletion.
2017	Chen et al.	Production of Caproic Acid from Mixed Organic Waste: An Environmental Life Cycle Perspective	Innovative technology; Hot-spots	Treatment	CA	Retail	1 kg of caproic acid	Global Warming; Acidification; Eutrophication
2017	Mondello et al.	Comparative LCA of alternative scenarios for waste treatment: The case of food waste production by the mass-retail sector	Hot-spots; Comparative	Collection; Pre-treatment; Treatment	La; In; AD; Co; Bi	Retail	1 tonne of food waste	CML 2 baseline 2000
2017	Welfle et al.	Generating low-carbon heat from biomass: Life cycle assessment of bioenergy scenarios	Comparative	Collection; Storage; Treatment	AD; La; Co	NA	1 MWh heat	Global warming
2017	Angelo et al.	Life Cycle Assessment and Multi-criteria Decision Analysis: Selection of a strategy for domestic food waste management in Rio de Janeiro	Comparative	Pre-treatment; Treatment	La; AD	Household	1 tonne wet weight	According to ILCD (e.g. Global warming; Ozone depletion; acidification; etc.).
2017	Eriksson Spångberg	Carbon footprint and energy use of food waste management options for fresh fruit and vegetables from supermarkets	Hot-spots; Comparative	Treatment	In; AD; Don; Con	Retail	1 kg of food waste	Global warming; Primary energy use
2017	Edwards et al.	Anaerobic co-digestion of municipal food waste and sewage sludge: A comparative life cycle assessment in the context of a waste service provision	Hot-spots; Comparative	Collection; Pre-treatment; Treatment	La; Aco-D	Household	8559 Mg of food waste (considering the annual quantity of municipal waste discarded)	CML-IA
2017	Salomone et al.	Environmental impact of food waste bioconversion by insects: Application of Life Cycle Assessment to process using Hermetia illucens	Innovative technologies; Hot-spots	Collection; Treatment	Bio	From MSW	1 tonne of biodigested food waste	CML 2 baseline 2000
2017	Salemdeeb et al.	Environmental and health impacts of using food waste as animal feed: a comparative analysis of food waste management options	Comparative	Treatment	AF; AD; Co	NA	1 tonne of food waste	According to Benini et al. (2014) (e.g. Climate Change; Human Toxicity; etc.)

2017	Mu et al.	Environmental and economic analysis of an in-vessel food waste composting system at Kean	Hot-spots; Comparative	Treatment	Co; La	Food services	1 tonne fresh matter in food wastes treated	TRACI 2
2017	Becker et al.	Co-management of domestic wastewater and food waste: A life cycle comparison of alternative food waste diversion strategies	Innovative technologies; Hot-spots	Collection; Pre-treatment; Treatment	AnMBR; La; AD; Co	Household	5 million gallons per day of domestic wastewater treated	TRACI 2
2016	Naroznova et al.	Global warming potential of material fractions occurring in source-separated organic household waste treated by anaerobic digestion or incineration under different framework conditions	Comparative	Treatment	In; AD	Household	1 kg biodegradable material (wet weight) treated	Global warming
2016	Chiu and Lo	Reviewing the anaerobic digestion and co-digestion process of food waste from the perspectives on biogas production performance and environmental impacts	Review	Pre-treatment; Treatment	AD: A-coD	NA	NA	Climate change
2016	Oldfield et al.	An environmental analysis of options for utilising wasted food and food residue	Comparative	Treatment	Min; Co; AD; In	NA	Annual amount of wasted food and food residue managed in Ireland (1,267,749 t)	Global Warming; Acidification; Eutrophication
2016	Abeliotis et al.	Life cycle assessment of food waste home composting in Greece	Hot-spots; Comparative	Treatment	HCo	Household	1 tonne of organic household waste	CML 2 Baseline 2000
2016	Cristóbal et al.	Methodology for combined use of data envelopment analysis and life cycle assessment applied to food waste management	Comparative	Collection; Treatment	AD; Co; La; In	NA	1 tonne of food waste	According to PEF (e.g. Climate change; Ozone depletion; Resource depletion; etc.)
2016	Ahamed et al.	Life cycle assessment of the present and proposed food waste management technologies from environmental and economic impact perspectives	Comparative	Collection; Treatment	In; AD; HTC	Household; Retail; Food services	1 tonne of food waste	Global Warming; Acidification; Eutrophication; Cumulative Energy Demand
2016	Hodge et al.	Systematic Evaluation of Industrial, Commercial, and Institutional Food Waste Management Strategies in the United States	Comparative	Collection; Pre-treatment; Treatment	La; AD; Co; In	Food services	1 kg of high food waste content industrial, commercial, and institutional (HFW-ICI)	TRACI 2; IPCC (2007)

2016	Bernstad Saraiva Scott et al.	Lifecycle assessment of a system for food waste disposers to tank - A full-scale system evaluation	Comparative	Collection	AD	Household	1 tonne of total solid source separated food waste from households	Primary Energy Use; Global warming
2016	Padeyanda et al.	Evaluation of environmental impacts of food waste management by material flow analysis (MFA) and life cycle assessment (LCA)	Comparative	Collection; Treatment	Co; AF	Household; Food services	1 tonne of food waste	Global Warming; Acidification; Eutrophication; Photochemical ozone creation
2016	Eriksson et al.	Enhancement of biogas production from food waste and sewage sludge - Environmental and economic life cycle performance	Hot-spots; Comparative	Collection; Pre-treatment; Treatment	AD	Household	NA	Global warming
2016	San Martin et al.	Valorisation of food waste to produce new raw materials for animal feed	Alternative technologies	Collection; Pre-treatment; Treatment	AF	Processing	1 tonne of vegetable wastes	According to ILCD (e.g. Climate change, Human toxicity, Eutrophication, etc.)
2016	Woon et al.	Environmental assessment of food waste valorization in producing biogas for various types of energy use based on LCA approach	Comparative	Pre-treatment; Treatment	AD	From MSW	1 tonne of food waste	ReCiPe
2016	Chiu et al.	Life cycle assessment of waste treatment strategy for sewage sludge and food waste in Macau: perspectives on environmental and energy production performance	Comparative	Pre-treatment; Treatment	In; AD; Aco-D	From MSW	1 tonne of sewage sludge and food waste	ReCiPe
2015	Xu et al.	Life cycle assessment of food waste-based biogas generation	Hot-spots; Comparative	Treatment	AD; La	NA	1tonne of volatile solid	ReCiPe
2015	Berge et sl.	Assessing the environmental impact of energy production from hydrochar generated via hydrothermal carbonization of food wastes	Innovative technology; Hot-spots	Treatment	HTC	NA	1 kg of food waste	According to ILCD (e.g. Climate change; Marine eutrophication; Freshwater ecotoxicity
2015	Jin et al.	Life-cycle assessment of energy consumption and environmental impact of an integrated food waste-based biogas plant	Hot-spots	Treatment	AD	Food services	1 tonne of food waste treated	CML2001
2015	Carlsson et al.	Importance of food waste pre-treatment efficiency for global warming potential in life cycle assessment of anaerobic digestion systems	Hot-spots	Pre-treatment	AD	Household	Pre-treatment of 1 ton FW intended for biogas production	Global warming

2015	Piccinno et al.	Life cycle assessment of a new technology to extract, functionalize and orient cellulose nanofibers from food waste	Innovative technology; Hot-spots	Treatment	CN	NA	1 g of microfibrillated cellulose	ReCiPe
2015	Strazza et al.	Life Cycle Assessment from food to food: A case study of circular economy from cruise ships to aquaculture	Comparative	Treatment	AF	Food services	1 tonne of proteins contained by the feed products	Global warming; Cumulative Energy Demand; Water scarcity
2015	Chiew et al.	Environmental impact of recycling digested food waste as a fertilizer in agriculture - A case study	Hot-spots; Comparative	Collection; Treatment	AD	Household; Processing; Food services	Production, handling and spreading of a fertilizer containing 1 kg plant-available nitrogen and 0.20 kg phosphorus after spreading on arable land	Global warming; Eutrophication; Acidification
2015	Bernstad and Andersson	Food waste minimization from a life-cycle perspective	Comparative	Treatment	Min; In; AD	Household	The service of managing one tonne of food waste	Global warming
2015	Eriksson et al.	Carbon footprint of food waste management options in the waste hierarchy - A Swedish case study	Comparative	Treatment	Don; La; In; AD; AF; Co	Retail	Removal of 1 kg of food waste (including packaging) from the supermarket	Global warming
2015	Van Zanten et al.	From environmental nuisance to environmental opportunity: Housefly larvae convert waste to livestock feed	Innovative technology; Hot-spots	Treatment	Bio	NA	1 tonne larvae meal on dry matter	Global warming; Land Use; Energy Use
2014	Ebner et al.	Life cycle greenhouse gas (GHG) impacts of a novel process for converting food waste to ethanol and co-products	Innovative technology	Treatment	Bio-ref	Retail; Processing	1 L of ethanol	Global warming
2014	Evangelisti et al.	Life cycle assessment of energy from waste via anaerobic digestion: A UK case study	Comparative	Pre-treatment; Treatment	AD; La; In	From MSW	35,574 tonnes/year	Global warming; Acidification; Photochemical ozone creation; Nutrient enrichment
2014	Vand ermeersch et al.	Environmental sustainability assessment of food waste valorization options	Comparative	Collection; Pre-treatment; Treatment	AD; AF	Retail	1000 tonnes of food waste	ReCiPe
2014	Zhao and Deng,	Environmental impacts of different food waste resource technologies and the effects of energy mix	Comparative	Treatment	AD; La; Co	NA	1 tonne of raw food waste	Global warming; Acidification; Human toxicity; etc.

2013	Saer et al.	Life cycle assessment of a food waste composting system: Environmental impact hotspots	Hot-spots	Collection; Treatment	Co	NA	Collection, processing, transportation and application of one tonne of compost	TRACI 2
2013	Kim et al.	Evaluation of food waste disposal options in terms of global warming and energy recovery: Korea	Comparative	Collection; Pre-treatment; Treatment	AD; In	Household	1 tonne of food waste	Global warming
2013	Patterson et al.	Life cycle assessment of biohydrogen and biomethane production and utilisation as a vehicle fuel	Alternative technologies	Collection; Pre-treatment; Treatment	AD	From MSW	The production of sufficient fuel to achieve 1 km of passenger vehicle transportation	Ecoindicator 99
2012	Bernstad and La Cour	Review of comparative LCAs of food waste management systems - Current status and potential improvements	Review	Collection; Pre-treatment; Treatment	AD; La; In; Co; AF	NA	NA	Global warming
2012	Nakakubo et al.	Comparative assessment of technological systems for recycling sludge and food waste aimed at greenhouse gas emissions reduction and phosphorus recovery	Comparative	Collection; Treatment	AD; In	Household	Processing capacity to provide disposal services for 100,000 people	Global warming
2012	Grosso et al.	The implementation of anaerobic digestion of food waste in a highly populated urban area: An LCA evaluation	Hot-spots; Comparative	Collection; Treatment	AD; In	Household	The total amount of food waste and residual waste produced in one year (504,000 tonnes)	Global warming; Cumulative Energy Demand; Human toxicity; etc.
2012	Takata et al.	The effects of recycling loops in food waste management in Japan: Based on the environmental and economic evaluation of food recycling	Comparative	Treatment	Co; AF; Bio-gas	NA	1 tonne of food waste	Global warming
2012	Bernstad and la Cour Jansen	Separate collection of household food waste for anaerobic degradation - Comparison of different techniques from a systems perspective	Hot-spots; Comparative	Collection	AD	Household	Collection, transportation and treatment of 1 tonne of source-separated wet food waste	Global warming; Acidification; Eutrophication; Primary Energy Use
2011	Bernstad et al.	Life cycle assessment of a household solid waste source separation programme: A Swedish case study	Comparative	Pre-treatment	AD	Household	1000 tonnes of deposited household waste	Global warming; Acidification; Nutrient enrichment; etc.
2011	Levis and Barlaz	What is the most environmentally beneficial way to treat commercial food waste?	Comparative	Treatment	Co; AD; La	Retail	1000 kg of food waste	Global warming; Total Energy Use
2010	Kim and Kim	Comparison through a LCA evaluation analysis of food waste disposal options from	Comparative	Collection; Treatment	AF; Co; La	NA	1 tonne of food waste	Global warming

		the perspective of global warming and resource recovery						
2010	Inaba et al.	Hybrid life-cycle assessment (LCA) of CO2 emission with management alternatives for household food wastes in Japan	Comparative	Collection; Treatment	In; Bio-gas	From MSW	1 tonne of food waste	CO_2 emissions
2010	Khoo et al.	Food waste conversion options in Singapore: Environmental impacts based on an LCA perspective	Comparative	Pre-treatment; Treatment	AD; In; Co	NA	Potential future amount of food waste generated in Singapore (570,000 tons/year)	Global warming; Acidification, Eutrophication, Photochemical oxidation; Energy use
2007	Lee et al.	Evaluation of environmental burdens caused by changes of food waste management systems in Seoul, Korea	Comparative	Treatment	La; In; Co; AF;	From MSW	1 tonne of food waste	CML 2001

2.3 Results and discussion

The results from the literature review will be reported firstly by including a general overview on the analysed articles, secondly by highlighting critical aspects, limits and potentialities in applying the LCA method in the food waste management sector.

2.3.1 Results from the literature review

Figure 1 shows the main results obtained from the literature review considering the articles published per year.

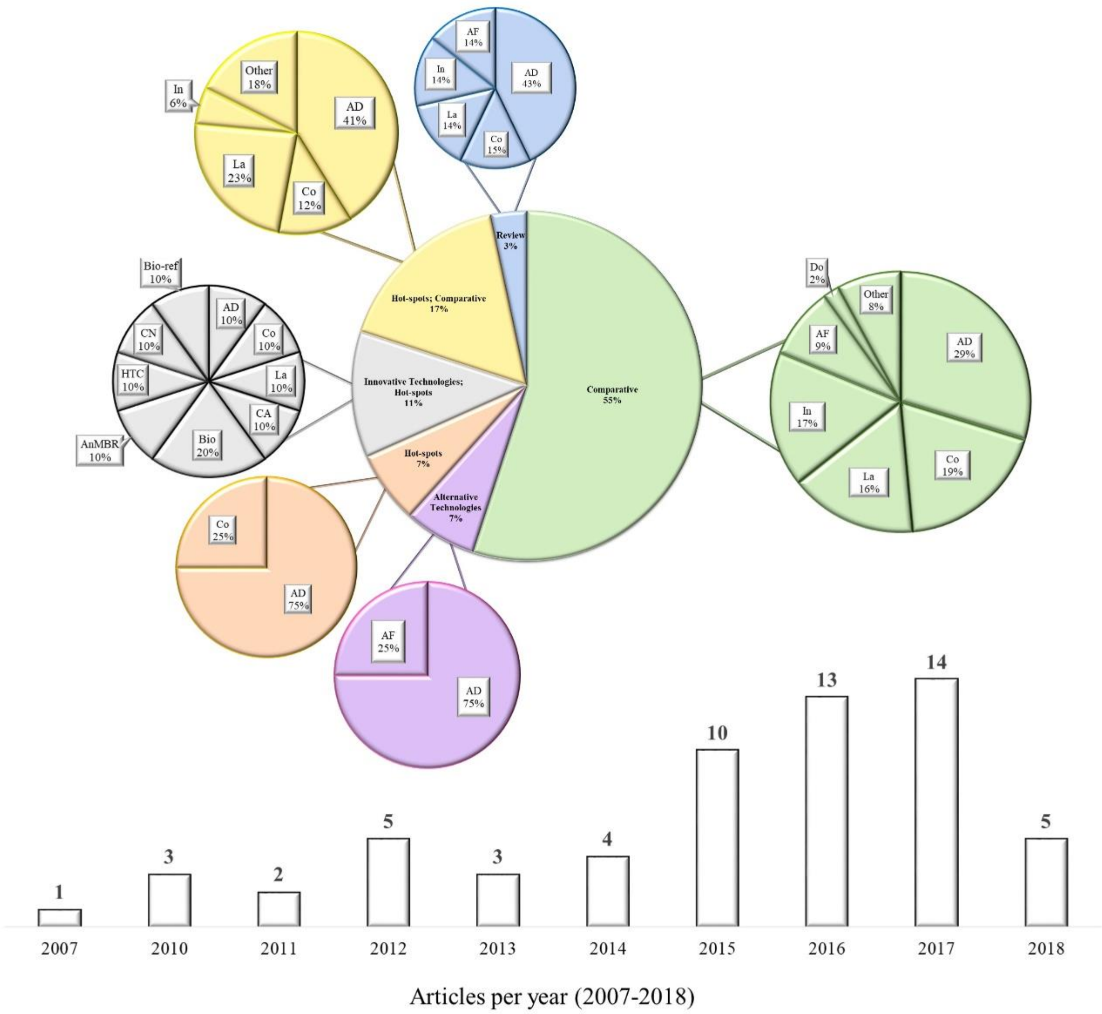


Figure 1. Overview of the literature review performed (AD – Anaerobic digestion; AF – Animal feed; AnMBR – Anaerobic Membrane Bioreactor; Bio – Bioconversion; Bio-ref – Biorefinery process; CA – Caprodic acid production; CN – Cellulose nanofiber production; Co – Composting; Don – Donation; HTC – Hydrothermal carbonisation; In – Incineration; La – Landfill).

Among the 60 analysed articles, more than half (33) is focused on a comparative analysis, while 10 articles include both hot-spots and comparative analysis. A lower number of analyses specifically focused on innovative or alternative technologies, and hot-spots analysis have been performed, respectively 7, 4 and 4. In addition, 2 review articles were accounted (Chiu and Lo, 2016; Bernstad and la Cour Jansen, 2012). Regarding the processes included in the study, 23 articles were related to the assessment of the treatment systems, while 11 included all the three phases, collection, pre-treatment and treatment. Despite these articles included such phases in the system boundaries, an analysis of the environmental performance connected to collection or pre-treatment is not always performed (e.g. Chen et al., 2017). Among the 60 articles 22 different treatment systems were evaluated. In particular, the anaerobic digestion (AD) process was evaluated in 42 different articles considering both comparison with other systems and analysis of alternative technologies. As specified by many authors, the food waste production at household is the most evaluated sector when food waste production is considered (Stenmarck et al., 2016). This is also confirmed by the present literature review given the fact that household sector has been assessed in 16 of the 60 articles considered. Despite this, information about production sector where not specified in 17 papers. Regarding the functional unit, the analysis underscored that not always a common reference unit is considered. In particular, only 13 articles selected a common functional unit considering “1 tonne of food waste”. In same case, the functional unit is directly connected to the analysis context and to the geographical location (e.g. Ankathi et al., 2018; Edwards et al., 2018: Oldfield et al., 2016; Khoo et al., 2010). Furthermore, some LCA study refers to a functional unit connected to the output produced from the treatment instead of the input to be processed (e.g. Lijo et al., 2017; Patterson et al. 2013). The Life Cycle Impact Assessment was performed considering, in particular, the greenhouse gasses (GHG) emissions, in all 60 articles. This is in accordance with Bernstad and La Cour (2012) who highlighted that Global warming is the most adopted impact category for assessing the environmental performance of food waste management.

Analysing the selected papers, it is evident as LCA has been widely adopted for evaluating different treatment strategies in order to propose the most appropriate, innovative and sustainable food waste management systems, as well as for assessing collection activities. For example, Berge et al. (2015) performed and LCA study in order to evaluate the energy production from hydrochar produced through hydrothermal carbonisation (HTC). HTC is a low temperature thermal process that allows treating food waste by using a low amount of electricity and thus causing lower environmental impacts in comparison with other systems, such as incineration. The product obtained by the treatment (hydrochar) is carbon reach and energy dense and represents a good substitute as soil amendment and for energy production (Berge et al., 2015). Salomone et al. (2017) assessed the so called bioconversion process in which the food waste is treated by using the insect *Hermetia illucens* (Black Soldier Fly). The analysis aimed to evaluate the environmental hot-spots connected to the process. Highest impacts are connected to the GHG emissions from the bioconversion process and the energy consumption (Salomone et al., 2017). The bioconversion process has been also assessed by Mondello et al. (2017) who compared this innovative system with other solutions, such as, landfill, incineration, composting and anaerobic digestion. The bioconversion showed the best environmental performance when the avoided production is considered. In contrast, when the substitution of conventional product is not evaluated, the anaerobic digestion causes the lowest environmental impacts (Mondello et al., 2017). Regarding the collection systems, Bernstad Saraiva

Scott et al. (2016) and Bernstad and la Cour Jansen (2012), compared the common collection of food waste in bags and an alternative collection system by using kitchen tanks, both for food waste anaerobic digestion treatment. The analysis showed that the tanks utilisation allows improving the environmental performance. Despite this, Bernstad and la Cour Jansen (2012) highlighted that ranking scenarios may change if only emissions in the foreground systems are considered and indicated the importance of considering also downstream emissions (Bernstad Saraiva Scott et al., 2016; Bernstad and la Cour Jansen, 2012). LCA studies were also focused on the evaluation of alternative treatment solutions such as the treatment of food waste with sewage sludge. In particular, Chiu and Lo (2018), Edwards et al. (2017) and Chiu et al. (2016) showed that the combined treatment of food waste and sewage sludge cause lower environmental impacts in anaerobic digestion (Chiu and Lo, 2018, Edwards et al., 2017 and Chiu et al., 2016). Other studies focused on the evaluation of the environmental impacts connected the utilisation of the by-products obtained from food waste treatment compared with the conventional products, thus moving the attention on the output of the systems. Woon et al. (2016) compared the use of the biogas produced through the treatment of food waste in an anaerobic digestion plant. The authors highlighted that using biogas as a petrol substitute for vehicles allows lower environmental impacts than producing electricity and heat or city gas (Woon et al., 2016). Furthermore, Ciew et al., (2015) assessed the use of digested food waste produced through anaerobic digestion as fertiliser in agriculture underscoring that its adoption causes higher environmental performance than chemical fertiliser. A general analysis of the comparative LCA studies, in which different food waste treatment technologies were assessed, underscored that anaerobic digestion was the best management solutions instead of other options, while landfill was considered as the system causing the worst environmental performance.

2.3.2 Critical analysis, limits and potentialities

The literature review performed allowed underscoring limits and potentialities connected to the application of the LCA tool for assessing food waste management. Among the 60 articles analysed some critical methodological and applicative aspects were underscored. In order to better define these aspects, an analysis considering the four phase of a LCA study (goal and scope definition; inventory analysis; impact assessment; interpretation) is proposed.

Regarding the first phase of goal and scope definition, key problems are connected to the definition of the functional units and system boundaries as well as to the assumptions made for carrying out the analysis. It is known that functional unit definition is one of the most important step in the goal and scope definition phase. According to ISO 14044:2006, the functional unit is reference unit for the comparison between different study (ISO, 2006b). In the context of food waste management, as highlighted by the literature review, the functional units adopted among the 60 articles are highly differentiated. Indeed, a common functional unit was only adopted in 13 articles. In this context, different functional units may cause difficult in the extraction and comparison of the results. In addition, the functional unit is not well specified in some articles, causing misunderstanding that can affect the interpretation of the results. System boundaries selection represents another important step in defining the goal and scope of the analysis. System boundaries allow understanding which phases and processes are included in the study and, in the specific context of food waste management, they allow highlighting if avoided products are considered or not. In this context, as highlighted by Mondello et al. (2017), the inclusion of the avoided may cause changing in the final results. Results from the literature review underlined that a wide type of by-product can be produced from the food waste treatment- This may cause confusion among the analysis in defining and including an appropriate avoided product in the system boundaries. In addition, none of the analysed articles included in the system boundaries the processes related to the production of food. Considering a life cycle perspective such processes should be accounted in order to have a comprehensive assessment of food waste treatment. Anyhow, problems in accounting food production processes may be connected to the data gathering. Regarding the assumptions, the analysis underscored that main difference in GHG emissions are due to the assumptions selected. In this context, assumptions are not always well justified as well as not always evaluated through sensitivity or uncertainty analysis.

One of the main limits connected to the inventory analysis phase is related to the data collection and availability. This is a problem that commonly occurs among the LCA studies applied in different sectors. Regarding the food waste management, main issues are connected to the inventory data related to the pre-treatment and treatment processes for which many studies adopted foreground data (es. Salomone et al., 2017; Mondello et al., 2017; van Zanten et al., 2015). Limits in data gathering mainly occur when new technologies are evaluated. In this context, the use of secondary data may strongly affect the final results. In addition, the analysed articles showed that transport activities are never responsible for higher environmental impacts. Despite this, data related to transportation are not always well specified due to absence of detailed information about distances and mode of transportation. Furthermore, despite food waste composition and characteristics (e.g. water content) are highly connected to the treatment efficiency and environmental performance, data related are not always presented or considered due to issues in performing chemical and physical analyses.

Regarding the impact assessment phase the main weaknesses are related to the selection of the impact categories. As shown in the previous section, the most evaluated impact category among the analysed articles was represented by the Global warming by which the GHG emissions are assessed. In addition, despite others impact categories were accounted, detailed results were mainly presented for GHG emissions. In this context, assessing a small number of impact categories or discussing the results only taking into consideration categories that may be considered as representative may, on the one hand facilitate the interpretation of the results, on the other, can cause the risk of excluding important aspects from the assessment. As demonstrate by Angelo et al. (2017) and Mondello et al. (2017) results can change in relation to the type of impact category selected. In this context, impact categories should be selected accordingly to the processes analysed as well as to the inventory data adopted. Another important aspect related to the impact assessment phase is the evaluation of particular impacts such as odour (Marchand et al., 2013) and noise (Cucurachi et al., 2012). These impact categories are specifically connected to the waste management sector but not commonly assessed. The assessment of the odour and noise impacts may be fundamental when new technologies or new treatment plants are evaluated and proposed to be adopted near to city.

Regarding the interpretation phase, the main limits and key aspects are connected to all the choices made among the previous phases. In particular, as previously reported, the results interpretation, may depend on the type of impact categories evaluated.

Furthermore, due to the issues in data gathering and the adoption of foreground date, further analysis, such as sensitivity or uncertainty should be commonly performed.

The application of LCA in food waste management also presents many potentialities. In this context, the LCA tools allow comparing the environmental performance of different management systems, including collection, distribution, pre-treatment and treatment. In addition, the hot-spots analysis allows identifying processes affected by higher environmental impacts in order to propose continuous improvement in the system. A strength point related to the LCA is the possibility of accounting and evaluating the use of the by-product obtained from the treatment as substitute for the conventional products. This allows moving the analysis beyond the treatment process and highlighting the real relevance of the analysed management system. The literature review also underscores that LCA is an appropriate tool for assessing particular and innovative technologies and thus for helping in decision-making when unknown processes have to be evaluated. Furthermore, the high number of LCA study applied to food waste management allows obtaining important information and data that can be adopted by local governments and businesses when sustainable food waste management options are considered

2.4 Conclusions

The aim of this study was to perform a literature review related to the application of Life Cycle Assessment tool for the evaluation of the environmental impacts connected to food waste management. The scope was to underline limits and potentialities through a critical analysis in order to define the suitability of the LCA tool in food waste management.

The literature review allowed detecting 60 articles different articles in which the LCA tool was applied for comparative analysis, hot-spots analysis or assessment of innovative or alternative food waste management solutions. The critical aspects resulted from the literature review are connected to the definition of the functional unit and system boundaries, data collection and impact categories selection. In particular, the analysis allowed highlighting that the main limits and critical aspects related to an LCA study applied in food waste management may be directly connected to the practitioner's choices instead of real methodological issues. In contrast to the underlined limits, LCA can be considered as a useful tool for comparative or hot-spots analysis, considering in particular the assessment and evaluation of innovative technologies. Furthermore, it can be considered as a valid method in making-decision process that allow moving towards a sustainable food waste management. Despite out the scope of this study, it is important to highlight that LCA is also an important tool for assessing strategies that allow avoiding food waste management processes, such as prevention. In this context, prevention is considered as the most preferable solution for facing the food waste problem (Papargyropoulou et al., 2014) and many LCA study underscored that it represents the highest environmental-friendly solution, Nevertheless, the concept and actions connected to the prevention should not be considered as integrated in food waste management but should be assessed as a separated option. In this context, the definition of waste management refers to all the processes in which waste is collected, transported, recovered and disposed. It considers all the activities involved after the production of food waste and thus excluding the possibility of prevention activities.

In general, the LCA method can be considered as an appropriate tool for evaluating the environmental sustainability of food waste management. Despite this, its suitability is strongly connected to the practitioner's choices and to the specific analysis context.

3. PAPER 2

ASSESSING THE ECONOMIC IMPACTS OF FOOD WASTE MANAGEMENT

3.1 Introduction

Food waste is an important issue that recently has been taken into consideration by scientific communities, institutions, governments and businesses. The amount of food waste globally produced (1.3 billion tonnes per year) represents one third of the total amount of food produced for human consumption (Gustavsson et al., 2011). The main issues connected to the food waste cover both environmental and economic aspects. Indeed, considering the only production phase along the Food Supply Chain (FSC), food waste contributes for about 2.2 Gt CO_2 eq in terms of greenhouse gasses (GHG) emissions (Porter et al., 2016). In addition, food waste is responsible for higher economic impacts, causing losses for about 1 trillion US dollars (Stenmarck et al., 2016) and negative contributing to the Gross Domestic Product (GDP) of different countries (Nahman and de Lange 2012).

Food waste is considered as a phenomenon that includes all levels of the FSC and, in this context, analysing its production and management considering a life cycle perspective represents a priority (Zaman, 2014). Life Cycle Assessment (LCA) has been widely adopted for analysing the environmental impacts connected to food waste management (Carlsson et al., 2015). Despite this and considering the context of sustainable development, the economic impacts related to food waste management needs to be evaluated. The Life Cycle Costing (LCC) is a tool for the evaluation of all costs, in monetary terms, related to a product throughout its life cycle, considering not only the purchase price but also the cost of production, maintenance, use and disposal (Hunkeler et al., 2008). The LCC method has been adopted in different sectors, considering in particular buildings, energy generation and use and transport (e. g. Kneifel, 2010; Frangopol and Liu, 2007; Fuller and Petersen, 1996). In contrast to

LCA, LCC does not refers to a specific standardization, except for the building and construction sector, for which the ISO 15686-2017 (Part 5) provides the guidelines for performing a LCC study related to the specific context (ISO, 2017).

According to Hunkeler et al. (2008) three different types of LCC can be performed, Conventional LCC, Environmental LCC and Societal LCC. The Conventional LCC allows assessing "all the costs associated with the life cycle of a product that are directly covered by a given actor in the life cycle". The Environmental LCC consists in the "assessment of all costs associated with the life cycle of a product that are directly covered by any one or more of the actors in the product life cycle with complementary inclusion of externalities that are anticipated to be internalised in the decision-relevant future". The Societal LCC refers to the "assessment of all costs associated with the life cycle of a product that are covered by the actors in society" (Hunkeler et al., 2008).

Regarding the application of LCC in the specific context of food waste management few studies have been performed (De Menna et al., 2018). In this context, it is still unclear if LCC can be considered an appropriated tool for assessing this specific sector. Starting from this point, the aim of this study is to perform a literature review related to the available researches in which LCC has been adopted for assessing food waste management strategies. The scope is to provide information regarding limits and potentialities as well as to understand if the LCC can be considered an useful tool for evaluating the economic impact in terms of monetary costs involved in food waste management activities.

3.2 Material and methods

The first step of the present study includes a detailed assessment of the articles which refers to the application of the LCC tool for assessing food waste management solutions. The literature review was performed by using Scopus® databases (Scopus, 2018) and Google Scholar (Google Scholar, 2018), and includes all the articles published in international scientific journals within May 2018, using the key word “Life Cycle Costing”, “Life Cycle Cost”, “LCC” and “food waste” in the title, abstract and keywords. Due to the novelty in applying the LCC in the considered sector, not specific selection criteria were adopted. In particular, the analysis refers to all the applicative case studies in which the economic costs of food waste management are evaluated by means of the LCC tool. The research through the selected keywords allowed detecting 16 different articles for which only four directly referred to the context of this analysis (Table 1). The problem related to the few amount of LCC articles applied in food management has been also confirmed by De Menna et al. (2018). In order to correctly fulfil the scope of the analysis and to obtain a high information level for proposing limits and potentialities related to the LCC application, a detailed description and evaluation of the selected articles is proposed in the next section.

The articles detected through the literature review are reported in table 1 by including the type of LCC method adopted, the functional unit selected and the inclusion of an integrated assessment LCA/LCC.

Table 1. Articles obtained from the literature review.

Year	Author	Title	Type of analysis	Conventional LCC	Environmental LCC	Societal LCC	Functional unit	Integration with LCA
2017	Lee et al.	Comparison and Evaluation of Large-Scale and On-Site Recycling Systems for Food Waste via Life Cycle Cost Analysis	Case study	YES	NO	NO	1 tonne of food waste	NO
2016	Martinez-Sanchez et al.	Life-Cycle Costing of Food Waste Management in Denmark: Importance of Indirect Effects	Case study	NO	YES	YES	210 kg of food waste produced by single-family housing; 143 kg of food waste produced by multiple-family housing	YES
2012	Takata et al.	The effects of recycling loops in food waste management in Japan: Based on the environmental and economic evaluation of food recycling	Case study	YES	NO	NO	1 tonne of food waste	YES
2011	Kim et al.	Evaluation of food waste disposal options by LCC analysis from the perspective of global warming: Jungnang case, South Korea	Case study	YES	NO	NO	1 tonne of food waste	YES

Despite the few number of articles to be evaluated, the information obtained from the literature review shows that all the studies cover different aspects connected to the LCC application in food waste management. In particular, the articles refer to case studies in which all the LCC methods are applied. This aspect may allow a first assessment of limits and potentialities connected to the LCC applied in food waste management as well as providing a general overview about the suitability of the tool in the specific sector.

3.3 Results and discussion

In this section, firstly a detailed analysis of the articles obtained from the literature review will be performed. Secondly, limits and potentialities related to the adoption of the LCC tool for assessing the economic impacts of food waste management strategies will be proposed.

3.3.1 Systematic analysis of the literature review

The study carried out by Lee et al. (2018) aimed to perform a Life Cycle Cost analysis with the scope of comparing two different systems for food waste recycling, in order to evaluate the costs and benefits connected to both alternative. In particular, the comparison was made between a large-scale recycling system, which represents the base case, and an on-site-scale recycling system, which refers to the alternative solution. The functional unit selected for carrying out the analysis was 1 tonne of food waste. The costs evaluated for the large-scale system were referred to collection, transport, food waste treatment through anaerobic composting facility, disposal of the food wastewater and utilisation of the by –product obtained from the treatment (compost). While, considering the on-site scale recycling the costs were associated to the collection, treatment through on- site fermentation system and the utilisation of the by-product (compost). The evaluation of the systems was performed by using a costs-benefits analysis. In addition, an economic efficiency analysis was performed considering both local governments and resident perspective. The results underscored that, although no economic benefits for local governments using an on-site recycling process were accounted, this system allowed economic advantages in comparison with the large-scale recycling process. In particular, the main economic benefits were associated with a lower cost in maintenance procedures. The analysis underscored how LCC can provide useful information for local governments regarding food waste management activities

Martinez-Sanchez et al. (2016) performed a LCC study in order to evaluate the economic performance of indirect effects connected to the food waste management in Denmark. The interesting aspects of the study are connected to the type of methods adopted. In particular, the authors performed an integrated assessment by combining LCA and Environmental LCC in order to make a environmental and financial assessment. In addition, the Societal LCC was adopted for assessing the economic welfare. The functional unit selected refers to “the management of annual food waste generated by Danish households” considering both single-family housing and multiple-family housing. The analysis focus on the comparison between different scenarios including, incineration, anaerobic digestion, animal feed production and prevention. System boundaries includes food production, food waste production, collection, treatment and utilisation of by-products by accounting avoided products. The results in terms of costs underscored that the highest economic impacts are connected to the food production in all scenarios except for prevention in which the production of food is considered as avoided. Regarding the scenarios, the anaerobic digestion and animal feed production showed lower economic performances than incineration because of the costs associated to the separation of the organic fraction. Regarding the environmental impacts, the prevention scenario showed the highest environmental performance, while anaerobic digestion, incineration and animal feed production caused higher impacts mainly due to the production of food. The assessment of the externalities through the application of the Environmental LCC showed that the costs associated to the emissions are higher than the internal costs, mainly due to the lack of specific data related to the costs of many emissions. Results from the Societal LCC highlighted that welfare losses are mainly connected to the purchase of unconsumed food. The study also underscored the importance in considering the economic impacts related to the indirect effects (such as changes in land use for food production) which can cause changes in the final results.

Takata et al. (2012) carried out and integrated assessment by applying both LCA and LCC in order to evaluate the environmental and economic impacts connected to the "looped facilities" with the scope of assessing the current situation of food waste recycling in Japan. The analysis focused on different food waste scenarios, composting, bio-gasification, animal feed production. The functional unit selected was 1 tonne of food waste. The LCA results highlighted that lower environmental impact in terms of GHG emissions are connected to the bio-gasification and animal feed production scenario. Regarding the LCC results, the study allowed underscoring that highest costs are associated to the maintenance activities. In addition, considering the scenarios, the lowest economic impacts are related to the composting treatment. Regarding the animal feed production, higher costs are connected to the inefficiency of the systems in terms of amount of feed produced by treating food waste, causing the purchase of conventional animal feed to satisfy the local request. Furthermore, the highest economic impacts are related to the bio-gasification due to laboratory costs. The analysis highlighted the discrepancy between LCA and LCC results that results in possible issues in decision-making activities.

Kim et al. (2012) performed a comparative LCA and LCC study in order to evaluate different scenarios for food waste treatment (animal feed production, anaerobic digestion, anaerobic co-digestion, incineration and landfill). In addition, the authors evaluated the analysis of the environmental and economic benefits connected to the utilisation of the by-products obtained from the food waste treatment The assessment was carried out by converting the environmental value to monetary value in the perspective of global warming. The LCC was performed by following the system boundaries adopted for the LCA which include all the processes from food waste generation the its final disposal. The main analysis results underscored that, on the one hand landfill scenario caused the highest environmental impacts, on the other, it allows lowest economic impacts. Despite this, performing the benefits analysis allows understanding that lowest environmental and economic benefits are connected to the treatment of food waste by landfilling. The analysis underscored the importance in going beyond the economic evaluation of the treatment system by also including the performance and benefits connected to the by-products utilisation.

3.3.2 Limits and potentialities in performing a LCC study

The literature review allows underscoring that LCC tool is still not widely adopted for assessing the economic performance of food waste management strategies. Despite this, some key aspects can be highlighted among the analysed articles. In particular, the LCC has been mainly adopted for comparing different food waste treatment systems considering a life cycle perspective, providing useful information regarding the economic performance among the scenarios. Instead of Conventional LCC the application of the Environmental LCC and Social LCC allow including the economic aspects connected to environmental and social issues. Despite this both the tools present some problems connected to data limitation that can cause issues in performing the analysis. In particular, the externalities considered in the Environmental LCC not always can be accounted due to the lack of data related to the monetary evaluation of the environmental impacts. This can cause problems when LCA and LCC are integrated because of restriction in the selection of the impact categories. In addition, difficulties can occur when complex environmental impacts needs to be evaluated in monetary terms. Among the analysed articles, it was evident that the integration between LCA and LCC can improve the level of the analysis by allowing a comprehensive assessment. In addition, as specified by Martinez-Sanchez et al. (2016), the possibility of including indirect factors makes LCC an important tool for assessing aspects that cannot be evaluated through LCA. Furthermore, the integration of LCA and LCC can help in obtaining results that can strongly affect the decision-making process. In this context, the analysis performed by Kim et al. (2012) highlighted that the landfill process, which is commonly considered as the worst food waste treatment systems considering an environmental perspective, can represents that best solution in terms of economic performance, when is compared to other management systems. Indeed, considering a life cycle point of view some management systems can include higher costs that are not directly related to the treatment process but connected to other activities such as collection or sorting. The study performed by Lee et al. (2016) also allows underlining that LCC can provide information regarding the assessment of the economic benefits among different actors (such as local government and residents). Another important aspect is connected to the inclusion of the avoided product. In particular, the assessment of the economic benefits related to the use of the by-products can make changes in decision-making by considering a treatment process with good economic performance as not preferable. Regarding the evaluation of the functional unit, detailed aspects cannot be provided due to lack of studies that consider different functional units. Indeed, among the analysed articles, three studies selected the same functional unit (1 tonne of food waste), while one study was performed by directly considering the analysis context (Martinez-Sanchez et al., 2016). The utilisation of the same functional unit of "1 tonne of food waste", among three of the four investigate articles can be justified by the fact that it represents one of the most used functional unit in LCA. Regarding the food waste sector analysed, all the articles referred to food waste produced at household level. This aspect may be useful when decision-making involves municipalities or residents. In contrast, it makes not possible evaluating the feasibility of LCC considering the perspective of a company involved in food waste production, that works, for example, in the retail sector. Lastly, important aspects are related to the inventory data adopted for carrying out the analysis. In particular, when background data are used some biases may occur among the results. This is mainly due to the fact that costs are often directly connected to the local context.

3.4 Conclusions

The scope of this study was to highlight limits and potentialities related to the application of the LCC in the of food waste management sector, in order to evaluate the suitability of the toll in this specific context. Limits and potentialities were detected through the implementation of a literature review.

The results obtained from the literature review pointed out that there is a lack of articles directly related to the application of the LCC for assessing food waste management options. Indeed, at the time in which the literature review was performed (May 2018), only four articles were specifically referred to the context of the study. The analysis allowed underlining the following aspects directly related to the food waste management sector:

- LCC has been mainly adopted for comparative analysis;
- the lack of market prices for emissions can cause issues in assessing the economic impacts connected to externalities through the application of the Environmental LCC;
- the integration of LCA and LCC may allow obtaining a high analysis level, but needs to be well defined in order to avoid problems in decision-making producers;
- when LCC is applied for comparing different management options, the assessment of the economic benefits related to the utilisation of the by-products should be considered in order to avoid partial results in the final evaluation;
- assessment of the food waste management considering production sectors such as retail, food services, or processing are still missing;
- LCC allows only focusing the attention on the economic performance of the analysed system without considering the overall impacts on the economic system;
- the adoption background data may strongly affect the final results.

The aspects here presented underscores that LCC method still presents methodological and applicative issues and needs to be improved and better evaluated. In addition, the lack of information specifically related to the application of this tool in food waste management underscores that we are in an early stage for providing detailed information on its suitability. Despite this, the LCC can be considered as a useful and important tool for evaluating the economic impacts considering a life cycle perspective.

4. PAPER 3

SOCIAL IMPACTS IN FOOD WASTE MANAGEMENT

4.1 Introduction

Life Cycle Thinking approach allows evaluating systems, processes or products by pointing out their environmental, economic and social performance in a life cycle perspective (Life Cycle Initiative, 2018). The Social Life Cycle Assessment (S-LCA) is a novel methodology that helps in evaluating the social impacts of a products (Benoît-Norris et al., 2012). Recently, S-LCA received growing attention by the scientific communities and has been adopted for assessing different sectors. Nevertheless, this tool still presents many methodological issues that causes high difficulties in moving towards a defined standardisation. In particular, the main consensus among the researchers is connected to the critical aspects related to the methodology, instead of a common procedural framework (Zanchi et al., 2018). In this context, the "Guidelines for Social Life Cycle Assessment of a product" proposed a methodological framework for performing a S-LCA study (UNEP/SETAC, 2009). The framework is based on the procedural phases proposed by the ISO 14040/44:2006 for applying the Life Cycle Assessment method, therefor considering, 1) goal and scope definition, 2) inventory analysis, 3) impact assessment and 4) interpretation (ISO, 2006a; ISO 2006b). According to Arcese et al. (2018), despite the interest in proposing a guideline for S-LCA is quite recent, the first idea of "socialising" the LCA tool and assessing social impacts was proposed by the Society of Environmental Toxicology and Chemistry (SETAC) with the development of the social welfare category in 1999 (Arcese et al., 2008). For definition the S-LCA is considered as a tool that allow assessing the social and socio-economic performance of a product along its whole life cycle, considering both positive and negative potential impacts (UNEP/SETAC, 2009). In addition, S-LCA is also considered as a tool for evaluating the consequences connected to changes among the life cycle of a product (Macombe et al., 2013).

Among the scientific community there is consensus regarding the problems related to food waste production and management. In this context, food waste is receiving growing attention due to its environmental, economic and social impacts (Papargyropoulou et al., 2014). Regarding the social aspects, food waste can cause higher impacts along all the stages of the Food Supply Chain (FSC). For example, considering the household or retail sectors, the portion of food that is still edible for human consumption but that is wasted for aesthetic characteristics can directly contribute to the reduction food and, indirectly, can cause negative social impacts connected, for example, to the availability of edible food for feeding poor people (Stancu et al., 2016). In addition, processes involved in food waste management may results in positive or negative social impacts. Despite this, there is a lack of detailed information and assessment on the social performance related to food waste management option. In this context the S-LCA may help in achieving such information by also considering a life cycle perspective. Despite this, the lack of a standardised framework as well as the different approaches adopted by researchers in performing a S-LCA may cause difficulties when a complex sector as food waste management has to be evaluated.

For the author's knowledge, none studies related to the assessment of the social implications connected to food waste management have been performed through the application of the S-LCA method. In addition, only one study directly focused on food waste, considering the social aspects connected to the prevention, which is commonly not considered as a management solution but as a procedure for avoiding food waste production (Ribeiro et al., 2018; Papargyropoulou et al., 2014).

The absence of specific applicative studies, may be justified, on the one hand, by the fact that S-LCA is still in a procedural development stage, on the other, by the lack of appropriate information related to its suitability for evaluating the food waste management sector.

In this context, starting from a literature overview related to methodological and applicative aspects of the S-LCA method, the present study aims to two main goals:

- underscoring methodological issues associated with the methodology;
- analysing such procedural limits considering the food waste management sector in order to evaluate the suitability of the tool.

4.2 Literature overview

The S-LCA has been widely evaluated by considering both, methodological and applicative aspects. In particular, according to the study performed by Arcese et al. (2018), in which a literature review was performed by selecting S-LCA studies by means of a statistical approach based on lexicon analysis, the number of methodological and applicative studies is quite equal. Indeed, among the 51 studies detected, 28 were performed for assessing methodological aspects connected to the S-LCA, while 23 were implemented for evaluating specific case studies.

The analysis of the international scientific literature underscores that S-LCA has been mainly adopted for evaluating the manufacturing, agricultural and energy sectors (Petti et al, 2018). For example, De Luca et al. (2015) proposed an approach that combines S-LCA with tools derived from qualitative and operational researches considering, in particular, the implementation of multi-criterial analysis in S-LCA application. The authors adopted this approach for evaluating the citrus growing in the 3 main cultivated areas and comparing organic and conventional agricultural practices (De Luca et al., 2015). Bouzid and Padilla (2014) used S-LCA in order to measure the social performance of sub-sectors of the industrial tomatoes food chain in Algeria. Mattioda et al. (2017) performed a S-LCA study in order to assess energy technology derived from hydrogen. Traverso et al. (2012) applied the LCA, the Life Cycle Costing (LCC) and the S-LCA through the implementation of the Life Cycle Sustainability Assessment in order to evaluate the assembly procedure of photovoltaic modules production. In addition, other studies have been performed considering the textile (Lenzo et al., 2018; Lenzo et al., 2017) and tourism (Arcese et al., 2013) sectors.

The analysis of the studies performed in the specific context of waste management allow finding five different S-LCA analysis (Table 1).

Table 1. Social Life Cycle Assessment studies applied in waste management sector.

Year	Author	Title
2015	Umair et al.	Social impact assessment of informal recycling of electronic ICT waste in Pakistan using UNEP SETAC guidelines
2014	Martinez-Blanco et al.	Application challenges for the social Life Cycle Assessment of fertilizers within life cycle sustainability assessment
2013	Foolmaun and Ramjeeawon.	Comparative life cycle assessment and social life cycle assessment of used polyethylene terephthalate (PET) bottles in Mauritius
2013	Aparcana and Salhofer	Development of a social impact assessment methodology for recycling systems in low-income countries
2013	Aparcana and Salhofer	Application of a methodology for the social life cycle assessment of recycling systems in low income countries: three Peruvian case studies

Umair et al. (2015) applied the S-LCA for assessing the social impacts related to the informal recycling of electronic information and communication technology (ICT) waste. The S-LCA was applied by following the UNEP/SETAC guidelines. The analysis was performed by considering four stakeholder categories: workers, society, local community and value chain actors. The functional unit selected was “the handling of electronic waste that enters the informal recycling sector in Pakistan in 2012. Martinez-Blanco et al. (2014) carried out a LCSA compared in order to compare fertilisers produced by composting organic waste and mineral fertiliser. The stakeholder categories selected were in accordance with the UNEP/SETAC guidelines, considering workers, society, local community and consumers. In addition, the authors defined a new stakeholder category called “citizens collecting the waste” that was directly connected to the context of the analysis. The functional unit of 1 tonne of fertilised tomato was adopted for performing the analysis. Foolmaun and Ramjeeawon (2013) performed an integrated analysis in which LCA and S-LCA were adopted for assessing different treatment systems (landfill, incineration and flake production). As for the previous articles the authors carried out the S-LCA by using the UNEP/SETAC guidelines and considering workers, society and local community as stakeholder categories. The “disposal of 1 tonne of used PET bottles to the respective disposal facilities” was selected as functional unit. Aparcan and Salhofer (2013a; 2013b) firstly developed a framework, based on the UNEP/SETAC guidelines, for assessing changes from informal to formal municipal solid waste (MSW) recycling activities in low-income countries. Secondly, carried out an analysis by applying the proposed framework. In particular, the case study was carried out by analysing the stakeholder categories related to workers and value chain actors and considering “the amount of household recyclable waste collected by one house during 1 year” as functional unit.

Regarding the impact assessment, the impact category "Type 1" were adopted in all the five analysis. According to the UNEP/SETAC guidelines, the impact categories Type 1 allow aggregating the results related to the subcategories considering a theme of interest to the stakeholder and are based on a performance reference point obtained from a scoring or weighting step (UNEP/SETAC, 2009). In particular, all the analyses were carried out by using a scoring method, except for Martinez-Blanco et al. (2014) in which the impact assessment was performed by adopting the Social Hotspot Database (SHDB). The SHDB represents the first database developed for S-LCA that allow accounting the social risk on country level and if applicable on sector level. Starting from 133 indicators, the database allows assessing five different impact categories: labour rights and decent work, health and safety, human rights, governance and community infrastructure (Benoit-Norris et al. 2013). Data are provided for 227 countries and 57 economic sectors.

Among the articles related to the waste management sector it is evident that, despite a "code of practice" on S-LCA is still not developed, the UNEP/SETAC guidelines represents a cornerstone for practitioners who perform a S-LCA study. In addition, considering the stakeholder categories, the workers is the most evaluated in waste management, while consumers is only considered in one article. Nevertheless, consumers may be considered as an important group of stakeholders when waste management and in particular waste collection processes are evaluated. Furthermore, looking at the titles of the articles in table 1 it is possible to deduce the site-specific nature of the S-LCA, given that social impacts are often directly connected to the local context.

Regarding the food waste sector, as already reported in the introduction section, only one article includes the application of the S-LCA method. Ribeiro et al. (2018) performed the sustainability performances of food waste prevention activities in Portugal. In particular, the analysis was based on the project "Fruta Feia", which aimed to the creation of a co-op with the intention of buying "ugly" fruits and vegetables (food that would be wasted due to aesthetic reasons) from local farmers and directly selling them to the consumers. The sustainability assessment was performed by applying LCA, investment appraisal, S-LCA and Social Return on Investment methods. Regarding the S-LCA, the study was performed by following the UNEP/SETAC framework and including all the stakeholder categories proposed by the guidelines, thus, consumers, local community, value chain actors, workers and society. The impact assessment was performed by applying the impact category Type 1 and in particular the scoring method. The authors highlighted that, despite the S-LCA method is still in a development phase, it was considered as a useful tool for assessing the social dimension related to the project. Nevertheless, due to lack of related impact categories and software the assessment can be conditioned by subjective evaluations.

4.3 Results and discussion

Among the articles published in the context of S-LCA, there is consensus between the authors regarding specific methodological weakness connected to the application of the S-LCA method.

The main methodological issues refer to:

- level of the analysis;

- functional unit definition;
- system boundaries definition;
- dedicated social indicators;
- data collection;
- impact assessment methodologies.

These methodological limits will be individually discussed below also considering the main context of this study related to food waste management activities.

The level of the analysis refers to point of view from which the analysis is performed. The definition of the level of the analysis is crucial point in performing a S-LCA study. Indeed, a not good characterisation of the analysis context can result in misunderstanding the system assessed, thus causing the achievement of results that do not satisfy the goal and scope of the analysis. In the context of food waste management, the definition of the level of the analysis can totally change on the basis of the system that needs to be assessed. For example, the evaluation of the social performance only related to the treatment processes brings in performing the study considering a company perspective. In contrast including other processes such as collection and pre-treatment in the analysis, can lead in going beyond the company point of view. The same issue can be observed when a specific food waste production sector (e.g. household, retail etc.) along the FSC is evaluated.

According to the ISO 14044:2006, the functional unit "defines the quantification of the identified functions (performance characteristics) of the product. The primary purpose of a functional unit is to provide a reference to which the inputs and outputs are related. This reference is necessary to ensure comparability of LCA results. Comparability of LCA results is particularly critical when different systems are being assessed, to ensure that such comparisons are made on a common basis" (ISO, 006a). Despite the UNEP/SETAC guidelines, in line with the ISO 14040:2006, claim that the functional unit should be selected in the goal and scope definition phase, many study are performed without referring to any functional unit or including a functional unit only for better defining the scope of the analysis (Manik et al., 2013). The decision of "not setting up" the analysis following with the functional unit is mainly due to the fact that the inventory analysis often refers to qualitative information and not quantitative data. Regarding the food waste management sector, the definition of the functional unit is a key aspect, in particular when different management options are compared. Therefore, the missed definition of the functional unit may result in making impossible an appropriate comparison.

The definition of the system boundaries is a crucial factor in life cycle approaches. The site-specific nature of the S-LCA can lead in excluding processes that are not directly linked to the geographical context of the analysis. A possible solution able to face this problem is related to the utilisation of background data. As demonstrate in many LCA studies (e.g. Mondello et al., 2017; Salomone et al., 2017), including the use of the by-products obtained from a treatment process, in the system boundaries may cause high environmental benefits and changes in the results. This is mainly due to the avoided production of the conventional product that is substituted. Despite this, the geographical context related to the utilisation of the by-product can be only defined by making assumptions and not evaluated by using direct information. Considering a social assessment perspective, the definition of the negative or positive social impacts related to the use of by-products or to the avoided production of conventional products, for which assumption are made regarding the geographical context and thus all the related social aspects, may result in obtaining information that are not useful for decision-making processes.

Social indicators should be directly related to the context of the analysis and represent the basis for the impact assessment. In addition, according to Martinez-Blanco et al. (2014), social indicators should be selected considering the relative relevance. The lack of dedicated social indicators for food waste management may bring the practitioner to create new indicators specifically related to the analysed process that, on the one hand, the satisfy the scope of the analysis, on the other can be affected by subjectivity resulting unadoptable in others analyses.

Another issue connected to the implementation of the S-LCA regards the data collection. As for the LCA, a S-LCA study should be performed by mainly using foreground data obtained by direct interviews or questionnaires instead of secondary data, in order to avoid uncertainty or biases in the final results. Despite this, many studies underscored that obtaining high quality primary data related to complex systems may be very difficult. In this context, the food waste management may be considered as a system in which many processes and aspects are involved. Therefore, assessing the social impacts of this sector may require a high amount of secondary data, both quantitative and qualitative. The lack of specific data on the food waste collection, pre-treatment and treatment may bring in modifying the system boundaries causing the exclusion of important aspects from the analysis. In addition, when both LCA and S-LCA are performed the same processes should be included in order to have a comprehensive assessment. Unfortunately, this cannot be always achieved due the impossibility of considering same processes in S-LCA (Lenzo et al., 2018).

Methodological issues in S-LCA are also related to the application of the impact assessment phase. Among the performed studies there is not a common use of the impact categories. The S-LCA studies performed on waste management and food waste underscored that only impact categories Type 1 were adopted by applying the scoring method. According to the intrinsic nature of the impact categories Type 1, these studies did not provided results on social impacts but allowed obtaining information on the social performance of the system. This highlight the necessity of correctly distinguishing social impacts and social performance when the goal and scope of the analysis is defined. Lastly, as for the social indicators definition and as highlighted by Ribeiro et al. (2018) the evaluation of the social impacts can be directly affected by subjectivity.

4.4 Conclusions

The aim of this study was to define methodological issues related to the application of the S-LCA and to evaluate such issues by considering the food waste management sector. In order to achieve this scope, a literature overview was presented by also including studies directly related to waste management and food waste.

The literature review allowed underscoring that the number of methodological and applicative articles related to the S-LCA method is quite similar. This highlighted that scientific community is still working in order to reach a common point of view that would allow the standardisation of the tool. The necessity of a standardised framework is underscored by the fact that, when S-LCA is applied, different aspects are still based on procedural questions. In addition, authors often adopted personal and subjective ideas creating their own methods even starting from a common framework (UNEP/SETAC guidelines).

Regarding the context of waste management, five applicative case studies have been performed. The analyses were focused on different topic area, considering in particular recycling and recovery processes related to plastic, electronic components, organic waste and municipal solid waste. Among all the articles, the S-LCA was performed by adopting the UNEP/SETAC guidelines. This underscores that, despite the S-LCA is still a not-standardised tool, the UNEP/SETAC procedural framework can be considered as a very important and useful guide.

In the specific context of food waste, an interesting article has been published regarding the evaluation of preventing actions for avoiding food waste (fruits and vegetables) production. The authors highlighted that S-LCA highly helped in evaluating the social performance, but the evaluation may be affected by subjectivity.

In addition, the literature overview allowed highlighting that the main procedural and methodological issues, related to the S-LCA tool, are connected to some aspects that can be considered as crucial in applying a life cycle thinking tool. In particular, the issues connected to the S-LCA refers to the functional unit and system boundaries definition, the availability of social indicator and inventory data and the application of the impact assessment phase. Despite all this issues may affect the application of the S-LCA method in food waste management systems. The main procedural limits are related to the qualitative characteristics of some inventory data that may bring in not defining a functional unit, as well as to the inability of performing a detailed analysis by including the evaluation of by-products and related avoided products. These two fundamental aspects may result in higher uncertainty related to the social impacts.

Among this considerations, it is evident that we are still far from defining the S-LCA as a suitable tool for assessing the social impacts connected to the food waste management. Despite this, the S-LCA is the only method that allows evaluating social aspects from life cycle perspective. Furthermore, in contrast of LCA, the S-LCA allows evaluating impacts as positive or negative considering two different dimensions. Considering the fact that S-LCA is a novel method in comparison with LCA and LCC, higher efforts have to be a “must” in order to achieve a common procedural framework that can be adopted in all the sectors. This have to be a key aspect for S-LCA’s standardisation.

5. OVERALL CONCLUSIONS

Assessing food waste and the related management activities became a fundamental prerogative in the context of the sustainable development. Even though some countries have already achieved higher performance in waste management systems, others are still applying procedures that can result in environmental, economic and social impacts. In this context, important activities have been carried out in order to propose improvement solutions in food waste production and management. In this context, the European Commission is working on a specific action plan that includes: the creation of a common methodology for quantifying the amount of food waste produced in EU, by 2019; the creation of a platform (since 2016) specifically dedicated to food waste management (EU Platform on Food Losses and Food Waste); the implementation of guidelines that would facilitate food donation and valorisation of food not used for human consumption as animal feed (EC, 2018b). In addition, the food waste hierarchy proposed by Papargyropoulou et al. (2014) can help governments, institutions and businesses in understanding how to achieve best performances in food waste management. In this context, a careful assessment on how these improvement solutions work, in an environmental, economic and social context, is highly required.

The evaluation of food waste management strategies by considering a life cycle perspective can allow a comprehensive assessment by considering the three pillars of sustainability. Despite this, the methodological aspects and the different level of development related to the application of the LCA, LCC and S-LCA in food waste management need to be evaluated in order to identify gaps and limits that must be addressed.

The present PhD thesis aimed in understanding if LCA, LCC and S-LCA are appropriate tools for assessing the environmental, economic and social impacts of food waste management activities. In this context, an analysis of the international scientific literature was performed in order to highlight limits and potentialities related to the LCA, LCC and S-LCA.

The state of the art was in line with the development progress and "age" of the tools. Indeed, regarding LCA many studies on food waste management have been performed, while few analyses on this specific context have been carried out by using LCC and S-LCA.

The analysis related to the evaluation of limits and potentialities in performing a LCA study for assessing food waste management strategies, highlighted that the selection of the functional unit, system boundaries, data collection and the definition of the impacts categories may represent the critical factors related to the context of the analysis. In contrast, LCA can be considered as a powerful tool due to its undiscussed capability to be adopted for assessing all the food waste management processes along the FSC. In addition, LCA allow reaching a high level of quality in the analysis resulting as an important tool for decision-making processes. Despite this, the suitability of the tool is strongly related to the practitioner's choices.

Regarding the LCC method, the lack of studies highlighted by the literature review, made difficult a detailed evaluation of the tool in the context of food waste management. Despite this, it was possible to define some key factors in particular related to the externalities assessment, the product oriented point of view of the method or the importance in assessing the use of the by-products. In addition, the integration of LCA and LCC can allow obtaining a higher analysis level.

In contrast with LCA and LCC, no available articles related to the application of the S-LCA for assessing the food waste management sector have been detected. Hence, the main findings were related to applicative case study studies on waste management in general and other sectors. The main methodological issues are connected to the functional unit and system boundaries definition, the availability of social indicator and inventory data and the application of the impact assessment phase. Regarding the food waste management sector, two main aspects were highlighted, the problem in referring qualitative data to the functional unit as well as the issues related to the inclusion and assessment of the by–products.

In general, the analysis of the scientific literature allowed proving an answer to the research question of the study, related to the suitability (or not suitability) of the life cycle thinking tools in assessing food waste management. In particular, Life Cycle Thinking tools can be considered as useful and important methods due their intrinsic nature of considering a life cycle perspective. Despite this, LCC and S-LCA still needs to be improved and applied in order to be considered as suitable tools for the assessment of food waste management activities.

For the author's knowledge this PhD thesis represents the first study in which methodological aspects of LCA, LCC and S-LCA related to the specific context of food waste management, are evaluated.

Future studies should focus on performing applicative analyses in order to find solutions for improving the suitability of the Life Cycle Thinking methods in food waste management assessment, considering in particular LCC and S-LCA.

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