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Environmental performance of waste management in an Italian region: how LCI modelling framework could influence the results

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Abstract

The constant growth of solid and hazardous waste production is increasing the European concerns about the protection of the environment and natural resources. It is estimated that Europe produces up to 3 billion tons of waste every year. EU is promoting several waste management policies aiming to reduce the environmental impacts of waste and improve Europe's resource efficiency. In this context, public administration of numerous Italian regions are showing more attention in order to reducing the environmental impacts related to solid and hazardous waste management. Life cycle assessment (LCA) is a powerful tool to quantify environmental impacts and determine the potential management strategies to reduce these impacts. Nevertheless, the identification of Life Cycle Inventory (LCI) modelling framework to model multifunctionality could be a very critical point. This study analyzed the environmental performance of the waste management, including municipal solid waste and industrial waste, in the Emilia Romagna region (Italy) adopting attributional and consequential approaches. The influence of LCI modelling frameworks on the environmental results has been investigated.

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Keywords: solid waste management, industrial waste management, LCI modelling framework, attributional, consequential.

1. Introduction

We live in the era of consumerism where the acquisition of goods and services is encouraged in ever-increasing amounts [1]. This leads to an inevitable production of wastes.

Solid waste can be classified in *i*) municipal solid waste (MSW), i.e. household waste, trash or garbage, and *ii*) industrial waste (IW), i.e. a wide variety of non-hazardous (NHW) or hazardous materials (HW) resulting from the production of goods and products. An improper waste management can provoke severe impacts on environment and human health. Therefore, Directive 2008/98/EC completes the waste framework, promoting the implementation of life-cycle thinking, creating a need for looking at products under the perspective of waste throughout the whole product life cycle [2]. Life Cycle Assessment (LCA) methodology [3, 4] is a powerful tool for decision-making process, which allows, firstly, the identification of hotspots associated with a specific waste management policy and, finally, the implementation of focused strategies to reduce environmental impacts [5, 6, 7, 8]. For this reason, the LCA methodology was chosen in the present study to assess and compare the environmental performance of waste management, comprising MSW and IW, for the Emilia Romagna (ER) a norther Italian region. In the last ten years, the LCA application to waste management field has been largely studied. In particular, different scenarios of solid waste management for different European countries have been largely analysed. Laurent et al. [7] carried out a critical review of 222 LCA studies. They compared these works to the ISO standard requirements [7,8] and the ILCD Handbook guidelines [9], determining a lack of compliance with the latter and therefore a significant influence on the results of the several investigated LCA studies. According, to Laurent et al. [8] this could lead to provide non-homogeneous recommendations to different stakeholders. Recently, Ekvall et al. [10] analyzed the ILCD guidance by comparing different

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statements in the handbook with each other and with previous research in this area. They concluded that ILCD handbook is internally inconsistent, in particular when it recommends the choices between *attributional* and *consequential* LCI (Life Cycle Inventory) modelling framework. Therefore, they indicate that the handbook must be revised. Furthermore, Weidema [11] pointed out a criticism in the current ISO 14044 related to *which unit processes to include in a product system and how to link these unit process data sets together*. He underlined that this causes different interpretations regarding LCI framework modelling [11]. Consequently, there are different scientific opinions on implementation of the ILCD recommendations and the standard ISO, disorienting practitioners during conducting LCA and especially in the LCI modelling framework definition.

2. LCI modelling framework

Attributional modelling is conducted to identify the existing impacts generated by a system [12] isolated from the rest of the technosphere or economy [13]. This approach answers to the question "*what environmental impact can be attributed to system X*?" [13]. Moreover, the attributional LCI is based on average data that represent the actual physical flows. In this modelling, the multifunctionlity can be addressed by *i*) 'substitution', where the functional unit is expanded to include the co-functions (avoided products) of the process/product [13], or by *ii*) 'partitioning', where inputs and outputs are allocated between the system function and the co-products generated by the system. The allocation can reflect physical relationships or other relationships e.g. economic value.

Consequential modelling describes how environmentally relevant physical flows will change in response to possible decision [10]. In fact, it answers the question "*what are the environmental consequences of consuming X*?". Contrary to attributional LCA, consequential LCA is associated with the use of marginal data for modelling the background system. Consequential modelling solve the multifunctionality by through 'substitution'. In fact, it identifies the co-products generated by the analyzed system and crediting the avoidance of those co-products and their associated impacts that are assumed to be a consequence of the decision taken. Therefore, in the present work both modelling have been adopted to evaluate the environmental burdens associated to the waste management for ER region (Italy).

Following the methodological guidance for the identification of the most adequate LCI-modelling framework presented by [8] the LCA study of waste management in ER region should conduct as a mix of long-term marginal processes since large-scale consequences on the background system are expected, namely context situation B (meso/macro-level decision support) [9]. This context situation is modelled adopting *consequential* modelling. Nevertheless, the main scope of the local public administration, who commissioned the study, was not to analyse the consequences of changes in the waste management system, but determining the real effects on human health and environment that the current waste management policies provoke. For this reason, we consider *attributional* with 'partitioning' approach the most adequate LCI modelling to better answer to the local administration request. In fact, this cause-oriented modelling allows to obtain a snapshot of the under studied system. According to Pelletier et al. [14] we believe unfitting the use of 'substitution' in the *attributional* data modelling. Indeed, as Pelletier et al. [14] stated, the determination of the single product systems, which provide functionally equivalent products, might be not possible. Moreover, the use of inventories from other product systems as proxies for inventories of co-products will not provide realistic results unless their inventory profiles are identical.

The environmental results of the present study performed by attributional and consequential modelling vary greatly leading to a different result interpretations.

3. Life cycle assessment

3.1. Goal definition

The goal of the work is to assess the environmental impacts of the solid and industrial waste management of ER region (Italy). In particular, MSW and IW (including HW and NHW) have been taken into account.

3.2. System and functional unit

The system studied is the integrated waste management of ER region in the 2014. The function is the total waste amount managed by ER region taking into account both MSW and IW, namely 16'598'169 ton.

3.3. System boundaries

The system boundaries encompass the entire waste chain of ER region from the waste collection to final disposal/treatment of residual waste (i.e. waste that does not undergo further treatment). In particular, the following steps have been taken into account and modelled into LCA study:

- MSW collection has been based on a number of collection systems: door to door, containers and pneumatic systems collection for separate waste and only dumpsters for unsorted waste. IW collection has been settled on containers as collection system.
- Diesel consumption of collection trucks for MSW and IW collections have been evaluated.
- A storage area for stocking and pre-sorting wastes before undergoing to further waste treatments have been considered.
- Processing of all waste flows has been analysed: recycling (or material recovery activities), composting, incinerating, landfilling and wastewater treatments. For each waste treatment plants and equipment necessarily to treat the waste have been considered and modelled.

3.4. Life Cycle Inventory of waste management of Emilia Romagna region

The area of ER is 22’453 km^2 and with a population of almost 4,5 million people. In the 2014, the amounts of MSW and IW collected by ER region were 2’929’953 tons and 13’668’216 tons respectively [15]. Therefore, the total waste managed by ER region is almost 16,6 million tons, of which 82,35% concerns IW. Separate waste (SW) collection involved the 58,2% of the total MSW (1’706’609 tons).

Table 1 Separate collection system of ER region

Material recovery activities	Amount of waste collected [ton/yr]	Amount of waste directly conferred to landfill [ton/yr]	Co-products
Organic waste	263’751	8	Compost Iron
Garden waste	418’659	231	Biogas Protein feed Grass fiber
Paper and cardboard	367’402,9		Sulfate Pulp
Plastic	133’893,42	26	Secondary plastic
Glass	155’208,99	-	Brown glass
Metals	44’878,1	-	Secondary aluminium, copper, iron
Wood	135’631,59	42	Woodchips
Textile	9’229	-	Recycled textile
WEEE	21’683	1	Secondary precious materials and reused EEE
Furniture	25’254	42’254	Secondary materials (wood, metal, polyurethane, etc)
Inert waste	78’257	69	Sand
Composite packaging	184	-	Pulp Maralhene
EoL tires	19’25	-	Steel wire Rich ZnO ash Sodium sulphate Electric energy
Mineral oil	1’068	-	Heavy and light fuel oil Bitumen adhesive compounds Low sulfur content diesel Sulfur (pure)
Vegetable oil	483	20	Vegetable oil fuel
Bacteries	1’400	24	Lead Polypropylene
Cartridges and toners	1’424	642	Secondary toner
Pharmaceutical waste	192	208	-
Insulating and building materials containing asbestos	51	1’471	-
Toxic and flammable wastes	368	670	-
Total	**1’660’943**	**45’666**	

Source: ARPAE, 2015

Table 1 per each type of residual waste reports the amount of waste collected, the amount of waste directly conferred to landfill and the coproducts generated by the recycling process. The waste stream of the separate collection takes into account: paper and cardboard, organic waste, garden waste, plastic, glass, metals and wood. Moreover, bulky municipal wastes have been included in the separate collection model, namely furniture, inert, WEEE (waste electrical and electronic equipment), composite packaging (Tetrapak), textile, End of Life (EoL) tires, mineral and vegetable oils, batteries, pharmaceutical waste, insulating and building materials containing asbestos, toxic and flammable wastes, cartridges and toners. Hence, in according to the annual waste report of ER region [15] all hazardous waste derived from household waste have been imputed to the separate collection system.

As shown in Table 1 part of waste sorting has been directly conferred to landfill (45’666 ton/yr) and the remaining waste flows undergo different treatment processes, which allow to recover secondary materials or biogas (co-products). In particular, 1) organic waste has been composted to obtain compost and secondary iron, 2) garden waste has been treated to store biogas, fiber grass and protein feed, 3) paper, glass, wood, plastic and metals have been recycled to upcycle into secondary materials, i.e. pulp, green glass, woodchip, secondary metals (aluminum, iron and copper) respectively. Moreover, in according to a local survey [16] each of the cited waste fractions is sorted and consequentially only part of them undergoes to waste treatment, in particular this part is the result of multiplication between the amount of waste collected and the recycling rate (Table 2).

Table 2 Recycling and reuse rate of separate collection system of ER region

Waste fraction	Recycling rate	Reuse rate
Organic waste	0,92	-
Garden waste	0,63	-
Paper and cardboard	0,96	-
Plastic	0,47	-
Glass	0,93	-
Metals	0,99	-
Wood	0,98	-
Textile	0,29 §	0,68 §
WEEE	-	0,1 *

Source: ARPAE 2015 [15], § Di Giacomo et al. 2013 [17], * Pini et al. 2016 [18]

The mixed waste (MW) collection produced in 2014 amounted to 1’223’344 tons (41,8%), of which 12’826 tons the result of the multimaterial waste of separate collection. The residual waste is the waste fraction that needs to undergo the most varied treatment and disposal operations. Table 3 reports the waste treatments adopted for the unsorted waste and the total amount of treated waste per each of them.

Table 3 Mixed waste collection of ER region (2014)

Waste Treatment	Amount of treated waste [ton/yr]	Amount of multi material waste derived by separate collection [ton/yr]
Metal recycling	10’470	0
Incineration	744’881	9’673
Biostabilization	133’079	
Landfill	322’087	3’153
Total	**1’223’344**	**12’826**

Source: ARPAE, 2015

Part of the total amount of MW (451814 ton) undergoes a sorting pre-treatment in Mechanical Biological Treatment (MBT) plant. This allows obtaining a pre-sorting of MW, separating the following fractions: 1) dry fraction (37,3%) of refuse derived fuel, which is sent to MWI plants for energy recovery; 2) stabilized organic fraction (29,45%), which is used as daily or final landfill cover material; 3) waste fraction

(32,48%), which is diverted to landfills (net of the SOF) and finally 4) metals (0,82%) that are sent to recycling.

Finally, this study assessed the IW management of ER region. These types of waste are the result of industrial activities and take into account both hazardous and non-hazardous waste, which are usually generated by disinfection processes such as sludge, leachate, reclamation materials, etc. as defined by art. 184-ter of Legislative Decree. N. 152/06. In the Italian context, the IW management is subject to free market rules and the responsibility for their correct recovery, treatment and disposal is imputed to the manufacturer. Table 4 reports the amount of industrial hazardous and non-hazardous waste of ER region for 2013 subdivided in disposal and recovery activities. On the total amount of IW (13'668'216 ton), 71% have been disposed of adopting waste treatments called "recovery activity" and 29% adopting the "disposal activity" ones. Non-hazardous wastes constitute the main part of the total amount of IW (93,8%), while hazardous wastes represent only 6,2%. Furthermore, materials recovery is the activity that contributes more (64,8%) to the total IW, in particular due to the amount of construction and demolition wastes (4'531'453 ton) [15].

Table 4 Industrial hazardous and non-hazardous waste of ER region (2013)

	Industrial waste	Non-hazardous waste ton	Hazardous ton	Total ton
Recovery activity	Energy recovery	574'875	62'770	637'645
	Materials recovery	8'861'300	181'890	9'043'190
Disposal activity	Incineration (without energy recovery)	219'236	68'283	287'519
	Disposal activities	1'884'320	420'977	2'305'297
	Landfill	1'279'881	114'685	1394566
Total		**12'819'611**	**848'605**	**13'668'216**

Source: ARPAE, 2015

In the *recovery activity*, energy recovery is meant as the waste incineration to generate energy (electrical and thermal), instead materials recovery takes into account all special treatments that aim to recuperate substances or resources. Furthermore, the *disposal activity* considers all treatments, i.e. incineration without energy recovery, physical, chemical and biological treatments (disposal activities) and landfill that are finalized to mere disposal operation. Since, the final aim of this study is to identify the environmental burdens associated with *material recovery activities - MRA* (recycling) and *energy recovery and disposal activities - ERDA* (incineration, landfill and wastewater treatment) of the analyzed waste management system, LCI has been model to best represent these two different waste treatment activities. Therefore, the separate and MW collections of MSW have been divided into the two types of above-mentioned waste treatment, i.e. *MRA* and *ERDA* (e.g. SW collection: the glass waste is 92,63% recycled and 7,37% disposed of; hence the first part goes to MRA and the latter part goes to ERDA. MW collection: per each kg of incinerated waste, 0,069 kg of iron scrap has been sorted and diverted to recycling; therefore 0,931 kg is included in the ERDA and the iron scrap goes to MDA). The compilation of inventory data has been conducted using different data sources. Primary data concerns 1) the waste stream, which has been directly collected by the waste regional report of ER region [15] and 2) waste processing such as biological mechanical treatment, composting and recycling/material recovery treatments that have been obtained by regional realities of waste treatments. Secondary data acquired from Ecoinvent database v3.3 [19] have been adopted i.e. incinerating of both solid and hazardous wastes, landfilling and wastewater treatment. As before mentioned this study adopted two LCI modelling approaches. In particular, the *attributional* LCI modelling (partitioning as basis of allocation) the *MRA* considered the environmental loads allocated 50/50 between the producer (e.g. recycling process or composting or incinerating etc.) and the consumer of the recycled material (e.g. secondary glass, secondary iron, and so on). The 50/50 allocation confers to the recycler half of environmental damage associated to the *MR*A and the other half damage to the co-product [19]. Instead, for incinerating, the allocation has been based on energy criteria and for WEEE treatment economic value based allocation has been adopted. Average data (secondary materials production and energy obtained by recovery activities) have been used. Contrarily, for the *consequential* modelling processes none allocation has been considered but a system expansion (avoided products) has been applied. In particular, the avoided production of primary resources has been taken into account in the *MRA* and the avoided energy production has been evaluated in the energy recovery, e.g. incinerating. Therefore, the boundaries of the study have been enlarged until embracing the consequences that the analyzed system might cause on market avoiding the production of that specific resource and consequentially changing the market demand. Consequential modelling has been here performed through the system model *Substitution, consequential, long-term* of Ecoinvent v3 database [20].

3.5. Impact assessment methodology

The analysis has been conducted using the SimaPro 8.3 software [21] and using the modified IMPACT 2002+ v2.10 [22] evaluation method. IMPACT 2002+ is an impact assessment method that covers more impact categories than other methods, includes more substances, and being a midpoint and endpoint oriented, it returns a complete overview of environmental performance. However, some additions and modifications have been implemented in order to describe the system considered in a more representative manner, i.e. modification to *Land use* (different types of land transformations were considered) and *Mineral extraction* categories (additional resources were added) [23].

The Life Cycle Impact Assessment (LCIA) results have been here performed on both midpoint and endpoint levels. Nevertheless, for the sake of brevity we reported only endpoint results. These are usually shown as impact on human health, ecosystem quality, climate change and resource depletion. We decided to report only endpoint results as the interpretation of these results does not require extensive knowledge of environmental effects, and who commissioned the study will be able to easily make decisions. Moreover, midpoint results can be more difficult to interpret because they consider a large number of impacts often difficult to understand. Therefore, they have a lower relevance for decision support [24].

4. Impact assessment

The environmental performance of MSW, including SW and MW collections, and IW of ER region in the 2014 have been carried out adopting both *attributional* and *consequential* approaches.

Attributional modelling. The analysis of the results shows that the total damage is 992,1 kPt mainly attributed to (Fig. 1):

- 52% to the IW recovery activity,
- 26,8% to IW disposal activity,
- 12,2% to SW MRA,
- 5,8% to MW energy recovery and disposal activities,
- 2,6% to SW energy recovery and disposal activities,
- 0,6% to MW MRA.

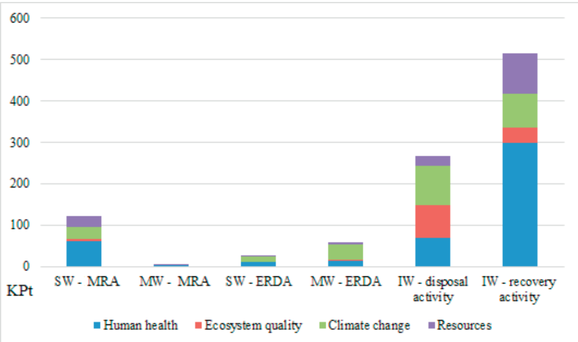

Figure 1 Environmental damage by single score – attributional modelling

Table 5 Environmental damage by damage category– attributional modelling

Damage category	SW - MRA	MW - MRA	SW - ERDA	MW - ERDA	IW - disposal activity	IW - recovery activity	Total
Human health DALY	4,26E2	2,10E1	7,00E1	9,85E1	2,13E3	4,81E2	3,22E3
Ecosystem quality PDF*m2*yr	9,05E7	4,52E6	4,18E6	1,76E7	4,86E8	1,11E9	1,72E9
Climate change kg CO2 eq	2,80E8	1,04E7	1,40E8	3,78E8	8,17E8	9,26E8	2,55E9
Resources MJ primary	3,94E9	1,79E8	1,56E8	6,01E8	1,49E10	3,64E9	2,34E10
Total kPt	120,85	5,53	25,39	57,29	266,62	516,09	

Table 5 reports the environmental loads at the damage categories level. In particular, the total damage effects for: Human health category contributes with 45,81% to the total damage, in particular due to *Particulates, <2,5 µm* in air, in particular caused by electric energy production used for material recovery in IW-recovery activity. Resources category provides 15,55% of the total damage, mainly for *Oil, crude*, in particular caused by waste collection in IW-recovery activity. The damage to Climate change (23,41%) is generated almost entirely by *Carbon dioxide, fossil*, mainly due to incinerating in IW-disposal activity. Aluminum in soil affects the category Ecosystem quality (12,63% of the total damage) and is linked to the disposal of biowaste to agricultural in IW-disposal activity). Furthermore, the total damage is due to 78,9% to IW and 21,8% to MSW. The unit damage of IW related to the disposal recovery and material recovery is pretty similar 5,49 Pt/ton and 5,86 Pt/ton respectively. Instead, the unit damage of MSW is equal to 5,91E-2 Pt/ton for solid waste treated with energy recovery/disposal activities and 8,26E-2 Pt/ton for solid waste processed with *MRA*. The unit damage increase is mainly due to the different waste treatment that the solid waste underwent to recover resources.

Consequential modelling. Generally, this modelling determines an environment benefit. Indeed, the environmental results of analyzed system carried out an eco-point equal to -1,38 MPt mainly caused by (Fig. 2):

- -52,7% IW recovery activity,
- -36,1% to SW MRA,
- -13,7% to MW energy recovery and disposal activities,
- -3,97% to SW energy recovery and disposal activities
- -0,003% to MW MRA,
- 6,5% to IW disposal activity.

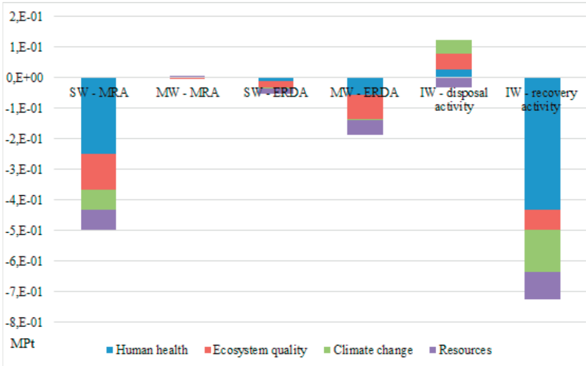

Figure 2 Environmental damage by single score – consequential modelling

Table 6 Environmental damage by damage category–consequential modelling

Damage category	SW - MRA	MW - MRA	SW - ERDA	MW - ERDA	IW - disposal activity	IW - recovery activity	Total
Human health DALY	-1,76E3	-4,88	-9,58E1	-4,10E2	-3,07E3	1,75E2	-5,18E3
Ecosystem quality PDF*m2*yr	-1,62E9	-2,41E6	-2,47E8	-1,10E9	-8,90E8	7,39E8	-3,12E9
Climate change kg CO2 eq	-6,59E8	3,22E6	-4,30E7	-1,04E7	-1,36E9	4,20E8	-1,65E9
Resources MJ primary	-9,64E9	7,60E7	-2,87E9	-7,65E9	-1,38E10	-4,80E9	-3,87E10
Total MPt	-4,9E-1	-3,79E-5	-5,48E-2	-1,89E-1	8,94E-2	-7,26E-1	

Table 6 reports the environmental benefit the environmental loads at the damage categories level. In particular, the total benefits are generated by:

Human health category contributes with -52.69% on the total benefit, in particular thanks to *Particulates, <2,5 µm* in air, mainly due to the avoided copper primary production (avoided product in the recycling process) in IW-recovery activity). Resources category provides -18.49% of the total benefit, mainly for *Coal hard* in particular caused by the avoided extraction of the coke used to producing thermal energy (avoided product in the incineration treatment) in IW-disposal activity. Climate change (-12.07%) the environmental benefit is generated almost entirely by *Carbon dioxide, fossil* mainly caused by the avoided production of primary glass (avoided product in the recycling process) in SW-MRA. Ecosystem quality (-18.49% of the total benefit) is benefited from *Occupation, forest intensive* in particular due to the avoided woodchip (avoided product of biological mechanical treatment in the MW - ERDA). Additionally, the overall benefit is due to 46,2% to IW and 52,7% to MSW. The unit benefit of IW related to the material recovery is equal to -8,2 E-2 Pt/ton more higher than the disposal recovery that is equal to -1,84E-2Pt/ton. Instead, the unit damage of MSW corresponding to -3,5E-1 Pt/ton for solid waste treated with energy recovery/disposal activities and -1,7E-1 Pt/ton for solid waste processed with MRA. The unit benefit of MSW is greater (almost twice) for MRA than ERDA this is mainly thanks to the resources recycling. Finally, the environmental benefit derived from material recovery is greater for MSW than IW, in particular due to waste treatment typologies.

5. Concluding remarks

In conclusion, a proper environmental assessment of a waste management system has to take into consideration the integrated waste management including both MSW and IW. In Italian context, the term "waste management" is typically interpreted as the only MSW management. However, as it emerged from this work, the complete analysis of the overall amount of treated wastes in a local area (Emilia Romagna) highlighted the huge quantity of industrial waste produced by industrial activities (77% on the total amount of wastes treated in ER) and its connected high environmental load (attributional modelling) or its corresponding environmental benefits (consequential modelling). Additionally, the wastes processed to recover resources generate greater environmental damage than those to produce energy, adopting the *attributional* modelling, and a greater benefit for waste treated to produce energy using the *consequential* modelling. These different outcomes depend on the LCI modelling framework implemented. *Attributional* LCI modelling returns an environmental damage albeit reduced of the allocation share considered in the material recovery activities. The environmental results carried out by *consequential* LCI modelling can be misleading; they might lead a decision-maker to adopt strategies that increase the volume of MSW and IW, in order to obtain environmental credits (positive effect on the environment). Instead, the only way to reduce the environmental damage is to limit the waste production and thus consume less. Plevin et al. stated that LCA practitioners should use *attributional* LCI modelling only for normative analyses, sensitivity analyses, and to gain a qualitative understanding of a production system [25]. For this reason, we believe that the attributional approach could proper satisfy the decision makers' requests. In fact, their scope was to understand the causes that determined the environmental harm of waste policies implemented. Therefore, attributional represents the proper LCI modelling to achieve this scope. The present work carried out the LCA of the current waste management scenario adopting both primary and secondary data (Ecoinvent v3 database). The following research steps will be 1) modelling of all waste treatments adopting solely primary data, 2) modelling a 'prevention' scenario considering the new waste management targets of *Circular Economy Package* proposed by European Commission for 2030. In particular, we will take into account i) reduction of landfilling to a maximum of 10% of MSW, ii) increase reuse/recycling of municipal waste to 65%, iii) increase recycling of packaging waste to 75%.

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References

[1] https://en.wikipedia.org/wiki/Consumerism
[2] European Parliament and Council, 2008. In: Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives (Waste Framework. LexUriServ) do 3e30. doi:2008/98/EC.; 32008L0098.
[3] ISO (2006a) ISO 14044—environmental management—life cycle assessment— requirements and guidelines. Geneva
[4] ISO (2006b) ISO 14040: environmental management—life cycle assessment— principles and framework. Geneva
[5] Ripa M et al. The relevance of site-specific data in Life Cycle Assessment (LCA). The case of the municipal solid waste management in the metropolitan city of Naples (Italy). J Clean Prod 2015;142:445-460
[6] Fiorentino G et al. Life cycle assessment of mixed municipal solid waste: multi-input versus multi-output perspectiveWaste Manag2015;46:599-611.
[7] Laurent A et al. Review of LCA studies of solid waste management systems e Part I: lessons learned and perspectives Waste Manag 2014;34:573-588.
[8] Laurent A, et al. Review of LCA studies of solid wastemanagement systems—part II: methodological guidance for a better practice Waste Manag 2014;34:589–606
[9] European Commission (EC) – Joint Research Centre – Institute for Environment and Sustainability, 2010a. International Reference Life Cycle Data System (ILCD) Handbook – General guide for Life Cycle Assessment, 2010. EUR 24708 EN, Luxembourg, LU.
[10] Ekvall T et al. (2016). Attributional and consequential LCA in the ILCD handbook. Int J LCA 2016;21(3):293-296
[11] Weidema B. Has ISO 14040/44 failed its role as a standard for life cycle assessment? J Ind Ecol 2014;18(3):324-326.
[12] Schrijvers DL et al. Developing a systematic framework for consistent allocation in LCA. Int J LCA 2016;21:976-993
[13] Hauschild MZ et al. eds. *Life Cycle Assessment: Theory and Practice*. Springer, 2017.
[14] Pelletier N et al. Rationales for and limitations of preferred solutions for multi-functionality problems in LCA: is increased consistency possible? Int J LCA 2015;74-86.
[15] ARPAE, Waste management in Emilia Romagna region, Report 2015
[16] ER ambiente,Chi li ha visti 4° Edizione, http://ambiente.regione.emilia-romagna.it/rifiuti/informazioni/Iniziative-comunicazione/chi-li-ha-visti-4deg-edizione, accessed October 3, 2017
[17] Di Giacomo et al. Il fine vita dei prodotti nel sistema moda, ARES 2.0, 2013
[18] Pini M et al. Analisi LCA di un possibile scenario di riuso delle apparecchiature elettriche ed elettroniche dismesse: il progetto WEEENMODELS. VIII Convegno Rete Italiana LCA, 2016, Italy