Chapter 11
Assessment and Improvement

Abstract Today's environmental concerns are related to the population and its consumption of resources, which have led to significant ecological global changes, such as climate change and resources overexploitation. The solid waste management, in an integrated way, has been capable of influencing and contributing to the solution of such challenges. The purpose of this chapter is to discuss the assessment and improvement of the waste collection system by using life cycle thinking, with a sustainable perspective. Several methodologies such as life cycle assessment, carbon footprint, life cycle costing, and social life cycle assessment will be presented and discussed concerning its application to waste collection systems and contribution to the integrated waste management system.

Keywords LCA · Social LCA · LCC · Environmental impacts · Public participation · Behavior studies

11.1 Life Cycle Assessment and Carbon Footprint

The life cycle assessment is a process to (a) evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying the energy and materials used, wastes, and emissions released to the environment; (b) assess the impact of those energy and material uses and releases to the environment; and (c) identify and evaluate opportunities that lead to environmental improvements (Fava et al. 1991; Consoli et al. 1993). According to the International Organization for Standardization (ISO 14040 2006a), LCA addresses the environmental aspects and potential environmental impacts throughout a product's life cycle, from raw material acquisition through production, use, end-of-life treatment, recycling, and final disposal (i.e., cradle to grave). LCA is divided into four phases: goal and scope definition, inventory analysis, impact assessment, and interpretation. The goal and scope definition intends to define the purposes, specifications, and limits in the evaluation. The inventory analysis phase is responsible for the collection of data of the unit processes within the system and relating it to a functional unit. Impact assessment intends to make inventory information more understandable

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through its translation into environmental impact categories. Final interpretation allows evaluating results obtained and comparing them with the initially defined goal (ISO 14040 2006a).

LCA applied to solid waste collection systems can serve two purposes: to evaluate the service provided (in terms of technology implemented) and find where more environmental impact is occurring and to evaluate which level of source separation (number of streams and quality of material source separated, recycling rate) should be promoted, to reach higher amounts of recyclables and higher quality of recyclables collected in such a way that could be beneficial to the environment. LCA has been applied to solid waste management since the 1990s to treatment and recovery technology processes, where the focus on specific collection and recycling schemes is being increasing more recently.

11.1.1 Goal and Scope Definition

For a waste collection system, the goal of an LCA study depends on the type of decision-making process: a microlevel decision, where the decision to be made will not impact the background system, and a meso−/macro-level, which can impact the background system. The micro-level decision is only devoted to the technical analysis and environmental inventory of the waste collection sector. Meso−/macro-level is related to the analysis of strategies with large-scale to background sector (like the market for recyclables), which are related to studies on a national scale, with implications on national and international plans. To understand which type of LCA to perform, foreground and background systems must be defined. In a waste collection system LCA study, the foreground system is the waste collection system to be analyzed, where real data will be gathered related to the collection and transport and to waste container production and transport; the background system is generic data which is more related to the electricity grid, for example.

Functions of the System, the Functional Unit, and Reference Flow

At a glance, a waste collection system just performs one function: allows the temporary deposition of waste, its collection, and transport to a specific destination. However, the destination can also be included in the LCA, because waste collection can influence its destination. If packaging waste is source separated, it has recycling features; if organic waste is source separated, the production of a high-quality compost occurs. Even if the waste results from mix collection, it can also generate electric energy. When mixed waste collected is send for mechanical-biological treatment (by anaerobic digeston), or to incineration or even at the landfill, the biogas is generated and used to produce electric energy. The way how the system is defined will determine the number of functions of the system, and, if multifunctionality occurs, it has to be solved. A possible functional unit is the collection of a specific amount of waste generated in a period by a specific group of inhabitants, for example, the selective collection service of 1500 tons a month of MSW generated in an urban locality with a density of 5000 inhabitants/km^2 applied by Iriarte et al. (2009). Related to the functional unit is the reference flow for the normalization of input and output data (Chang and Pires 2015). In the case of Iriarte et al. (2009), the reference flow considered the theoretical recovery of 100% for the fractions: organic, paper, packaging, and glass present in the MSW. When comparing waste collection system for a specific waste stream, waste properties need to be studied, to ensure that the functional unit and the reference flow are the same. It is common that different waste collection vehicles have different waste compaction rates, changing the density of waste collected. Density is just one of the critical physical properties, but also moisture can be relevant for the collection of biodegradable waste or waste paper and waste cardboard.

System Boundaries

The waste collection system studied in the LCA can be:

- The service provided by a municipality or a private company.
- The number of recyclables collected by the collection system.

From a generic point of view, the waste collection system to be analyzed has, in the beginning, the stages of temporary deposition (containers) and waste collection vehicles. The frontiers of the waste collection also need to be addressed. The frontiers can be related to geographic locations, timescales, and technical components. Considering the technical components, LCA studies can be cradle-to-grave (starts with the extraction of materials, going through all life cycle), cradle-to-gate (from raw material extraction, going until the product leaves the factory), gate-to-gate (only regards a manufacturing process), and cradle-to-cradle (with a metabolic view where no waste exists) (Chang and Pires 2015). In waste collection systems, LCA can be only cradle-to-gate if the intention is to assess a particular waste collection technology without the use phase (like an environmental product declaration for waste bins), or the waste collection system itself can be a cradle-to-gate of the entire waste management system. A cradle-to-cradle applies to reverse logistic cases when the product is not waste or is for reuse. A typical waste collection LCA is a cradle-to-gate, or a streamlined LCA (also named screening and matrix LCA) because the assessment is only for a part of the life cycle. The definition is also applied when the LCA is not assessing all the environmental impact categories (Crawford 2011). The case study on Box 11.1 is an example of a streamlined LCA at recycling schemes.

Box 11.1 Comparison of Recycling Schemes in Portugal (Pires et al. 2017)

A comparative study based on LCA and economic analysis through indicators was conducted for three waste collection systems for packaging waste in a municipality in Portugal. The analysis compares the environmental impact of existing collection systems and the costs involved in the operation of those systems. For the LCA, Umberto 5.5 software package was used.

Three waste recycling systems were compared: a curbside system, where all non-glass packaging waste is collected by the curbside bags; a drop-off system, where all packaging waste is collected by drop-off containers; and a mixed system, where glass is deposited at drop-off containers and lightweight packaging is deposited at drop-off and curbside systems. The LCA was used to analyze the environmental impacts, but only the collection system was assessed (the subsequent recycling was excluded). The results showed that the curbside system was less favorable economically and environmentally due to the more packaging and more fuel consumption per ton of waste, compared to drop-off collection system. Optimization of the curbside system is needed, through the use of reusable boxes and efficient collection routes (SEP 2018).

In a waste collection LCA, there is no need to include the environmental impacts resulting from the extraction of material and production of goods that originate waste, neither product reuse with the application of the "zero burden assumption." The zero burden assumes that waste brings no upstream environmental impacts into the waste collection system neither to the waste management system (Ekvall et al. 2007). Such can be applied because all product life cycle phases previous to the waste phase occur in the same way in the next waste collection alternatives.

To conduct an LCA is also needed to have in consideration aspects related to geographic boundaries and time horizons. Concerning geographic boundaries, the waste collection systems are typically local and regional, but also can be national or international, when materials collected are sent to recycling, which can be outside the borders of the country. Data referent to process far from the place where waste collection efficiently occurs can be hard to collect (Chang and Pires 2015). In the case of time horizon, the functional unit in a waste collection system can be dependent on the respective year or another time unit, which is the case of the amount of waste generated and collected, which is not constant through the years, with fluctuations during the year. There is the need to identify the time horizon of the analysis appropriately. When conducting an LCA for a waste collection system which the system is only the collection itself, there is the need to include equipment and infrastructure data. In this situation, the useful life of devices needs to fit into the functional unit period.

Another aspect to be defined during the goal and scope definition is the allocation procedure. According to ISO (2006b), allocation represents the portioning of input and output flows of a process or a system concerning the system under analysis and one or more other systems. Allocation applies in cases of multifunctionality and when open recycling inside the system occurs (Ekvall and Tillman 1997). Multifunctionality is related to a multi-output and multi-input processes (or systems). A multi-output process occurs when a single system produces more than one product or only one product is processed inside the system and at least one product is generated and is used outside the system (what is called a coproduct) (Klöpffer and Grahl 2014). A multi-input process in waste management systems occurs when several waste streams are collected and treated, while LCA tries to isolate one of them (Tillman 2010). When a product is recycled not at the same product but in a different one, it is a case of open recycling (Tillman 2010). The way how to proceed to solve them is different if the LCA is of attributional type or consequential type, although there is no universal consensus. In general, the multi-output systems in waste management is usually solved by system expansion/substitution, whatever is an attributional or a consequential LCA, by ISO (2006b) and recommendations from EC-JRC-IES (2010). In a first step, system expansion is performed until all expanded systems produce the same quantities of the coproducts identified in the system, and in the next step, product outputs and inputs related with the coproducts are subtracted from all expanded systems (Bueno et al. 2015). In the case of multi-input, portioning made by physical or chemical classification is typically conducted (Meijer et al. 2017; Guinée et al. 2002). In the case of recycling allocation, "recycled content approach" (or cutoff approach) and the "end-of-life recycling approach" (or avoided burden approach) are used (Frischknecht 2010) (Fig. 11.1). The cutoff method considers the share of recycled material in the manufacture of the product, where the environmental impacts of recycled material were not attributed to the system under investigation because once recycled, they start a new life in a second product/process (Frischknecht 2010; Zampori and Dotelli 2014). In the avoided burden approach, the environmental impacts from the recycling include the system under investigation, avoiding the extraction of raw materials for the production of the product, and relating environmental impacts, crediting them to the product in the system in assessment (Frischknecht 2010; Zampori and Dotelli 2014).

According to Pelletier et al. (2015), the multifunctionality needs to be adequately justified, and the different approaches to solving multifunctionality mostly relate to the schools of LCA practitioners, which view the purpose of LCA in different ways:

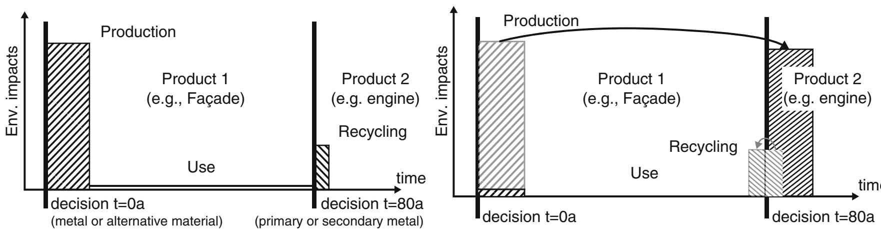

Fig. 11.1 Environmental impacts in the course of time during production, use, and end of life (recycling) of a long-living metal product. Left, recycled content approach; right end-of-life recycling approach. (Source: Frischknecht (2010))

Table 11.1 Alternative multifunctionality hierarchies consistent with competing for understanding of nature, purpose, and conditions necessary to LCA

ISO 14044	Consequential data modeling approach	Attributional data modeling approach	
		Physical perspective	Socioeconomic perspective
Tier 1: Avoid allocation via subdivision or system expansion	Avoid allocation by subdivision or “system expansion + substitution”	Avoid allocation by subdivision or system expansion (reporting at level of all coproducts)	Avoid allocation by subdivision or system expansion (reporting at level of all coproducts)
Tier 2: Allocation based on an underlying physical relationship	NA	Avoid based on a relevant underlying physical relationship	Avoid based on a relevant underlying economic value of coproducts
Tier 3: Allocation based on some other reason	NA	NA	NA

Pelletier et al. (2015)

multifunctionality is to be solved by system expansion or by physical allocation or by economic allocation (representing allocation based on “some other relationship”). Whatever the school of the practitioner, Pelletier et al. (2015) suggest the alternative multifunctionality to help in making allocation consistent and more transparent to practitioners (Table 11.1).

11.1.2 Life Cycle Inventory

LCI represents the phase in the LCA where the collection and treatment of the data to perform the assessment occur. The steps of LCI include the data collection planning, collection itself, and validation of data. Concerning planning, there is the need to define the data to be collected regarding the type of LCA (attributional or consequential), type of the system (is data for the foreground or the background), and the LCA scale (is a full LCA or a streamlined). Depending on the type of LCA conducted – attributional or consequential – the type of information to be collected differs. For an attributional LCA, data to be collected is average or generic data that best represent the waste collection system. In consequential LCA, marginal data collection is related to operations during the life cycle that are affected by a change in the system under investigation (Ekvall and Weidema 2004). To develop the consequential analysis, scenario development and market forecasting can be applied. The one more used is the market forecasting, which only implies the knowledge of the existing market for outputs and inputs of the system, when the scenario development is critical to their application.

Concerning foreground and background data, the approaches to collect information are different. In the case of foreground data, or primary data, data collection intends to characterize as far as possible the system, being collected all data possible concerning inputs and outputs; background data, or secondary data, are related to information of secondary processes with no apparent influence on the core system (Chang and Pires 2015).

Choosing between a full and a streamlined LCA should be based on the goal and scope of the study and the time available to conduct the assessment, because LCA is time-consuming and expensive (Wang et al. 2016). Streamlined LCA occurs by (1) adjusting the system boundary (both foreground and background systems) and (2) limiting the inputs, outputs, and environmental impacts considered in the assessment. Previous full LCA studies can indicate areas which have low significance to the LCA results, allowing a justified streamlined LCA (Chang and Pires 2015).

LCI databases provide ready-made inventories to characterize waste collection systems. There are several databases which characterize several processes including waste collection and treatment processes. Most complete databases are the Ecoinvent (http://www.ecoinvent.org/), US Life Cycle Inventory Database (https://www.nrel.gov/lci/), and European Life Cycle Database (ELCD) (http://eplca.jrc.ec.europa.eu/ELCD3/), just to name a few.

Documentation of data calculation for LCI occurs explicitly, where the explanation of all assumptions occurs. The validation of data and relating data to unit processes and functional unit is needed to ensure the quality of LCA (ISO 2006b). The validation of data during LCI should be made through mass balances, energy balances, and comparison with data from other sources, like emission factors for specific processes (Guinée et al. 2002).

11.1.3 Life Cycle Impact Assessment

The result of the LCI phase is the quantification of materials, energy, and substance flows which impact the environment. The LCIA intends to understand and evaluate the environmental impacts resulting from the system in the analysis, regarding the magnitude and the significance (ISO 2006b). The critical steps of the LCIA are (Curran 2006) selection and definition of impact categories, classification of substance flows with the selected impact category, and characterization of LCI impacts based on conversion factors scientifically based.

Complexity reduction of the conversion of inventory into impact categories occurs by the impact categories definition in midpoint and endpoint indicators. Midpoint indicators calculate the impact of LCI outputs through various environmental mechanisms with less uncertainty; endpoint indicators include the characterization factors to link midpoint indicators through additional environmental mechanisms, which incorporates greater uncertainty (Li and Khanal 2016) (Fig. 11.2).

In addition to the fundamental steps, other steps can be added to reach a more clear result, such as normalization, grouping, and weighting of impact categories, which will facilitate the comparison of LCA results and the interpretation phase (ISO 2006b). According to ISO (2006b) and Ashby (2009), normalization intends to

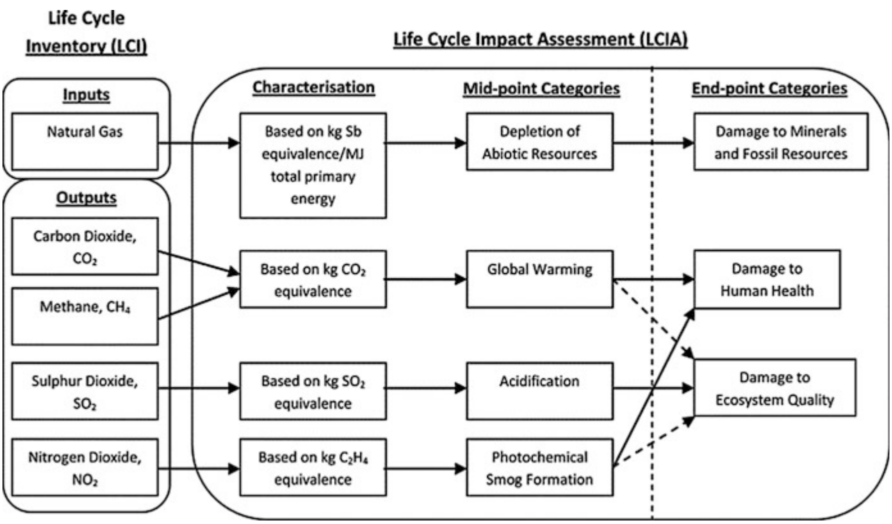

Fig. 11.2 Typical LCA framework linking LCI via midpoint categories to endpoint categories for selected damage types. Indicators can be formed from either category after normalization and optional weighting step. (Source: Rimos et al. (2014))

remove the units and reduce the data to a standard scale, grouping intends to sort and rank the impact categories if possible, and weighting of each impact category helps to understand which are the most critical impacts compared to the other category impacts. The result of these additional key steps is a value, an eco-indicator, which condensates all the information resulting from the LCA into one number. There is some criticism on the use of eco-indicators since there is no agreement on normalization and weighting factors and the value has no physical significance (Ashby 2009).

The LCIA is typically made by different methodologies, from their resulting indicators that could help to quantify and compare the environmental impact of the product or service. Several methodologies exist: CML (Guinée et al. 2002), Eco-Indicator 99 (EI'99) (Goedkoop and Spriensma 2000), Environmental Priority System 2000 (EPS 2000) (Steen 1999), EDIP (Hauschild and Potting 2005), IMPACT 2002+ (Jolliet et al. 2003), TRACI (Bare et al. 2003), USEtox 2.0 (Fantke et al. 2015), ReCiPe (Goedkoop et al. 2009), and ES'06 (Frischknecht et al. 2008). Choosing the LCIA system should address the following questions (Rosenbaum et al. 2018):

- Which impact categories do I need to cover and can I justify those that I am excluding?
- Which are the features of the region where the system in the analysis occurs?
- What kind of LCIA do I need, midpoint, endpoint, or both, and are the normalization steps also needed?
- Which elementary flows do I need to identify and know?
- Is there any information from organizations that could help me to choose?

- How can the LCIA results be interpreted and communicated?
- How well is the method scientifically supported?
- How proven is the method?
- Is there available data from my LCI to support the LCIA method?
- Is uncertainty an issue that needs to be quantified?

One possible strategy to choose an LCIA method can be the existence of LCA studies made to the waste collection system and the LCIA method used. Probably there is a method more frequently used, which can also be chosen, helping in the comparison of the results.

11.1.4 Interpretation

According to ISO (2006b), the interpretation is the last phase of the LCA, where results are summarized for conclusions and recommendation and help on decision-making, depending on the goals and scope defined at the beginning of the LCA. Due to its looping plus iterative procedure, the discussion conducted can dictate changes in previous decisions during the LCA like allocation rules, system boundaries, goal and scope features, data collected to perform the LCA, and environmental impact categories chosen, just to name a few of the possible consequences of interpretation phase (Chang and Pires 2015; ISO 2006b). Interpretation phase recommends a critical analysis done by an external entity (ISO 2006b).

Uncertainty and sensitivity analyses are conducted during the interpretation phase. Sensitivity analysis intends to understand how the model inputs influence the results; uncertainty analysis (also named propagation) aims to know quantitatively the overall uncertainty of results reached during LCA (Laurent et al. 2014). The most common method used to assess sensitivity is scenario analysis. These are one-factor-at-a-time (OFAT) methods with the intention to investigating the robustness of the results and finding the sensitive parameters that could influence LCA results and, in the last case, alter the recommendations to decision-makers (Laurent et al. 2014). Sensitivity analysis is performed by varying the inputs within a specific range and analyzing the impacts on the results, showing which are the results that must be regarded more carefully, and which assumptions must be justified and validated (Li and Khanal 2016). Uncertainty in waste collection system is generally related to the waste composition itself and the waste fraction distributions and chemical composition (e.g., water content, density). The system model used for the collection itself, the choice of a collection scheme, and the parameters dependent of the collection scheme, like fuel consumption, emissions, source-sorting efficiencies, and the transport distance, at least should be subjected to uncertainty analysis (Clavreul et al. 2012). Uncertainty analysis is usually conducted by Monte Carlo analysis, which consists in randomly sampling the probability distribution of each uncertain parameter in a large number of times, resulting in a frequency histogram and a probability distribution representing model results (Clavreul et al. 2012). When conducting an LCA comparing different waste management solutions, the

Monte Carlo simulation can indicate, for each solution, which is the probability that a specific result occurs (e.g., which is the probability of the result "incineration is better than anaerobic digestion" occur).

11.1.5 LCA Software

There are several on-market software to conduct an LCA study on waste collection, like Gabi, SimaPro, Team, and Umberto software. There is also more friendly software explicitly devoted to waste management, including solid waste collection, which can make the streamlined LCA easier. Those software/applications are IWM-2 (McDougall et al. 2001), WISARD/WRATE (Ecobilan 2004), EASEWASTE (Christensen et al. 2007), and ORWARE (Dalemo et al. 1997; Björklund et al. 1999). The development and use of waste LCA tools justify the need to deal with a reference flow composed of a mixture of materials (waste and its several waste streams); the LCA practitioner can evaluate more natural the influence of several parameters of the waste management scheme on the LCA results, making more accessible for the practitioner to track the impacts from heterogeneous waste streams and the impacts caused by each material (Clavreul et al. 2014).

No matter which is the software, the practitioner of an LCA to waste collection system must have in mind that capital goods may have significant importance on the LCA environmental impacts, not being adequate to exclude them. According to Brogaard and Christensen (2012), the impact of producing the capital goods for waste collection and transport – vehicles and containers – should not be neglected as the capital goods can be responsible for more than 85% of some of the environmental impact categories from all environmental impacts occurring for collection and transport waste (when a transport distance of 25 km was assumed).

11.1.6 Carbon Footprint

Common to most of these environmental impact systems is the one related to GHG emissions and climate change impact, i.e., when using LCA only to calculate the impact on climate change). GHG emissions impact can have several designations, where the most known is carbon footprint. Carbon footprint is also a subcomponent of ecological footprint, which is estimated by calculating the embodied life cycle energy plus GHG emissions associated with a specific system (Cifrian et al. 2013). According to EPLCA (2007), carbon footprint (also named as carbon profile) is the inventory of greenhouse gas emissions associated with a product, along with its life cycle, from the supply chain, use, and end-of-life.

Carbon footprint results from the indicator global warming potential (GWP), used in LCA. As defined by IPCC, the GWP reflects the relative effect of a GHG regarding the climate change, considering a fixed period (e.g., 100 years is GWP_{100}). GHG can have a different global warming impact, i.e., can contribute differently to the climate change, presenting different GWP_{100}. Carbon dioxide has 1, methane has 25, nitrous oxide has 298, HFCs have between 124 and 14,800, sulfur hexafluoride has 22,800, and PFCs have 7390–12,200 GWP_{100} (IPCC 2007).

Carbon footprint is a streamlined LCA, where the analysis is made only to the emissions that have a potential effect on climate change. Carbon footprint calculation uses databases for the background data, and for the foreground, it is necessary to collect real information as possible. When making a carbon footprint, it is necessary to have in mind that a possible "shifting of burdens" may occur, because other relevant environmental impacts are neglected (EPLCA 2007).

Several standards and norms could help in the development of a carbon footprint. The one specific for carbon footprint from ISO is ISO/TS 14067 (ISO 2013), which is based on the ISO norms for LCA (ISO 14040-14044 (ISO 2006a, b)), on standards for quantification, and on environmental labels and declarations for communication (ISO 14020, ISO 14024, and ISO 14025). Public initiatives to develop carbon footprint calculation methodologies also exist: the British Standards Institution Norm PAS 2050:2011 (BSI 2011), Protocol for the Quantification of Greenhouse Gases Emissions from Waste Management Activities (EpE 2010), Product Life Cycle Accounting and Reporting Standard of the GHG Protocol (WRI and WBCSD 2011), and US EPA Waste Reduction Model (WARM) (USEPA 2009), just to name a few.

Waste collection and transport contribute significantly to GHG emissions from municipal solid waste management system (Bernstad and la Cour Jansen 2012; Jaunich et al. 2016; Cleary 2009). The sources and magnitude of GHG depend on the type of collection and transport system in place: pneumatic systems (Teerioja et al. 2012; Punkkinen et al. 2012) or trucks (Fernández-Nava et al. 2014; Maimoun et al. 2013; Rose et al. 2013). In trucks' case, the fuel used by collection vehicles has a significant influence on the carbon footprint (López et al. 2009; Maimoun et al. 2013; Rose et al. 2013) and urban air quality (Fontaras et al. 2012; Sandhu et al. 2014). Authors have tried to adapt existing methodologies to calculate LCA or carbon footprint of waste collection systems, to reach more detailed inventories instead of just using average data. In Table 11.2 is presented a short review on assessment on waste collection systems made by LCA and carbon footprint.

11.2 Life Cycle Costing

Economic life cycle analysis, most known as life cycle costing (LCC), gives an economic perspective on the life cycle of the product or service. LCC involves three types of LCC assessments (Hunkeler et al. 2008): conventional, environmental, and societal. Conventional LCC represents standardized financial assessments, like accounting for marketed goods and services carried out typically by individual companies focusing on their direct costs. Environmental LCC includes the conventional LCC (also named financial LCC, where albeit costs from all stakeholders are included), to be in line with the system boundaries of the LCA (Rödger et al. 2018). The societal LCC further includes externality costs (i.e., it "internalizes"

Table 11.2 LCA and carbon footprint case studies on waste collection

LCA of waste collection systems		Carbon footprint of waste collection	
Source	Description	Source	Description
Punkkinen et al. (2012)	Comparing pneumatic and door-to-door collection systems	Pérez et al. (2017)	Developed a methodology for calculating the carbon footprint of waste collection vehicles
Rose et al. (2013)	Comparison of diesel and compressed natural gas-powered refuse collection vehicles	Maimoun et al. (2013)	Compare different fuels for waste collection vehicles
Pires et al. (2017)	Comparison of different packaging waste collection systems: curbside, drop-off, and mixed	Eriksson et al. (2015)	The carbon footprint of food waste management options

environmental and social impacts by assigning monetary values to the respective effects), by using accounting prices (Martinez-Sanchez et al. 2015; Rödger et al. 2018). The three types of LCC give the holistic view of the system, including LCA perspective and well societal concerns.

For each type of LCC, different costs may be considered (Table 11.3), such as internal costs, external costs, and social costs. Internal costs are referent to monetary costs occurring both inside and outside the waste management system in the analysis, being measured by market prices (Martinez-Sanchez et al. 2015). External costs occur outside the economic system, having no direct monetary value in the market, reflecting the impacts on third parties resulting from production and consumption (Martinez-Sanchez et al. 2015; Rödger et al. 2018). Social costs are the sum of internal and external costs, being defined as society's costs for managing waste (Porter 2002).

The results from the LCC are expressed in monetary terms per functional unit, for each of the life cycle phases, which can also be defined in the budget, transfers, and its sum (named convention LCC), and from the LCC result indicators that help to understand the assessment made. The societal LCC presents results from external costs, being divided into budget costs, externality costs, and societal costs (Martinez-Sanchez et al. 2015). Martinez-Sanchez et al. (2016), who have applied LCC to a food waste management system, have included in the LCC the indirect costs, related to the income effect associated with the marginal consumption and to indirect land use changes.

11.3 Social Life Cycle Assessment

To assess the social impact of a product, but also of services including waste collection system (also applicable to waste management system), a social life cycle can be conducted. Social impacts focus on aspects related to the well-being of humans (Yildiz-Geyhan et al. 2017). According to UNEP/SETAC (2009) and Benoît et al. (2010), social life cycle assessment (SLCA) is an assessment technique capable of evaluating the socioeconomic and societal impacts of products during their life cycle. Social impacts are consequences of behaviors/decisions,

Table 11.3 Overview of costs incurred by waste agents and all members of society with regard to waste systems. Cost classes are (1) internal and external costs and (2) budget costs, externality costs, and transfers

	Internal costs	External costs	Social costs
Incurred by	Waste agents (e.g., waste generator and operators)	All the members of society (waste generators, waste management operators, and others)	Society
Budget cost	Bags, bins, capital goods, materials, and energy consumption, labor costs, material and energy sales		
Externalities cost		Time consumptions to source separate, health issues, disamenities, working environment issues	Sum of internal costs (excluding transfers) and external costs for society (i.e., waste generator, waste operator, and other agents)
Transfer	Fees, taxes, pecuniary externalities		Not applicable

Martinez-Sanchez et al. (2015)
Pecuniary externalities may be related to energy and material recovery within the waste system. These transfers represent financial losses occurring when existing facilities or industries outside the system boundary of the assessment have to operate below their design capacity as a result of the additional supply of energy and material resources offered by the waste system

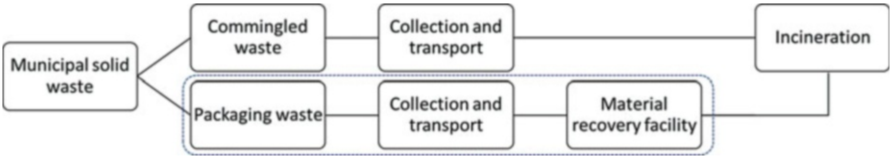

Fig. 11.3 Existing municipal solid waste collection system and system boundaries of the packaging waste collection system to be assessed in a hypothetical SLCA

socioeconomic processes, and capitals (human, social, and cultural), which can be either positive or negative (UNEP/SETAC 2009).

The methodology of SLCA follows the environmental LCA: goal and scope definition, inventory, impacts, and interpretation. In goal and scope definition, the critical aspect to have in mind is the functional unit to be defined, because it can be difficult to correlate a social impact with a process of a product or a service (Dreyer et al. 2006; Hauschild et al. 2008; Klöpffer 2008). For instance, Hosseinijou et al. (2014) indicated the social impacts would hardly be related to the functional unit (FU) of the product if the inventory data is based on semi-qualitative and qualitative data. Also, the frontiers of the system can also be challenging, although on assessing waste collection system, the task can be facilitated. In the case of Fig. 11.3, to assess a packaging waste collection system, only the packaging collection and transport are to be considered in the SLCA.

Another aspect to be defined in goal and scope definition is the impact categories to be assessed. There are 6 impact categories (human rights, working conditions, health and safety, cultural heritage, governance, socioeconomic repercussions) and 31 subcategories related with stakeholders' categories. In Table 11.4 are represented the stakeholders and a resume of the subcategories proposed by Benoît-Norris et al. (2011).

Since its beginnig in the 1990s, the SLCA has not been capable of being fully standardized, like what happens to LCA (Iofrida et al. 2018; Sureau et al. 2018). There is a difficulty in addressing social impacts into a physical flow of a product or of a service (Dreyer et al. 2006). Also, the SLCA published by UNEP/SETAC

Table 11.4 Five stakeholder categories in production system based on the UNEP's guideline for SLCA

Stakeholder categories	Subcategories
Worker	Freedom of association and collective bargaining
	Child labor
	Fair salary
	Working hours
	Forced labor
	Equal opportunities/discrimination
	Health and safety
	Social benefits/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
	Community engagement
	Local employment
	Secure living conditions
	Public commitments to sustainability issues
	Contribution to economic development
Society	Prevention and mitigation of armed conflicts
	Technology development
	Corruption
Value chain actors (excluding consumers)	Fair competition
	Promoting social responsibility
	Supplier relationships
	Respect of intellectual property rights

Source: Benoît-Norris et al. (2011)

(2009) lacks on specific impact assessment methodology, which has made practitioners apply different approaches (Chhipi-Shrestha et al. 2015) to solve it. Site-specific data collection is needed to characterize the foreground system in assessment, and those procedures are complicated to be implemented, requiring prioritization or cutoff criteria, as well a global social database to provide the rest of the data needed (Chhipi-Shrestha et al. 2015). All these issues make SLCA a not well-proven technique to assess the social impact of a product or a service, in this case, a waste collection system. The missing robustness of SLCA is even more problematic for a sector which is characterized by an informal sector in developing countries mostly, but also in developed countries, informal work may occur. In the study from Yildiz-Geyhan et al. (2017), the intention was to conduct an SLCA to packaging waste collection schemes, with scenarios of the formal and informal collection. The results showed that informal collection scenarios had socially fewer score than the formal scenarios in almost all impacts, but the best scenario was the ameliorate scenario, where the integration of formal and informal collection occurs.

11.4 Behavior Studies and Awareness Campaigns

The assessment of a waste collection system and, especially, of recycling schemes is mandatory to understand the effectiveness and what needs to be improved. The identification of residents' participation and acceptance of the recycling scheme is essential to the success of the scheme. Doing behavior studies and awareness campaigns will be helpful to reduce misjudgments that led to poor scheme design and performance, leading to high operational costs (Altaf and Hughes 1994; Jenkins et al. 2003). Although the behavior study is here presented as an assessment of waste collection or recycfling schemes, behavior studies are also made during the design, like is the case at Box 11.2, where public participation was considered in the design if the waste collection at the community of Didimoticho in Greece (Keramitsoglou and Tsagarakis 2013) (Box 11.2).

Box 11.2 Public Participation in Designing a Recycling Scheme in Didimoticho, Greece (Keramitsoglou and Tsagarakis 2013)

A public participation process was implemented in Greece, in a town where no source separation of waste exists. The process based on a structured questionnaire is divided into four parts: questions about residents' knowledge on recycling, including advantages and disadvantages; questions about nine recycling programs, intention to participate, and number of materials to be source separated; questions to assess attitudes to financial incentives; and questions on socioeconomic situation of respondents. A total of 343 validated answers were gathered. The result of this participative process was the strategy

(continued)

Box 11.2 (continued)
for the introduction of recycling schemes in the town, where two stages were defined. In the first stage, drop-off systems should be provided for four waste flows, and simultaneously, domestic composting and hazardous waste recycling should be ensured. In the second stage, financial instruments and a curbside collection scheme in combination with the drop-off system should be explored. At the end of the two stages, evaluations must be conducted to verify if the strategy is successful or not.

When conducting the behavior studies, the intention is to understand which factors are affecting the participation of citizens in the collection system. Several factors have been studied so far by scientists (Miafodzyeva and Brandt 2013; Varotto and Spagnolli 2017):

- Socio-demographic factors: Include age, education level, income, gender, dwelling type, household size, home ownership, household type, employment status, and ethnicity.
- Psychological factors: Include information and knowledge, convenience/effort, social influence, responsibility, environmental attitudes, beliefs/perceptions of recycling consequences, specific recycling attitudes, motivation, recycling experience, behavior skills, the perception of the service provider, personality characteristics, emotion, and sense of community.
- Contextual factors: Include service, monetary incentives, the location of bins, characteristics of bins, and product characteristics.
- Other study-specific factors: Related to individual factors influencing the recycling behavior, including the share of immigrants in a community and significance of behavior habits and shopping behavior.

Understanding which are the factors affecting the recycling behavior will, consequently, determine the success of the source-separated collection system and influence the contents and shapes of the awareness campaign has to be elaborated. Awareness campaigns intend to communicate using strategies which could increase recycling behavior of citizens. Prompts, persuasive communication, verbal commitment, written contracts, and feedback, i.e., “the transmission of information about the effects of the behaviors of an individual or a group,” are approaches reviewed and highlighted by Dupré and Meineri (2016).

11.5 Final Remarks

The assessment of any waste collection system requires a complete and robust definition of the system, to ensure that the goal of the assessment is correctly assessed. Most of the time, the missing data, the reduced time available, the budget constraints, and, most of all, the missing support of directors and managers to proceed with an accurate assessment of the system may lead to biased results that do not reflect the reality of the waste collection system. Efforts should be made, firstly, to make the assessment tools based on life cycle thinking available to this sector. Make available means cost affordable and scientifically understandable (concerning running the methods and result interpretation). However, such natural access (economically and technically) cannot make life cycle thinking models too simplified, in such way that it will not reflect the life cycle of the service provided – the collection of waste. The development of methodologies that could assess the sustainability of waste collection should be made at the light of Open Innovation 2.0 (Curley and Salmelin 2013). Practitioners, methodology developers, and academics should work together to make life cycle thinking methods, leading to the creation of wealth in the waste sector. When the waste sector reaches sustainable standards due to those assessment methods, the governments may establish such standards as the norms for an appropriate waste collection system operation. Citizens, in contact with those waste collection system, will demand all waste collection to perform in such sustainable way. The academia will force the entrance of the sustainable, holistic, and life cycle thinking in the waste-related course programs, repeating the quadruple helix cycle (academia, business, government, and citizens). In this new paradigm, waste collection and waste management sector can make the assessment and improvement of the sector a reality, preparing it for the challenges that will come in the future.

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