Environmental Technology

ISSN: 0959-3330 (Print) 1479-487X (Online) Journal homepage: https://www.tandfonline.com/loi/tent20

Environmental and economic benefits of the recovery of materials in a municipal solid waste management system

Giovanni De Feo, Carmen Ferrara, Alessio Finelli & Alberto Grosso

ENVIRONMENTAL TECHNOLOGY
2019, VOL. 40, NO. 7, 903–911
https://doi.org/10.1080/09593330.2017.1411395

Taylor & Francis
Taylor & Francis Group

Environmental and economic benefits of the recovery of materials in a municipal solid waste management system

Giovanni De Feo[a], Carmen Ferrara[a], Alessio Finelli[a] and Alberto Grosso[b]

[a]Department of Industrial Engineering (DIIn), University of Salerno, Fisciano (Sa), Italy; [b]Agenzia Regionale per la Protezione dell'Ambiente della Campania (ARPAC), Naples, Italy

ABSTRACT

The main aim of this study was to perform a Life cycle assessment study as well as an economic evaluation of the recovery of recyclable materials in a municipal solid waste management system. If citizens separate erroneously waste fractions, they produce both environmental and economic damages. The environmental and economic evaluation was performed for the case study of Nola (34.349 inhabitants) in Southern Italy, with a kerbside system that assured a source separation of 62% in 2014. The economic analysis provided a quantification of the economic benefits obtainable for the population in function of the achievable percentage of source separation. The comparison among the environmental performance of four considered scenarios showed that the higher the level of source separation was, the lower the overall impacts were. This occurred because, even if the impacts of the waste collection and transport increased, they were overcome by the avoided impacts of the recycling processes. Increasing the source separation by 1% could avoid the emission of 5 kg CO_2 eq. and 5 g PM10 for each single citizen. The economic and environmental indicators defined in this study provide simple and effective information useful for a wide-ranging audience in a behavioural change programme perspective.

ARTICLE HISTORY
Received 12 May 2017
Accepted 27 November 2017

KEYWORDS
Extended producer responsibility; LCA; materials' recovery; packaging waste; municipal solid waste

1. Introduction

Population growth brings about an inevitable increase in human activities and, consequently, a growth in generation of waste, which must be treated and disposed of. An ineffective or irresponsible waste disposal pollutes the environment and creates health risks to the public [1]. However, what apparently seems a problem can become a resource. In fact, the implementation of a sustainable waste management is an excellent opportunity to recover resources and energy. Recycling processes allow recovering secondary raw materials from municipal solid waste, with promoting these processes being a moral, legal and ethical duty [2]. Wasting resources is not acceptable especially in Italy, which strongly depends on the import of raw materials [2].

The research for a continuous improvement of waste management sustainability pushes to use adequate environmental evaluation tools. Life cycle assessment (LCA) methodology is the most widely used tool for this purpose [3]. LCA allows one to evaluate the environmental performance of alternative systems considering their entire life cycle [4]. LCA allows one to compare different systems considering the consumption of resources as well as the emission of pollutants that may occur during their life cycle [5], which may include the extraction of raw materials, the production and processing of materials, the transport, the phase of use and, finally, the end of life [6,7].

In the last decades, many studies have applied LCA to waste management. These studies have shown that how waste management is a complex and multidisciplinary field and that its evaluation needs a holistic approach [8]. The performance of waste management systems depends on assumptions made for the study as well as on the quality and type of input data [9]. Some authors have provided a contribution in this sense, defining types of operating data about waste collection operations [10], or methods for evaluating waste composition analysis [11] that can be used in modelling LCA future studies.

In order to increase and promote a more comprehensive sustainability of waste management and treatment, some authors suggested combining environmental and economic evaluations [12–15].

In the light of the above considerations, this study combines economic and environmental approaches in order to perform a sustainability evaluation of the waste management system of Nola, a town of around 34,000 inhabitants in the Campania region of Southern

CONTACT Giovanni De Feo g.defeo@unisa.it Department of Industrial Engineering (DIIn), University of Salerno, via Giovanni Paolo II, 312–84084 Fisciano (Sa), Italy

Italy. The study evaluates the margins of improvement of both environmental and economic performances of the system in function of the separate collection level.

The LCA approach was used for the environmental analysis, while the environmental impacts were calculated with the ReCiPe 2008 H method, adopting both the midpoint and endpoint approaches.

The economic analysis was based on the calculation of indicators related to real and potential gains for the local population in function of source-separated recyclable packaging waste.

Four different scenarios were defined and evaluated:

- Scenario S1: waste management system of the town under study in 2013, with 54% of separate collection (real scenario);
- Scenario S2: waste management system of the town under study in 2014, with 62% of separate collection (real scenario);
- Scenario S2 (65%): scenario S2 considering the effects of increasing the source separation of urban waste up to the minimum Italian required level of 65% (hypothetical scenario);
- Scenario S2 (80%): scenario S2 considering the effects of increasing the source separation of urban waste up to 80% (hypothetical scenario).

The main aim of the study is to provide environmental and economic indicators that report simple information and indications, usable from a heterogeneous public, despite them being the result of scientific study and complex calculations. This is very important from an environmental policy perspective since a powerful tool is provided to politicians and decision-makers operating in the waste field.

Thereby, the study answers one of the main goals of the Industrial Ecology that was born to drive the decisional processes showing what are the industrial processes' effects in terms of their impact on the environment [16].

2. Material and methods

2.1. The area and the separated collection system under study

The study area was the town of Nola, in the province of Naples (in the Campania region of Southern Italy). Nola occupies an area of 39.19 km^2, with a population of 34,349 (National Institute for Statistics, 2015) inhabitants and a consequent population density of 876.47 inhabitants/km^2.

Its municipal waste management system is based on a door-to-door separate collection system (kerbside collection). The waste fractions collected are the following: putrescibles (three times a week), paper and cardboard (once a week), plastics and metals together (once a week), unsorted residual municipal waste (or dry residue or simply residue) (twice a week) and glass (once a week). Bulk refuses and Waste Electrical and Electronic are conferred directly by the citizens to a separate collection centre.

After the collection phase, the recyclable fractions are sent to intermediate treatment plants for selection and pre-treatment operations and then to recycling plants (in and out of Campania Region). The putrescible fraction is sent to aerobic composting plants (out of the Region), while for the dry residue, there is a mechanical biological treatment plant (MBT) from which the light fractions are separated (mainly paper, cardboard and plastics) and sent for incineration with energy recovery (in the only incinerator of the Region).

2.2. Economic benefits' calculation

The main goal of the economic analysis conducted on the waste management scenarios considered was to show what the potential economic rewards could be for the population on the basis of the extended producer responsibility (EPR) for the packaging management. In fact, with the EPR system, a Municipality receives an economic amount for each kilogram of packaging waste collected. In Italy, this activity is managed by CONAI (a private system created and designed by companies). The 'CONAI system' is based on the activities of six consortia, each dedicated to promoting and controlling the most used materials in the packaging production, i.e. steel, aluminium, paper, wood, plastics and glass.

Therefore, the economic rewards related to both source-separated recyclable fractions and recyclables virtually still present in the residue were evaluated for the four scenarios considered (S1, S2, S2 (65%) and S2 (80%)).

As shown in Table 1, CONAI recognises economic reward for the several source-separated packaging waste on the basis of the quality level of collected materials (in function of the discards contained). For

Table 1. Italian EPR economic rewards applied for each source-separated packaging waste on the basis of the quality of the collected materials (Min and Max) and adopted values (Medium).

Material	Min (€/ton)	Max (€/ton)	Adopted values (Medium) (€/ton)
Steel	42.00	108.00	75.00
Aluminium	150.00	550.00	350.00
Paper and Cardboard	49.50	99.00	74.25
Plastic	39.97	366.51	203.24
Glass	5.00	45.50	25.25

Table 2. Amounts of the source-separated fractions ('Separate Collection') and the unsorted residual waste ('Residue') for all the scenarios considered.

	S1		S2		S2 (65%)		S2 (80%)	
Fraction	Separate collection kg	Dry residue kg	Separate collection kg	Dry residue kg	Separate collection kg	Dry residue kg	Separate collection kg	Dry residue kg
Aluminium	33,563	116,012	33,944	127,821	45,494	116,271	96,450	65,315
Glass	886,080	609,673	860,830	756,817	927,930	689,717	1,223,959	393,687
HDPE plastic	145,384	147,784	175,336	141,723	187,656	120,598	242,009	75,050
Mix plastic	255,100	268,413	308,286	257,890	331,249	224,008	432,553	133,623
Organic	5,121,050	310,5589	6,862,572	203,4485	7,042,422	1,854,635	7,835,878	1,061,180
Paper and cardboard	940,200	130,3429	897,280	152,9190	1,032,580	1,393,890	1,629,492	796,979
PET plastic	619,918	657,455	749,524	631,947	805,541	551,907	1,052,678	328,793
Steel	66,943	680,933	71,306	737,517	136,756	672,067	425,506	383,317
Total	8,068,238	6,889,288	9,959,078	6,217,391	10,509,628	5,623,094	12,938,524	3,237,944

the calculations, the medium value for each fraction was adopted but even the minimum as well as maximum values were considered in order to show the error range variation.

A packaging waste that goes into the residue represents an economic damage due to the loss of the 'CONAI contribution', but there is still another negative economic aspect: the payment of the disposal fees. Therefore, the calculation of the potential economic rewards related to the packaging waste theoretically present in the residue is made up of two voices: the EPR contribution and the avoided fee for the mechanical and biological treatment and subsequent incineration (assumed equal to 170 Euros/t).

2.3. Environmental benefits' calculation

The LCA methodology was applied to evaluate the four scenarios considered (S1, S2, S2 (65%) and S2 (80%)). All the scenarios include the treatment and disposal phases, the kerbside collection phase inside the municipal boundaries and the waste transport phase from the municipal collection centre to an intermediate treatment plant (step 1) and, then, to the final treatment plant (step 2). The following (in alphabetical order) are the waste fractions taken into consideration in the study: Aluminium, Glass, HDPE plastic, Mix plastic, Organic, Paper & Cardboard, PET plastic, Residue and Steel.

The modelling of the scenarios was performed with the SimaPro 8 software tool (PRé Consultants, Amersfoort, The Netherlands), using the Ecoinvent v.3 database.

The functional unit of the study is the amount of municipal solid waste produced in the town of Nola for the year considered, i.e. 14,957 t/year for the scenario S1 in 2013, and 16,176 t/year for the scenarios S2, S2 (65%) and S2 (80%) in 2014.

Table 2 shows the amounts, expressed in kg, of the source-separated fractions and dry residue for all the evaluated scenarios. The modelling of most waste-treatment and -disposal plants was performed using specific processes of the Ecoinvent System v.3 database.

Table 3 shows the main features of the processes used for the modelling of plastic recycling processes [17] and MBT plant [18].

Regarding the modelling of the waste transport phase, Table 4 shows the distance in km covered by the vehicles for the waste transport from the municipal collection centre to the intermediate treatment plants (step 1) and then, to the final treatment plants (step2). For the internal waste collection phase, it was considered the path that the vehicles have to cover for all the municipal area (228 km).

For the modelling of the vehicles used, for both the internal and external transport phases, specific processes of the Ecoinvent System v.3 database were adopted. The

Table 3. Main characteristics of the mechanical and biological treatment (MBT) and plastic recycling facilities (considering the consumption per t of recycled plastic material) adopted in all the scenarios considered.

Mechanical biological treatment (MBT)			
General characteristics			
Polyethylene film (kg)/kg RDF	Water (l)/kg RDF	Diesel (MJ)/kg RDF	Electricity (MJ)/kg RDF
1.6 E-4	0.088	0.01	0.083
Plastics recycling processes			
General characteristics			
Plastic fraction	Electricity (Kwh/t)	Natural gas (MJ/t)	
HDPE plastic	440	510	
PET plastic	320	2,560	
Mix plastic	440	510	

Table 4. Distances in kilometre for the waste transport to the intermediate treatment plants (step 1) and to the final treatment plants (step 2) and the Ecoinvent 3 System Process used for modelling the vehicles (the distances for step 1 and step 2 differ in S1 and S2 due to the change in some treatment facilities).

	S1				S2				
	Separate collection		Dry residue		Separate collection		Dry residue		
Fraction	Step 1	Step 2	Step 1	Step 2	Step 1	Step 2	Step 1	Step 2	Vehicles
Aluminium	15.9	100	5	100	14	100	5	100	Transport, lorry >32 t, EURO3 Ecoinvent System Process
Glass	5	550	5	63	5	100	5	63	
Organic	42	630	5	63	45	630	5	63	
Paper and cardboard	5	100	5	20	5	100	5	20	
Plastics	15.9	32.2	5	20	14	32.2	5	20	
Steel	15.9	100	5	100	14	100	5	100	

process used for the external transport phase is shown in Table 4, while the process *Transport, lorry 3.5–7.5 t, EURO3* was used for the internal collection phase.

The environmental impacts were evaluated with the ReCiPe 2008 H method. This method combines a midpoint-level approach (problem-oriented) with an endpoint approach (damage-oriented) considering impact categories such as ozone depletion, agricultural land occupation, fresh water depletion and fossil fuel depletion. The hierarchist perspective (H) is based on the most common policy principles concerning the time frame and other issues [19].

The transition from the midpoint approach to the endpoint approach involves more approximations due to a higher level of hypothesis and assumptions [19]. The uncertainty increase, thus, could push the scientific community to use only the midpoint approach. However, this would be a mistake since the endpoint level provides an overall vision through clear and understandable information even for the non-scientific community. Such an approach allows one to compare the final impacts of the alternative systems, providing a very useful support decision-making tool.

Based on these considerations, this study combined (in an innovative way) the endpoint and midpoint approaches of ReCiPe 2008, reporting the results obtained with both the methodologies. Therefore, firstly, the endpoint results of the comparison among the scenarios are presented in order to provide an overall and clear vision; secondly, the midpoint results of the most impacting categories are discussed.

3. Results and discussion

3.1. Economic results

The economic analysis was performed on the basis of the EPR economic rewards obtainable for the Municipality for both the source-separated packaging waste as well as those recyclable virtually collectable in the dry residue for the four defined scenarios, considering a range of economic benefits obtainable in function of the quality level of the collected materials.

Figure 1 shows the economic rewards obtained and obtainable for the four scenarios (S1, S2, S2 (65%) and S2 (80%).

Figure 1(a) shows how, going from S1 to S2, an increase in the economic rewards is obtained for both the source-separated, collected and collectable fractions into the residue for scenario S2. This occurs because between the 2 years (2013 and 2014), there was an increase in both the separate collection percentage (+8%) and waste production (+20,000 t).

For both scenario, S1 and S2, Figure 1, however, shows also that the economic benefits obtainable for collectable fraction may vary greatly depending on the quality level of materials. The error is not negligible and it is similar for both scenarios because although in scenario S2, the separate collection percentage is higher than in scenario S1, this is offset by the increase in the total waste production verified in S2.

Figure 1(b), which proposes a comparison among the results of scenarios S2, S2 (65%) and S2 (80%), shows what the obtainable economic rewards could be with an improvement in the waste management system due to an increase in the separate collection percentage. In fact, considering the medium value of 'CONAI contribution' for each material, it emerges that with 65% of the source separation, it could be possible to have an increase of 11%, while with 80% of separate collection, the municipality could gain 40% more. An increase in the separate collection percentage of a waste management system implies intercepting a greater amount of recyclables from the residue that, instead of following the disposal path (MBT and incineration), can be recycled. This effect is clearly reflected in the results. In fact, passing from S2 to S2 (65%), and from S2 (65%) to S2 (80%), the potential gain obtainable from the residue decreases. This effect, obviously, occurs also in the error calculation of the economic benefits. Indeed, Figure 1(b) highlights that, for the collected fractions, there is an increase in results ranging from S2 to S2

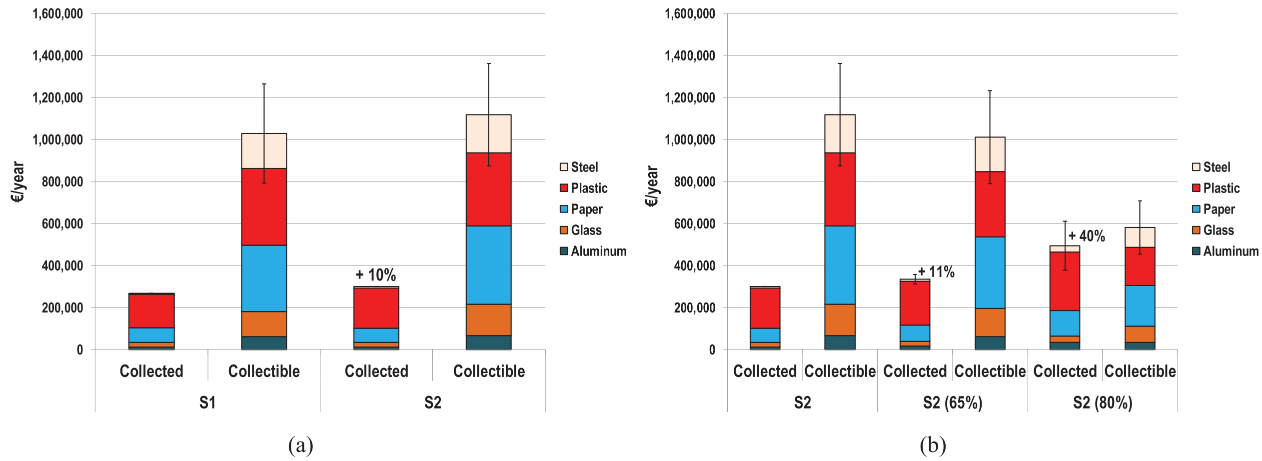

Figure 1. Amounts of the EPR economic rewards related to both the source-separated fractions' recyclables (collected) and the recyclables theoretically contained in the residual waste (collectable) for the scenario S1 and S2 (a) and for the scenarios S2, S2 (65%) and S2 (80%) (b) (The error bars indicate the minimum and maximum values).

(65%) and then to S2 (80%) and the opposite happens for the collectable fractions.

3.2. Environmental results: S1 vs. S2

The environmental analysis of the scenarios considered (S1, S2, S2 (65%) and S2 (80%)) was performed applying the LCA methodology. Impacts were calculated with the ReCiPe 2008 H evaluation method.

Figure 2 shows the environmental impacts of the scenarios S1 and S2 for the treatment and disposal, internal waste collection and external waste transport to treatment plants' phases.

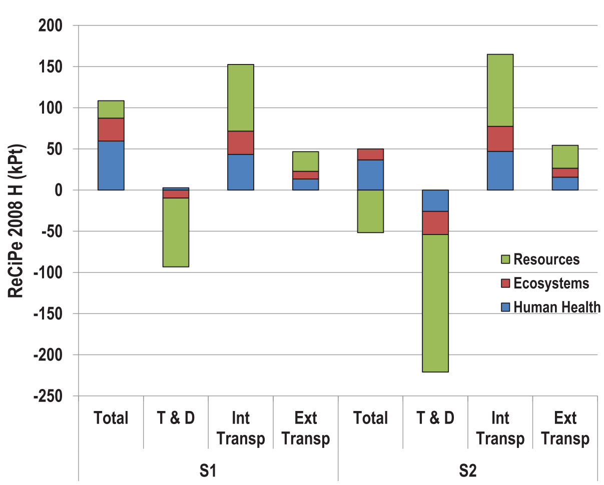

Figure 2. Environmental impacts calculated with the method ReCiPe 2008 H at the endpoint level for the treatment and disposal phases (T & D), for the internal collection of the source-separated waste fractions (Int Transp) and for the external transport to treatment and disposal facilities (Ext Transp) for the scenarios S1 and S2 (Total = T & D + Int Transp + Ext Transp). The impacts are expressed in kPt (1000 Pt). The Pt is the unit of measure of ReCiPe 2008 method after the normalisation and weighting of the three endpoint categories (Human Health, Ecosystem and Resources).

In Figure 2, the negative values represent an advantage in environmental terms since they are avoided impacts. If a process provides negative impacts, it means that, after its adoption, the avoided impacts are greater than the produced impacts, i.e. it is environmentally beneficial [20–22].

The obtained results show that the total endpoint impact of S2 (i.e. 2014 with 62% of the source separation) was significantly less than the corresponding value of S1 (2013 with 54% of the source separation). This was due to the significant improvement of the environmental performance of S2 treatment and disposal phase compared with the analogue phase of S1. The avoided impacts were higher for S2 due to an increase in both the percentage of separate collection and the amount of municipal solid waste produced in 2014. These results are in agreement with other literature studies that showed that recycling of packaging materials leads to environmental and energy benefits because for many materials, the primary production processes are heavier in environmental terms [23–25].

However, increasing the source separation in 2014 (S2) even produced an increase in the environmental loads related to the collection service that, as shown in Figure 2, caused higher impacts for both internal collection and external transport phases.

The high environmental loads of material collection due to the impacts produced by transport are highlighted also in other studies [21].

Resources was the ReCiPe damage category that contributed the most to the total impact for each single waste management phase for both scenarios considered. This category evaluates the environmental impacts due

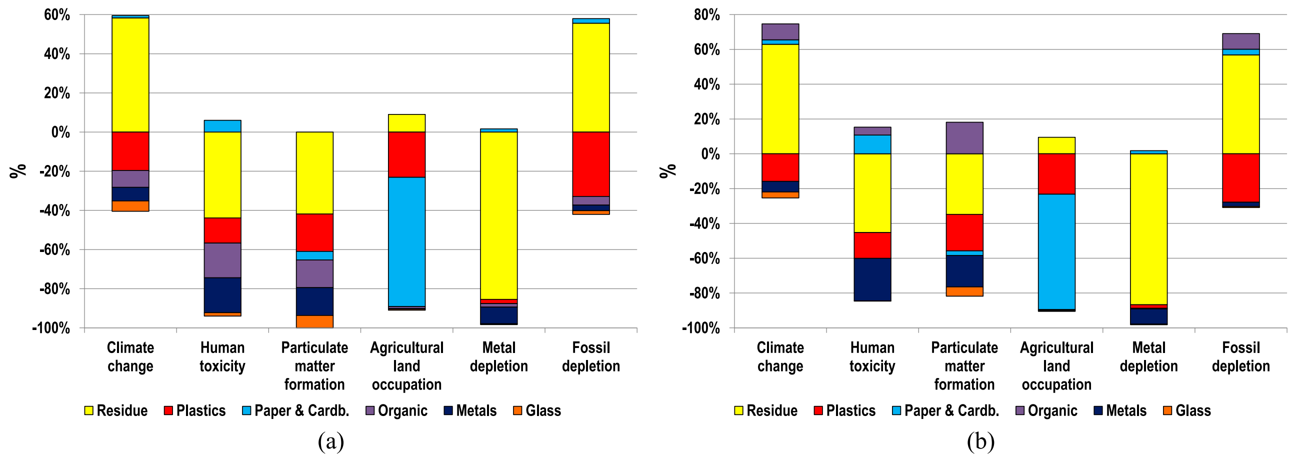

Figure 3. Contribution analysis of all the municipal solid waste components for scenario S2 and for each ReCiPe midpoint impact category considered, related to the treatment and disposal phase (a) and to the total (as the sum of all the phases) (b).

to the resources' consumption related to fossil fuels' and metals' consumption.

The predominance of the category *Resources* for the treatment and disposal phase derives from the environmental advantage related to the materials' recycling that allows one to avoid the use of virgin raw materials. Regarding the transport phases, the resources' consumption derives from the high use of fuel for the vehicles.

It is interesting to note the LCA midpoint results obtainable for the impact category. Figure 3 shows, only for scenario S2, the results of the contributions' analysis of each waste fraction for the ReCiPe midpoint impact categories that, at the endpoint level, provide a contribution to the total impact greater than 1%. This is an example of how the endpoint level can help in the choice of the midpoint impact categories to examine in detail. In many papers, the choice of the analysed midpoint impact categories is not justified.

The waste fractions provided different percentage contributions to the several impact category considered; furthermore, the same materials could contribute positively or negatively to the total impact of each category. The source-separated materials provided a negative contribution for all the impact categories, due to environmental benefits related to recycling materials that compensate and exceed the impacts generated from treatment processes [26,27]. The only exception was the paper and cardboard fraction that provided a positive contribution to four of the six midpoint categories considered (*Climate change, Human toxicity, Fossil depletion and Metal depletion*). The reasons for these results were derived from the fact that the paper and cardboard recycling process has high consumptions of energy and fossil fuels [28]. Nevertheless, Figure 3(a) shows how the source-separated paper and cardboard fraction provided a very high contribution (in negative terms) to the category *Agricultural land occupation*. This category highlights the environmental advantages of the paper recycling process related to the avoided use of soil for the planting of trees needed for virgin paper production. Therefore, the paper and cardboard recycling process is advantageous in environmental terms. In fact, the ReCiPe 2008 H single endpoint for paper and cardboard was −21.75 kPt.

The dry residue provided a positive contribution to the impact categories *Climate change*, *Fossil depletion* and *Agricultural land occupation* in consequence of the environmental loads of the MBT process. The negative contribution provided to the remaining three categories considered was because these categories take into consideration the environmental advantage related to the recycling of the metals recovered from the residue.

Summing the results of the transport phases to those of the treatment phase for scenario S2, as shown in Figure 3(b), some variations occurred. For example, the total impact of source-separated organic fraction was positive for all the midpoint impacts' categories considered. This occurred because the transport phase of this waste fraction produced very high impacts due to the large amounts collected as well as the long distances necessary to reach the treatment plants. Increasing source-separated collection percentage, indeed, is not enough to ensure the improvement of the environmental performance of waste management system; it is also necessary to ensure the presence of appropriate waste facilities [26,29] on the territory.

3.3. Environmental results: S2 (65%) and S2 (80%)

Figure 4 shows the environmental benefits arising from the potential increase in the separate collection percentage for scenario S2. The midpoint impact categories

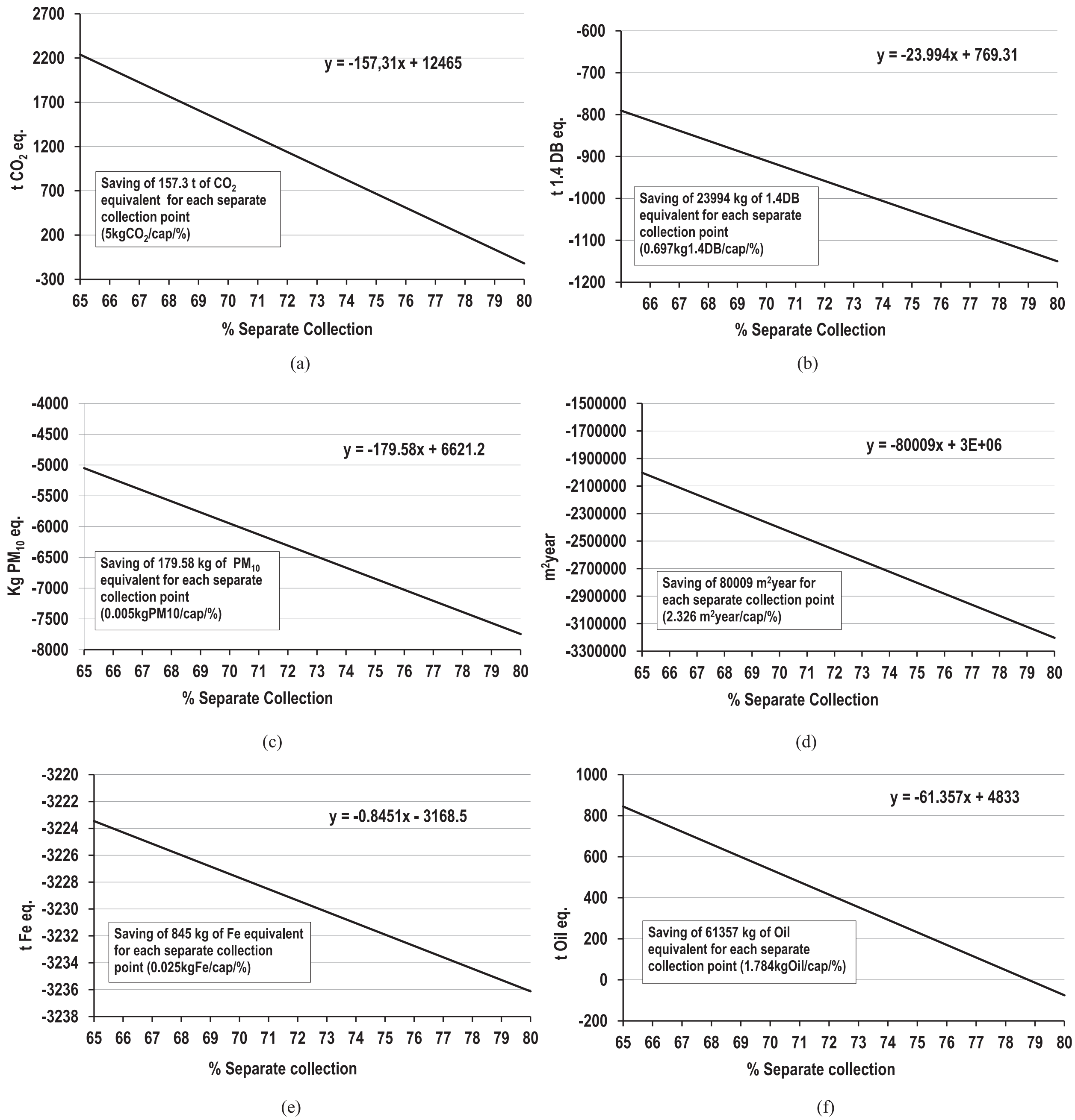

Figure 4. Environmental benefits arising from the potential increase in the source separation for scenario S2 in terms of ReCiPe 2008 H midpoint impact categories: *Climate change* (a), *Human toxicity* (b), *Particulate matter formation* (c), *Agricultural land occupation* (d), *Metal depletion* (e) and *Fossil depletion* (f).

considered are those that, at the endpoint level, provided a contribution to the total impact greater than 1%.

For each midpoint impact category considered, the reference function was calculated that allows one to obtain the environmental benefit in terms of avoided impact and per-capita avoided impact for one single point of separate collection.

The obtained results are very useful from an environmental policy perspective since they provide readily actionable information. For example, it is possible to show that each citizen can contribute to avoiding the emission of 5 kg CO_2 eq. (Figure 4(a)) as well as 5 g PM10 (Figure 4(c)) in the atmosphere by only increasing the source-separation level by 1%.

These types of environmental (Figure 4) and economic (Figure 1) indicators are very useful and powerful since they provide simple information, understandable to a heterogeneous and wide audience, even if they derive from a scientific study and complex calculations. The dissemination of such indices could be a powerful incentive towards the adoption of sustainable practices by citizens. In fact, they quantify, in a very comprehensible manner, the economic and environmental benefits related to the increase in the source separation. This is very important since the participation and involvement of the citizens are vital to obtaining an increase in the sustainability level in the waste management sector [30,31] through a greater effectiveness of the separate collection [32].

4. Limitations of the study

In the study, the economic benefits are calculated only in function of the revenue (€) for the recovered material, but the municipality has to consider also the costs' variation in the waste management, increasing the source-separation percentage for the calculation of the net revenues.

Regarding the environmental evaluation, we assumed linearity in modelling, even at high recycling rates.

5. Conclusions

This study combined economic and environmental aspects to evaluate the sustainability of a municipal solid waste management system. The economic–environmental approach was also used to evaluate the improvement margins of the system sustainability in function of the source-separation level, through the definition of four scenarios.

The study expresses the analytical scientific method in terms of economic and environmental indicators that are more simple and understandable for the non-scientific community in order to provide a useful tool for effective environmental communication programmes.

The economic analysis provided a quantification of the obtainable economic benefits for the population of the town under study in function of the separate collection percentage achievable. For example, with an increase of only three percentage points (from the current level of 62% up to the minimum required target of 65% in Italy), it could be possible to obtain an increase of 11% due to the economic benefits derived from greater material amounts to recycle. The gain could be increased by 40% if the separate collection reaches 80%.

The comparison among the environmental performance of the four considered scenarios showed that the higher the level of source separation was, the lower the overall impacts were. This occurred because, even if the impacts of the waste collection and transport increased, they were overcome by the avoided impacts of the recycling and composting processes.

Resources was the ReCiPe 2008 H damage category that influenced the endpoint result the most. The results obtained with the midpoint approach provided the quantification of the environmental benefits (in terms of avoided impacts) obtainable for each single separate collection point, for the impact categories considered. Moreover, the results were expressed in per-capita values, allowing one to show that the emission of 5 kg CO_2 eq. and 5 g PM10 in the atmosphere could be avoided by each citizen increasing the source separation by 1%.

The economic and environmental indicators defined in this study provide simple and effective information, useful for a wide-ranging audience inside a behavioural change programme. The dissemination of such indices could be a powerful incentive to obtain sustainable practices by citizens who can easily understand the economic and environmental benefits related to the increase in the waste source separation.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

[1] Desa A, Kadir NBA, Yusooff F. A study on the knowledge, attitudes, awareness Status and behaviour concerning solid waste management. Procedia Soc Behav Sci. 2011;18:643–648.
[2] De Feo G, Polito A. Using economic benefits for recycling in a separate collection centre managed as a "reverse supermarket": A sociological survey. Waste Manage. 2015;38:12–21.
[3] De Feo G, Ferrara C. Investigation of the environmental impacts of municipal wastewater treatment plants through a life cycle assessment software tool. Environ Technol. 2016;38(15):1–6.
[4] Curran MA. Life cycle assessment. Encycl Ecol. 2008;3:2168–2174.
[5] Foolmaun RK, Ramjeeawon T. Disposal of post-consumer polyethylenen terephthalate (PET) bottles: comparison of five disposal alternatives in the small island state of Mauritius using a life cycle assessment tool. Environ Technol. 2012;33(5):563–572.
[6] ISO 14040. Environmental management e life cycle assessment e principles and framework: international standard 14040. Geneva: International Standards Organisation; 2006.
[7] ISO 14044. Environmental management e life cycle assessment e requirements and guidelines. Geneva: International Standards Organisation; 2006.
[8] Bing X, Bloemhof JM, Ramos TRP, et al. Research challenges in municipal solid waste logistics management. Waste Manage. 2016;48:584–592.
[9] Bernstad A, Schott S, Wenzel H, et al. Identification of decisive factors for greenhouse gas emissions in comparative

life cycle assessment of food waste management – an analytical review. J Cleaner Prod. 2016;119:13–24.
[10] Jaunich MK, Levis JW, De Carolis JF, et al. Characterization of municipal solid waste collection operations. Resour Conserv Recycl. 2016;114:92–102.
[11] Liikanen M, Sahimaa O, Hupponen M, et al. Updating and testing of a Finnish method for mixed municipal solid waste composition studies. Waste Manage. 2016;52:25–33.
[12] De Feo G, Malvano C. Technical, economic and environmental analysis of a MSW kerbside collection system applied to small communities. Waste Manage. 2012;32:1760–1774.
[13] Li J, He X, Zeng X. Designing and examining ewaste recycling process: methodology and case studies. Environ Technol. 2017;38:652–660. doi:10.1080/09593330.2016.1207711.
[14] Menikpura SNM, Sang-Arun J, Bengtsson M. Assessment of environmental and economic performance of waste-to-energy facilities in Thai cities. Renewable Energ. 2016;86:576–584.
[15] Rigamonti L, Sterpi I, Grosso M. Integrated municipal waste management systems: An indicator to assess their environmental and economic sustainability. Ecol Indic. 2016;60:1–7.
[16] Duchin F, Levine SH. Industrial ecology. Encycl Ecol. 2008;3:1968–1975.
[17] Rigamonti L, Grosso M, Møller J, et al. Environmental evaluation of plastic waste management scenarios. Resour Conserv Recycl. 2014;85:42–53.
[18] Arena U, Mastellone ML, Perugini F. The environmental performance of alternative solid waste management options: A life cycle assessment study. Chem Eng J. 2003;96:207–222.
[19] Goedkoop M, Heijungs R, Huijbregts M, et al. ReCiPe 2008-A Life Cycle Impact Assessment Method Which Comprises Harmonised Category Indicators at the Midpoint and the Endpoint Level First Edition (Version 1.08), Report I: Characterisation. 2013 Available from: http://www.lcia-recipe.net
[20] Rigamonti L, Grosso M, Giugliano M. Life cycle assessment of sub-unit composing a MSW management system. J Cleaner Prod. 2010;18:1652–1662.
[21] De Feo G, Ferrara C, Iuliano C, et al. LCA of the collection, transportation, treatment and disposal of source separated municipal waste: A southern Italy case study. Sustain. 2016;8(1084):1–13.
[22] Herva M, Neto B, Roca E. Environmental assessment of the integrated municipal solid waste management system in porto (Portugal). J Cleaner Prod. 2014;70:183–193.
[23] Giugliano M, Cernuschi S, Grosso M, et al. Material and energy recovery in integrated waste management systems-An evaluation based on life cycle assessment. Waste Manag. 2011;31:2092–2101.
[24] Brogaard LK, Damgaard A, Jensen MB, et al. Evaluation of life cycle inventory data for recycling systems. Resour Conserv Recycl. 2014;87:30–45.
[25] Simon B, Amor MB, Földényi R. Life cycle impact assessment of beverage packaging systems: focus on the collection of post-consumer bottles. J Cleaner Prod. 2016;112:238–248.
[26] Chi Y, Dong J, Tang Y, et al. Life cycle assessment of municipal solid waste source-separeted collection and integrated waste management systems in Hangzhou, China. J Mater Cycles Waste. 2015;17:695–706.
[27] Yildiz-Geyhan E, Yilan-Çiftçi G, Altun-Çiftçioglu A, et al. Environmental analysis of different packaging waste collection systems for Istanbul–Turkey case study. Resour Conserv Recycl. 2016;107:27–37.
[28] De Feo G, Malvano C. The use of LCA in selecting the best MSW management system. Waste Manage. 2009;29:1901–1915.
[29] Cremiato R, Mastellone ML, Tagliaferri C, et al. Environmental impact of municipal solid waste management using life cycle assessment: The effect of anaerobic digestion, materials recovery and secondary fuels production. Renewable Energy. 2017. doi:10.1016/j.renene.2017.06.033.
[30] Polanec B, Aberšek B, Glodež S. Informal education and awareness of the public in the field of waste management. Procedia Soc Behav Sci. 2013;83:107–111.
[31] Malik NKA, Abdullah SH, Manaf LA. Community participation on solid waste segregation through recycling programmes in Putrajaya. Procedia Soc Behav Sci. 2015;30:10–14.
[32] Sukholthaman P, Sharp A. A system dynamics model to evaluate effects of source separation of municipal solid waste management: a case of Bangkok, Thailand. Waste Manage. 2016;52:50–61.