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Environmental, economic and social costs and benefits of a packaging waste management system: A Portuguese case study

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ABSTRACT

The impact of the management of packaging waste on the environment, economic growth and job creation is analyzed in this paper. This integrated assessment intends to cover a gap in the literature for this type of studies, using the specific case study of the Portuguese packaging waste management system (SIGRE).

The net environmental benefits associated with the management of packaging waste, are calculated using the Life Cycle Assessment methodology. The results show that, for the categories studied, the impacts associated to SIGRE's various activities are surpassed by the benefits associated to material and energy recovery, with special focus on recycling. For example, in 2011 SIGRE avoided the emission of 116 kt CO_2 equiv. – the equivalent carbon emission of the electricity consumption of 124.000 households in Portugal.

The economic impact of SIGRE is evaluated through Input–Output Analysis. It was found that SIGRE's activities also have a significant economic impact. For example, their added value are ranked amongst the upper third of the economic activities with highest multiplier effect at national level: this means that for each Euro of value added generated within SIGRE, 1.25 additional € are added to the rest of the economy (multiplier effect of 2.25).

Regarding the social impacts of SIGRE, the number of direct jobs associated with the system is estimated to be more than two thousand and three hundred workers. Out of these, 83% are connected to the management of municipal waste packaging (selective collection and sorting), 15% are connected to the management of non-municipal packaging waste and only 2% are connected to the Sociedade Ponto Verde (SPV, green dot society in English) – the management entity responsible for SIGRE.

In general terms, the results obtained provide quantitative support to the EEA (2011) suggestion that moving up the waste hierarchy – from landfilling to recycling – creates jobs and boosts the economy.

1. Introduction

A shift to a green economy – an economy that generates prosperity while maintaining a healthy environment and social equity among current and future generations (EEA, 2011) depends on the promotion of recycling, particularly if it enables reducing environmental impacts from raw material extraction and materials processing. As suggested by the EEA (2011), recycling generates jobs, provides business opportunities and ensures secure supplies of essential resources. However, understanding the contribution of recycling activities to the green economy is difficult – e.g. impact on employment – mainly because economic and environmental data are not structured for that particular focus.

A literature review finds that there is a consistent knowledge base associated to environmental assessment of waste management systems e.g. Lazarevic et al. (2010), Lenzen et al. (2010),

Abbreviations: EEA, European Environment Agency; ELCD, European reference Life Cycle Database; GDP, gross domestic product; GHG, greenhouse gases; GVA, gross value added; LCA, life cycle assessment; MWS, municipal waste systems; NACE, general nomenclature for economic activities; REC, recyclers; ROE, rest of the economy; SIGRE, Portuguese packaging waste management system; SPV, Sociedade Ponto Verde (Green Dot Society); UNEP, United Nations Environment Program; VIM, information and motivation value; VLR, net payback value; VPV, Valor Ponto Verde (green dot value); WIO, waste Input–Output; WMO, waste management operators.

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Table 1
Packaging waste quantities managed by SPV through SIGRE in 2011.

Flow/Material (t)	Steel	Aluminum	Wood	Paper and cardboard	Plastics	Glass	Others[a]	Total
Packages placed in the market								
Urban system	44.978	8.778	3.258	220.746	182.256	397.371	2.004	859.391
Extra-urban system	6.296	274	51.243	164.140	16.902	13.016	505	252.376
Total	51.274	9.052	54.501	384.886	199.158	410.387	2.509	1.111.767
Household packaging waste (municipal system)								
Recycling	18.676	840	4.516	104.907	47.933	210.422	0	387.295
Organic recycling (composting)	0	0	0	5.401	0	0	0	5.401
Energy recovery	0	0	215	27.105	42.715	0	0	70.036
Landfill	26.302	7.938	0	83.333	91.608	186.949	2.004	398.133
Total	44.978	8.778	4.732	220.746	182.256	397.371	2.004	860.865
Industrial and commercial packaging waste (Extra-urban system)								
Recycling	30.294	503	38.013	216.895	25.840	6.736	0	318.281
Unknown	0	0	11.757	0	0	6.280	505	18.542
Total	30.294	503	49.769	216.895	25.840	13.016	505	336.823
Total municipal + urban systems	75.272	9.281	54.501	437.641	208.096	410.387	2.509	1.197.688

[a] "Others" include materials such as textiles.

Merrild et al. (2008) and there are studies that combine both environmental and economical evaluation e.g. Larsen et al. (2012), Emery et al. (2007), Reich (2013). However, very few references combine environmental, social and economical tools in an integrative, triple-bottom line analysis of dedicated waste management systems (e.g. Klang et al., 2003). This paper contributes to fill this gap by offering a set of methodological approaches that contribute to quantify the environmental, economic and social impacts of the Portuguese integrated packaging waste management system, SIGRE.

The European Union Directive on Packaging and Packaging Waste (Directive 94/62/EC) was the precursor of SIGRE, which is managed by Sociedade Ponto Verde – Green Dot Society (SPV). SPV is a non-profit organization, which is owned by the companies that distribute products whose packaging falls within the scope of the Directive. In practice, SIGRE includes a circuit that ensures the collection, recycling and recovery of non-reusable packaging waste, organized and managed by SPV.

Currently, SIGRE comprises two subsystems with different management models: (1) management of household and small service companies packaging waste (municipal system); (2) management of industrial, commercial and big service packaging waste (extra-urban system).

In the municipal system, SPV provides financial support to the municipalities and/or its Municipal Waste Systems (MWS), to encourage the collection and/or sorting systems for packaging waste from households and small services' companies. This waste is sent to recycling through existing partnerships with pre-qualified recycling processors. The remaining packaging waste can be directed to composting, energy recovery or simply landfilled if there are no other options available. In the case of the extra-urban system, which processes wastes produced in industries, commerce and large service companies, SPV provides a financial incentive to certified waste management operators (WMO), which collects and transports this waste for recycling.

We estimate that 711 thousand tons of packaging wastes were sent for recycling out of a total of 1.198 thousand tons of waste packaging managed by SPV through SIGRE, as quantified in Table 1. If we consider the total amount of packaging placed in the market, these numbers imply an overall recycling rate of 64% and a recovery rate of 70%. If we consider the household packaging waste alone, the recycling and recovery rates stands at 46% and 54%, respectively.

This paper is organized in six sections, including this introduction. Section 2 presents the methodological frameworks adopted to support the quantification of the environmental, economic and social impact of the waste packaging management system. Sections 3–5 provide the main results obtained and Section 6 draws the main conclusions.

2. Methodological framework and data sources

2.1. Environmental assessment

The environmental assessment was performed using the methodology of life cycle assessment (LCA), which requires the compilation of data for the most representative material and energy inputs and outputs of the processes under analysis, and the evaluation of their associated environmental impacts (ISO 14040, 2006). For the present study, the Unit Function selected for reference was "total packaging waste managed by the SPV under SIGRE in 2011", which corresponds to the type of wastes presented in Table 1. It is important to remind that SPV manages all waste packaging that enters SIGRE, regardless if it is packaging from a financial contributor of the system or not.

LCA studies can adopt different approaches, namely the attributional or descriptive model and the consequentional model, presented for example, by Heijungs (2007), Tillman (2000), Thomassen et al. (2008) or Lund et al. (2010). Whereas the attributional LCA model is rather undisputed (theoretically founded by Heijungs, 2007), as discussed by Frischknecht and Stucki (2010), the appropriate approach to model the effects of a decision is still subject to debates. The main point of discussion is whether or not actual economic relations are followed to identify the suppliers in the situation after the decision has been taken. Some proponents of the consequential approach (Ekvall and Weidema, 2004) use market information and price elasticities to identify those suppliers that are affected by the decision and will increase or decrease their production. Others plea for the consideration of the actual (future) suppliers based on factual or anticipated economic business-to-business relationships (Frischknecht, 1998).

In this paper, the model adopted for the calculation of the environmental impacts associated with SIGRE was the "attributional model". Both municipal and extra-urban systems were modeled according to their 2011 setting, and co-products were taken into account by the "substitution by system expansion" or "avoided burden method" (Finnveden et al., 2009), considering the average primary route market consumption mix.

The "consequential approach" was used in scenario analysis of the avoided impacts resulting from the recovered packaging materials, as in the case of the electricity production, where the environmental profile resulting from the use of the average

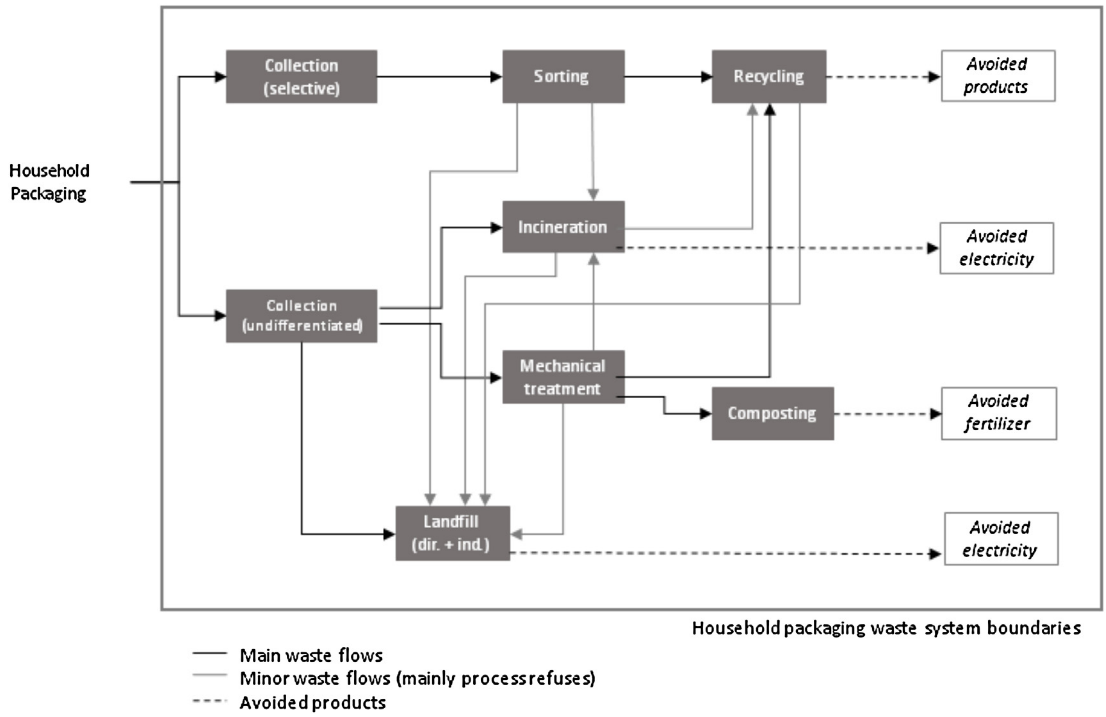

Fig. 1. System boundaries.

Portuguese electricity system was compared with current marginal technology, which is the natural gas fired power plant.

The “zero burden assumption” was also used, which means that it was considered that he waste carries none of the upstream burdens into the waste management system (Ekvall et al., 2007).

The system boundaries for both the municipal an non-urban system begin when the packaging waste is collected selectively or together with the remaining household waste (undifferentiated waste collection) and ends when those packages are effectively recovered (e.g. by recycling) or eliminated in landfills. Fig. 1 presents a schematic representation of the system boundaries, process and waste flows considered.

SIGRE manages a complex network of processes which include more than 130 distinct entities responsible for various unit operations management, which were organized in eight main clustered processes, as follows: (1) selective collection; (2) undifferentiated collection (concerns the packaging which is still recovered from the processing of undifferentiated waste); (3) sorting; (4) recycling; (5) energy recovery; (6) mechanical treatment; (7) organic recycling (composting and anaerobic digestion); (8) landfill.

The LCA model developed is based on an extensive characterization of the flows of energy and materials through the eight clustered processes previously mentioned, including the materials that constitute the packaging, namely: steel; aluminum; wood; paper/cardboard; plastics and glass. This was performed both for the municipal and extra-municipal management systems. The LCA modeling was done using the Simapro software, version 7.3, from PréConsultants (PRé, 2006a, PRé, 2006b, Pré Consultants 2006a,b,c).

The detailed analysis of the most important foreground processes constitutes the backbone of the life cycle inventory and was based on the following key sources. In terms of the selective and undifferentiated collection, the operational characteristics of SIGRE were derived from SPV internal data and other bibliographic sources (SPV, 2012a; Lavita, 2008; APA, 2011; Swiss Centre for Life Cycle Inventories, 2010), according with the packaging materials breakdown. For instance, the average diesel consumption for selective collection of glass and metals/plastics considered was 6.1 L/ton and 41.2 L/ton, respectively, and 5.27 L/ton for the undifferentiated collection (Santos, 2011).

The operational data to characterize the sorting process was based on SPV internal data and from Bovea and Powell (2006) and Pires et al. (2011) and includes electricity, water, lubrificants, diesel and steel wire consumption. The average sorting efficiencies in the sorting units of the municipalities, were 76.9% for metals and plastics, 96.2% for paper and cardboard and 95% for glass.

The mechanical treatment to which the undifferentiated household waste is subjected was also considered, since some packages are sorted in this process and delivered to recycling. The remaining ones are subjected to composting, energy recovery and landfill. In this process, the consumption of fuel, electricity and lubricants without the biological phase was considered, based on Pires et al. (2011).

The energy recovery processes were modeled according with the specific materials process included in the Eco-invent 2.2 database (Swiss Centre for Life Cycle Inventories, 2010) (e.g. energy efficiency from paper: 1.55 MJ/kg of electricity produced; energy efficiency from PET: 3.47 MJ/kg of electricity produced).

The avoided impacts resulting from the electricity production were modeled taking into account the environmental profile of the average Portuguese electricity system,[1] which was modeled for this specific purpose (REN, 2011). This is a conservative assumption: for example, the direct and indirect GHG emissions from the Portuguese electricity system, at medium tension in 2010, were calculated to be 263 g CO_2 equiv./kWh, which is significantly lower when compared to the emissions from natural gas power plants – the marginal technology – of 417 g CO_2 equiv./kWh). Finally, the reclamation of the bottom slag was also considered, since its steel

[1] Electricity mix for the Portuguese system (base year 2010): coal – 12.4%, natural gas – 20.3%, hydro, with reservoir – 12.3%, hydro, without reservoir – 18.5%, wind – 17.1%, solar – 0.4%, co-generation from various sources (biomass, waste, industrial natural gas, etc.) – 13.9%, imports – 5.0%.

Table 2
Recycling process characteristics.

		Pre-treatment efficiency (A)	Recovery efficiency (B)	Recycling efficiency ($A \times B$)	Secondary material	Avoided material	Substitution ratio
Steel	Steel from selective sorting	1	0.84	0.84	Ferrous metals	Pig iron	1
	Steel from energy recovery	0.8	0.84	0.67	Ferrous metals	Pig iron	1
Aluminum	Aluminum from selective sorting	1	0.93	0.93	Aluminum ingot	Aluminum ingot from virgin aluminum	1
	Aluminum from energy recovery	0.95	0.93	0.88	Aluminum ingot	Aluminum ingot from virgin aluminum	1
Wood							
Paper and cardboard	Paper and cardboard	0.86	1	0.86	Particle board	Plywood	0.60
	Liquid cardboard packages[a]	0.86	1	0.86	Recovered cardboard	Cardboard from virgin pulp	0.83
	EPS	0.86	1	0.86	Recovered liquid carton packaging board	Cardboard from virgin pulp	0.83
Plastics	LDPE	0.8	0.9	0.72	Recycled EPS lightweight soil	Virgin EPS lightweight soil	1
	Other plastics	0.8	0.9	0.72	Granules of LDPE	Granules of LDPE from virgin materials	0.81
	HDPE	0.8	0.9	0.72	Granules of PP	Granules of PP from virgin materials	0.81
	PET	0.8	0.9	0.72	Granules of HDPE	Granules of HDPE from virgin materials	0.81
	Mixed plastics	0.8	0.76	0.61	Granules of PET	Granules of PET from virgin materials	0.81
Glass		0.8	0.6	0.48	Outside furniture blocks from recycled mixed plastics	Outside furniture blocks from wood	1
		0.94	1	0.94	Glass cullet	Glass from virgin materials	1

[a] The cardboard fraction amounts to 75% of the Liquid cardboard packages (e.g. Tetra-Pak) mass.

Table 3
GHG avoided emissions per t of waste processed (ton CO_2 equiv./ton waste).

Process type	Steel	Aluminum	Wood	Paper and cardboard	Plastics	Glass
Recycling	0.98	10.7	0.21	0.21	0.71	0.44
Energy recovery	−0.01	−0.02	0.08	0.09	−2.3	−0.01

Notes: A negative value indicates a net emission of GHG. These values include the transport from sorting plants and other waste treatment units to the recycling plants and reflect the specific material mixes in each material type (e.g. plastics – EPS, LDPE, Other plastics, HDPE, PET, Mixed plastics). Taking into account the differences in terms of scope, these results are relatively conservative from the environmental point of view comparing with other sources (see for example MAOTDR (2007), Prognos (2008), EPA (2006), CEPA (2011)).

and aluminum content is recycled and included in SIGRE recycling rates.

The recycling modeling considered: (1) 14 different materials, classified in their six most important materials types, (2) the transport since its origin (sorting, energy recovery, undifferentiated mechanical treatment plants) to the recycling unit and (3) the open route and downcycling characteristics of the materials. The recycling processes characterization reflects data from various sources, namely SPV (2012a, 2012b), Rigamonti et al. (2009a, 2009b, 2010), Merrild et al. (2008), Pires et al. (2011), Lazarevic et al. (2010) and Swiss Centre for Life Cycle Inventories (2010), which were adapted to better reflect the Portuguese reality. In Tables 2 and 3 some characteristics of the recycling processes are presented.

The characteristics of the organic materials recycling process–composting – were based on Pires et al. (2010) for the electricity, fuel, water and other materials consumption and on Rigamonti et al. (2010) and Giugliano et al. (2011) for the avoided products associated with the use of compost.

The landfilling of the different materials was based on the ELCD 2.0 database (JRC and DG Environment, 2008), adapted to better reflect the Portuguese landfills, namely in terms of biogas and electricity production generated from the biodegradable packaging materials (paper and cardboard).

Finally, the background information used was mainly based on Ecoinvent 2.2 database (Swiss Centre for Life Cycle Inventories, 2010) and also, for specific processes the ELCD database (JRC and DG Environment, 2008), considering average European technologies. For the specific case of electricity production and consumption, for a more realistic modeling, the process used reflects not only the Portuguese electricity mix for 2010, but also the operation conditions of the Portuguese power plants and distribution system (efficiencies, emissions factors, etc.), as well as the breakdown and origin of imports (ERSE, 2011; REN, 2011).

The impact assessment was focused on five main environmental impact categories, namely: (1) Climate change; (2) Photochemical ozone formation; (3) Acidification; (4) Water resource depletion, and; (5) Mineral, fossil and renewable resource depletion.

The impact assessment considering these categories was based on the factors set forth in the characterization method ILCD 2011 Midpoint, version 1.01 (September 2012) by the Joint Research Center of the European Commission (JRC, 2012).

It should be noted that the LCA study conducted was based on the requirements of ISO 14040, 2006 and ISO 14044, 2006, published in 2006.

2.2. Economic assessment

The economic assessment of the SIGRE was performed using Input–Output (IO) analysis, which is a well-established technique to account for the indirect effects of economic activities (Miller and Blair, 2009) and has already been applied to waste management (Nakamura and Kondo, 2002; Barata, 2010).

The economic assessment considers that in the course of its economic activity, a firm uses resources, such as labor or imports – these are the direct impacts of the firm. A firm also purchases goods and services from other companies, which themselves are going to use resources (these are the first order indirect impacts of the first firm). These firms in turn make purchases to other firms, leading to second order indirect effects of the first firm, and so on. To understand how these indirect effects are calculated we must first describe the national economy.

Let matrix **Z** denote the set of transactions between sectors in the national economy and vector **x** denote total revenues by sector. Matrix **Z** and vector **x**, together with the final demand vector, **y**, and the vector of primary inputs, **v**, describe the set of transactions that take place in the national economy, and are connected as follows:

$$\mathbf{x} = \mathbf{Ze} + \mathbf{y}; \tag{1}$$

$$\mathbf{x}' = \mathbf{e}'\mathbf{Z} + \mathbf{v}', \tag{2}$$

where **e** is a vector of ones, all vectors are in column format by default and' denotes transpose. The following subsection describes the data sources for each element in **Z**, **x**, **y** and **v**.

The Leontief quantity model (Miller and Blair, 2009) assumes that industries generate output using a fixed production recipe, that is:

$$x_i = \sum\nolimits_j A_{iji} Z_{ij},$$

where each A_{ij} is a technical coefficient, and the matrix of technical coefficients, **A**,is calculated as:

$$\mathbf{A} = \mathbf{Z}[diag(x)]^{-1}. \tag{3}$$

In this study the indirect effects were quantified for quantities: gross value added (GVA), wages and total revenue (or income). For each of these, the type I Leontief multiplier (Miller and Blair, 2009), which quantifies the sum of direct and indirect effects resulting from the use of a unit of resource, was calculated:

$$m_i = \left(\sum\nolimits_j d_j L_{ij}\right) / di, \tag{4}$$

where i and j are sectors, d_j is the direct coefficient, and indicates the use of resource over total revenue, and L_{ij} is an element in the Leontief inverse matrix, which is calculated as follows:

$$L = (I - A)^{-1}, \tag{5}$$

where **I** is the identity matrix.

SPV charges a fee (VPV, translated as Green Dot Value) to those that place packages in the market. It then uses this financial source to support the end-of-life processing system, namely the MWS and other entities, thus promoting the recycling of packaging waste. The MWS are responsible for guaranteeing the collection, separation and treatment of both packaging waste and undifferentiated municipal solid waste.

The materials sorted for recycling are auctioned by SPV, which receives (or pays, in some cases) a net payback value (VLR) from/to recyclers, for the recycling operations to be effective. In addition, SPV also offers an information and motivation financial incentive (VIM) to the managers of non-urban waste that collect packaging

Table 4
Interaction between SIGRE and the rest of the economy.

Z	ROE	SPV	MWS	REC	**y**
ROE	A	B	C		E
SPV	F			G	
MWS		J			K
REC	L				
v'	O	P	Q		

waste directly from industry and transport them to recycling, for them to provide SPV with the accounting of those materials.

The model developed to study the economic impact of SIGRE involves four sectors: the SPV, the MWS sector, the recyclers (REC) and the rest of the economy (ROE). This model is described in Table 4, which indicates the non-zero elements of **Z**, **x**, **y** and **v**. The table is read in the usual format whereby rows describe the source and column the destination. For example, B contains the purchases of SPV to the rest of the economy whereas contains the purchases of the rest of the economy to SPV. A more detailed account of the nature of the flows in each element and a description of data sources and data processing are found below.

- Modeling of the rest of the economy – ROE

The sector ROE (components A, E and O of Table 4) was modeled using the 2008 basic prices symmetric product-by-product Input–Output tables of the Department of Prospective Planning and International Relations (Dias and Domingos, 2011), with an aggregation of 85 sectors using the official Portuguese NACE Rev.3 two digit classification (INE, 2007). Investment was endogeneized using table C.3 of the National Accounts[2] with the method described in Lenzen and Treloar (2004).

- Modeling of packaging waste management – SPV

The economic impact of SPV was modeled using the 2009 activity report (SPV, 2009). Components *B e P* are purchases of SPV to other companies and primary factors; component F is the VPV fee paid by package producers (which are taken as a subset of ROE); component *G* is the VLR payment received by SPV from recyclers; component *J* is the financial support given by SPV to the waste management sector.

- Modeling of the Municipal Solid Waste Management Sector – MWS

MWS represents the collection and sorting of packaging waste as the financial incentive for these activities represents more than 90% of total payments from SPV to the municipal waste sector.

The management of undifferentiated solid waste is a part of NACE 37. Components *C*, *K* and *Q* of Table 4 were modeled from the following sources. Cruz et al. (2012) presents general information about the current costs and depreciation associated to packaging waste collection and sorting. Expenditure was disaggregated by type of product and service using the characterization of Lavita (2008) for collection and of Rodrigues (2009) for sorting. Both Lavita (2008) and Rodrigues (2009) analyze small-scale case-studies, that were extrapolated to the national ensemble using complementary information provided in SPV (2010), which describes the physical flows of waste for each municipality.

The studies mentioned in the previous paragraph addressed mostly expenditure on investment and current use goods. To estimate expenditure on human resources and ancillary costs such as machine repair, consulting, electricity, etc. we used additional sources: the report of the Portuguese Regulatory Entity for Water and Waste (ERSAR, 2011) describes economic flows for some municipal solid waste companies; LIPOR (2010) provides a well-detailed accounting report; and the Waste Input–Output table, described by Nakamura and Kondo (2002).[3]

- Modeling of recycling sectors – REC

The Recycling sector was split into four material categories: paper and wood, plastic, glass and metals (steel and aluminum). Each category was modeled as being technologically similar to the corresponding sector in ROE which produces the same commodity (these are, respectively, NACE 17, 22, 23 and 24). We considered that the magnitude of each recycling sector relative to the corresponding non-recycling sector was given by the ratio of the VLR payment to the total amount of intra-sectoral transactions.

For computational purposes, each recycling activity branch was modeled as a subsector within the non-recycling activity branch, and REC becomes an intermediate sector, which receives the VLR payment from SPV and delivers it to the corresponding material sector, with no additional revenue or expenditure. Thus, entry L in Table 4 was modeled directly from SPV (2009).

2.3. Social assessment

The social assessment was focused on the characterization of the employment generated by SIGRE activities. The longitudinal analysis draws on the population of companies and organizations collaborating with SPV from year 2000 to 2009.

Information on the partner companies was provided by SPV and organized according to the specific type of relationship they have with SPV: MWS; WMO; REC; and, since there are entities that accumulate two functions, we may have REC/WMO; and MSW/WMO.

Additional data on SPV partners – namely NACE code, foundation year and location – was collected in a website specialized in corporate information.[4] Specific information on workers and companies and economic activity originates from Quadros de Pessoal – a unique micro data set gathered from mandatory information submitted yearly by private Portuguese firms to the Ministry of Social Security and Labor. The longitudinal matched employer-employee data include extensive information on firms, establishments and workers for the period in analysis (2000–2009). Quadros de Pessoal includes yearly data for all private establishments with at least one wage-earner in the Portuguese economy. Firms and workers in each annual survey are fully linked and tracked over time through the use of a unique identification number, thus allowing for the recognition of industrial and labor market dynamics.

The data collection process was hindered for various reasons: for some companies there were several locations attributed (different addresses for the headquarters and plants); some firms have more than one economic activity code attributed (sometimes there is one primary sector of economic activity and several different secondary activities); the legally founding year was not the same as the start-up year (it may happen in the case of a merger and acquisition). Consequently, from the initial list of partners, we were able to find complete and rigorous information on about 75% of the companies economically related to SPV.

The sample was broke down into different reference groups: one group composed of SPV partner companies, a counterfactual group including those companies that are not SPV partners but operate

[2] (http://www.ine.pt).

[3] (http://www.f.waseda.jp/nakashin/WIO.html).

[4] (http://www.netresiduos.com).

on the same industry, and a third group composed of all the companies that are not SPV partners (regardless of their industry or economic activity). For confidentiality reasons, information at the company and worker level is not reported individually; hence data and results are aggregated into the aforementioned groups (SPV partners; non-SPV among same industry; non-SPV).[5]

3. Environmental Impacts – main results

The environmental impacts and benefits of SIGRE, are quantified in Table 5, by type of packaging material, where negative values correspond to avoided environmental impacts. The results presented include the direct and indirect emissions resulting from the operation of the system, i.e. include for example, direct emissions resulting from disposal of packaging waste into landfill, as well as indirect emissions associated, for instance, with the production of the electricity that is consumed in the packaging waste sorting operations.

The relative importance of each material to the outcome of the environmental impacts in 2011, shows that the materials contributing the most to the overall benefit of SIGRE are glass and paper/cardboard. For instance, the contribution of glass to the environmental performance of the system varies between 29% and 58%, except for the category mineral, fossil and renewable resource depletion, which is relatively minimal.

The relevance of glass and paper/cardboard in terms of SIGRE's environmental performance in 2011 is due to the combination of two factors: first, the high quantity of these materials that were managed in 2011 in comparison to other materials (848 kt in a total of 1.198 kt managed) and secondly, the benefit resulting from their recovery. For example, in relation to climate change category, this benefit was estimated at 435 kg CO_2 equiv./t of recycled glass packaging.

The results presented in Table 6, quantify the relative importance of each clustered process for the overall contributions of the environmental impact of packaging waste in 2011, and show that recycling of packaging waste is the key process in avoiding environmental burdens for all the environmental impact categories.

The results show that, overall and for the 5 impact categories presented, the management of packaging waste in SIGRE presents an environmental benefit, i.e. the impacts generated by the various activities of collection, sorting, transport, treatment, disposal and recovery of waste are offset by impacts avoided due to the material and energy recovery processes.

The good performance of recycling results from the balance between the impacts generated by the recycling of packaging waste (e.g. consumption of natural gas to melt the glass), and the benefits associated to incorporating secondary materials into new products, thus avoiding the use of virgin raw materials. Overall, the net result of the various management operations in 2011 is estimated to represent an environmental benefit of approximately 115.9 kt CO_2 equiv.

In order to assess the relative merit of the current system, the environmental impacts of urban waste management within SIGRE in 2011 (Baseline 2011 scenario), were compared with two hypothetical alternative scenarios:

- "Landfill Scenario" – consideres that all packaging waste would be collected and sent to landfill.
- "Energy recovery Scenario" – considers that all packaging waste would be collected and sent for incineration.

[5] A list of all the NACE codes considered for SPV partners and used for the purpose of the present analysis can be delivered upon request to the authors.

The evaluation was performed for the same mix and quantities of waste that have been effectively managed in 2011 under SIGRE and based on the same technologies, and function as "what-if scenarios" built to evaluate the benefits/impacts of current management of packaging waste, in face of extreme scenarios SIGRE configuration. Note that for the sake of simplicity, the analysis did not take into account the implications that such nonlinear scenarios could lead to the level of technological infrastructure (e.g. construction of new landfills, incinerators, etc.). The results obtained are quantified in Table 7.

The results presented in Table 7 shows that the "Baseline 2011" set is the only one that reduces environmental impacts across all categories. The "Energy recovery scenario" generates increases climate change impacts, while the "Landfill scenario" is the worst option, with a clear increase of all impact categories.

For example, with regard to climate change category, the "Baseline Scenario 2011" entails the reduction of GHG emissions equivalent to about 116 kt CO_2 equiv., while the scenarios "Landfill" and "incineration" represent, respectively, the emission of about 285–280 kt CO_2 equiv., and this clearly demonstrates the benefits of the current system.

4. Economic impacts – main results

At an international level, there are few studies available that quantify the economic impact of specific waste management systems. The UNEP estimates that the waste management industry as a whole, in 2011, accounted for 0,16% of the Gross domestic product (GDP), or about 108 billion dollars, and could triple in value by 2050 (UNEP, 2011).

In more specific terms for the waste recycling sector, for example, NRC (2001) evaluated the multipliers associated with recycling in the United States and compared them with those of other industries, estimating a multiplier effect of 2.43 for GVA.

Another study, developed by the Australian council of recyclers, found that the multiplier varied widely according with the type of material considered. Thus, for each Australian dollar invested in recycling aluminum, $ 1.08 additional dollars were created indirectly (multiplier of 2.08) (Inside waste, 2008).

In this section we assess the economic impact of SIGRE in the Portuguese economy, in terms of gross value added, wages and total revenue. The effect on GDP of an alternative scenario in which SIGRE is absent is analyzed. Finally, an uncertainty analysis is presented.

Table 8 presents the type I multipliers obtained for SIGRE and for representative sectors of Portuguese economy. Each row indicates the total impact on the national economy (direct and indirect) associated with one unit of resource use in a particular sector, where the resources considered are GVA, wages and total revenue. For example, for each Euro of value added generated in SIGRE 1.25 €, are added to the rest of the economy (multiplier effect of 2.25). Moreover, for every Euro of wages paid by SIGRE, an extra 1.30 € of wages are paid for in the rest of the economy. Finally, for each Euro of turnover in SIGRE an extra 1.04 € of turnover circulate in the rest of the economy.

The analysis of SIGRE multipliers offers a global view of the role of packaging waste management in the economy. Concerning added value, SIGRE occupies the 28th position in 88 branches of economic activity and in terms of wages it is ranked in the 25th position and concerning total revenues it occupies the 32nd position. It can be concluded that this sector has a significant impact in the economy, given that it is positioned among the upper third of sectors with highest multiplier effect. These results are consistent with previous studies, which show that the GVA multiplier of recycling in the USA is 2.43, the wage multiplier is 2.18 and total revenue is 1.7 (NRC, 2001).

Table 5
Material contribution for the environmental impacts and benefits of SIGRE in 2011.

Impact category	Unit	Steel	Aluminum	Wood	Paper and cardboard	Plastics	Glass	Total
Climate Change	kg CO_2 equiv.	−4.98E+07	−1.43E+07	1.61E+06	−1.83E+07	4.92E+07	−8.44E+07	−1.16E+08
Photochemical ozone formation	kg NMVOC equiv.	−1.04E+05	−2.78E+04	−7.16E+04	−3.24E+05	−1.89E+05	−6.15E+05	−1.33E+06
Acidification	mol H+ equiv.	−2.20E+05	−7.70E+04	−9.80E+04	−5.59E+05	−2.36E+05	−1.63E+06	−2.82E+06
Water resource depletion	m^3 H_2O	−7.27E+04	−8.99E+03	−1.72E+04	−3.64E+05	−2.67E+04	−1.99E+05	−6.89E+05
Mineral, fossil & renewable resource depletion	kg Sb equiv.	2.13E−05	−4.92E−03	−1.35E−03	−3.69E+01	2.61E−03	−7.29E−02	−3.70E+01

Table 6
Process contribution for the environmental impacts and benefits of SIGRE in 2011.

Impact category	Units	Selective collection	Undifferentiated collection	Sorting	Energy recovery	Mechanical treatment	Recycling	Organic recycling	Landfill	Total
Climate Change	kg CO_2 equiv.	2.3E+07	8.6E+06	1.6E+06	9.7E+07	3.3E+05	−3.3E+08	−1.5E+05	8.2E+07	−1.16E+08
Photochemical ozone formation	kg NMVOC equiv.	1.3E+05	7.0E+04	1.2E+04	3.0E+04	4.0E+03	−1.7E+06	−7.9E+01	1.2E+05	−1.33E+06
Acidification	mol H+ equiv.	1.1E+05	5.7E+04	1.1E+04	−9.5E+02	3.2E+03	−3.1E+06	−6.3E+02	1.0E+05	−2.82E+06
Water resource depletion	m^3 H_2O	6.9E+03	2.4E+03	2.0E+03	2.0E+04	1.0E+02	−7.3E+05	−4.8E+01	5.6E+03	−6.89E+05
Mineral, fossil & renewable resource depletion	kg Sb equiv.	6.0E−03	2.0E−03	1.5E−04	−5.5E−04	3.9E−05	−3.7E+01	−1.7E−03	−4.0E−04	−3.70E+01

Table 7
Comparative analyses of different waste management scenarios.

Impact category	Units	Baseline 2011	Landfill scenario	Energy recovery scenario
Climate Change	kg CO_2 equiv.	−1.16E+08	2.85E+08	2.80E+08
Photochemical ozone formation	kg NMVOC equiv.	−1.33E+06	4.97E+05	−6.45E+04
Acidification	mol H+ equiv.	−2.82E+06	3.81E+05	−8.46E+05
Water resource depletion	m^3 H_2O	−6.89E+05	2.10E+04	−1.94E+04
Mineral, fossil & renewable resource depletion	kg Sb equiv.	−3.70E+01	2.33E−03	−3.68E−02

SIGRE has several components: the managing entity (SPV), the MWS and the recyclers of the different types of material. From the analysis of Table 8 it is clear that SPV has a strong impact on value added and wages. This result is due to the fact that the use of primary factors of production represents only a small proportional of the total turnover of SPV. MWS has multipliers lower than two because waste collection and sorting require few purchases of goods and services to other sectors, when compared to primary factors, such as labor and financing costs. Regarding recycling, metals and paper the highest indirect effect is on value added and wages. Concerning total revenues there is a smaller variation of the multiplier by type of material. These results are consistent with the literature (NRC, 2001; EIERA, 2005).

Table 9 shows the type I multipliers of SIGRE, disaggregated by the activity branch where the indirect impact takes place. Concerning GVA, the greatest impact is on the MWS sector. Of 1.25 € of GVA indirectly generated in the economy by one euro of SIGRE, 64 cents are in the MWS sector, 34 cents in the paper and paper products sector, 12 cents in the rubber and plastic sector and 9 cents in building construction and wholesales. The wage multiplier exhibits a similar pattern. Concerning total revenues, the greatest impact is on paper and paper board, followed by MWS.

Globally, MWS, paper, plastic, building construction, gross sales and electricity are the sectors which benefit the most (directly and indirectly) from the activity of SIGRE.

Table 8
Multipliers (€/€), of SIGRE and representative sectors of the Portuguese economy.

Sectors	GVA	Wages	Total revenue
Sea transport	3.82	3.94	2.63
Distribution of natural gas	3.34	8.38	2.02
Manufacture of chemicals and chemical products	2.85	2.86	1.97
Manufacture of coke and refined petroleum products	2.34	2.81	1.26
Crop and animal production, hunting and related service activities	2.28	2.90	2.33
Telecommunications	2.03	3.18	2.10
Manufacture of fabricated metal products, except machinery and equipment	1.93	1.78	1.88
Repair and installation of machinery and equipment	1.84	1.77	1.82
Real estate, except renting and operating own real estate	1.79	5.30	2.50
Silviculture, forestry and related service activities	1.43	2.10	1.66
SPV	5.35	10.11	1.99
MWS	1.32	1.31	1.65
REC Paper	2.84	3.07	2.33
REC Plastic	2.09	2.03	1.84
REC Glass	2.34	2.28	2.20
REC Metals	3.14	3.29	1.96
SIGRE	2.25	2.30	2.04

Table 9
Disaggregation of SIGRE type I multiplier by sector (€/€), selected values.

Sector	GVA	Wages	Total revenue
MWS	0.643	0.733	0.317
Manufacture of paper and paper products	0.340	0.292	0.410
Manufacture of rubber and plastic products	0.121	0.134	0.135
Construction of buildings	0.089	0.101	0.083
Wholesale trade, except of motor vehicles and motorcycles	0.088	0.102	0.056
Electricity, gas, steam and air conditioning supply	0.075	0.033	0.111
SPV	0.070	0.037	0.191
Manufacture of other non-metallic mineral products	0.069	0.075	0.064
Financial services activities, except insurance and pension funding	0.060	0.054	0.028
Civil engineering	0.059	0.074	0.064
Land transport and transport via pipelines	0.058	0.074	0.045
Repair and installation of machinery and equipment	0.049	0.059	0.039
Silviculture, forestry and related service activities	0.038	0.012	0.017

Table 10 shows the leveraging of SIGRE on selected sectors, in absolute terms. Leveraging is understood here as the monetary value associated to the indirect effects of a given sector on the rest of the economy. The total leveraging of SIGRE is 147 million € in GVA, 80 million € in wages and 391 million € in total revenues. These values can be placed in perspective by noting that the direct impact of SIGRE is, respectively, of 117, 61 and 377 million €.

Globally, the sector which benefits the most from the leveraging of SIGRE is the MWS sector (25 million € of GVA, and 15 million € of wages). Afterwards there are several sectors external to SIGRE, related to investment (e.g. building construction) and utilities (e.g. electricity, with an effect of 42 million €). Within the sectors that form SIGRE, paper benefits from the highest leveraging, after the MWS.

4.1. Analysis of alternative scenarios

In contrast to the current scenario in which there are incentives to packaging waste recycling, we assessed the effect on the added value of an alternative scenario in which SIGRE would not exist. The effect on GVA of this alternative scenario was modeled as follows:

Variation of GVA = $A + B + C + D$, where each term A, B, C and D is given below:

- A (Effect of removing the VPV fee):

In the absence of SIGRE, package producers are not entitled to pay the VPV fee. To assess the effect that this reduction in production costs has on household consumption two limit cases were considered. First, if the product price remains constant, the value added of packaging firms increases. This provides additional income to the owners of production factors. Second, if the reduction of production costs is manifested in a decrease in product prices, consumers additional disposable income to spend. Thus, we considered that the consumption bundle of the average consumer remains unchanged and that the VPV savings are translated directly as an increase in average household consumption. The increase in final demand stimulates the consumption of domestic and imported products: the former contributes to value added while the latter does not. Considering a VPV of 56 million € (SPV, 2009), the net effect of the increase in demand due to the elimination of the VPV fee is estimated in +45 million €.

- B (Effect of municipal waste management costs):

In the alternative scenario, the packaging waste which is currently recycled needs to be treated. We considered that packaging waste would be treated as conventional municipal solid waste. That means an increase in the costs of municipal solid waste collection and treatment (incineration and landfill), which must be supported by municipalities and households, reducing the income available for consumption. According to Cruz et al. (2012), the average cost of treating packaging and municipal solid waste is, respectively, 189 and 103 €/ton. Considering a total volume of packaging waste of 458.324 ton (SPV, 2010), and a financial support of 60 million € from SPV to MWS (VC-RS, VC-CI and VIC), households support the collection and sorting of packaging waste in 26 million €. In the alternative scenario the treatment of this waste volume would be fully supported by households, in the amount of 47 million €. Considering that this increase translates as a reduction in household consumption of 21 million €, the net effect on GVA would be of −17 million €.

- C (Effect of the operation of municipal solid waste treatment):

In the alternative scenario the GVA of the SPV and MWS sectors (respectively, 8 and 51 million €) disappears. The 458.324 ton of packaging waste currently processed by SIGRE would be treated

Table 10
Selected values of SIGRE's leveraging by sector (million €).

Sector	GVA	Wages	Total revenue
MWS	24.78	14.83	39.37
Construction of buildings	10.39	6.23	31.46
Wholesale trade, except of motor vehicles and motorcycles	10.30	6.26	21.27
Electricity, gas, steam and air conditioning supply	8.79	2.05	42.01
Financial services activities, except insurance and pension funding	7.00	3.29	10.72
Civil engineering	6.87	4.57	24.07
Land transport and transport via pipelines	6.76	4.56	17.15
Repair and installation of machinery and equipment	5.76	3.62	14.81
Manufacture of machinery and equipment n.e.c.[a]	4.28	2.85	13.38
Manufacture of paper and paper products	2.94	1.33	11.43
Manufacture of chemicals and chemical products	2.02	1.06	11.08
Manufacture of coke and refined petroleum products	0.85	0.33	15.61

[a] n.e.c – not elsewhere classified.

using the same technology as the 5.227.402 ton of municipal solid waste (SPV, 2010). This change implies an increase of 9% in the GVA currently generated by the municipal solid waste sector.

Considering a cost of MSW of 103 €/ton (Cruz et al., 2012) and the total of MSW mentioned above, the total cost of MSW treatment is 538 million €, which represents 21% of the total expenditure of NACE 37. Because the GVA of NACE 37 is 977 million €, we considered that the GVA of MSW treatment is 202 million €. Thus, the addition of 458.324 ton of MSW in the alternative scenario leads to an increase of GVA of 18 million €.

The net effect on GVA is −41 million €.

- D (Effect of eliminating recycling of packaging waste):

In the alternative scenario, the sectors which currently use packaging waste as production factors will need to replace them by virgin raw materials. We assumed that the market price of secondary products is similar to that of the main products which they replace, taking into account the loss of quality of recycled products (Nakamura and Kondo, 2002). Additionally, we considered that these replacing raw materials are imported. Thus, we obtain a reduction of GVA of 37, 13, 6 and 3 million € in the sectors of paper, plastic, glass and metals.

These values were obtained considering that the ratio between the GVA of the recycling sub-sector and the aggregate activity branch equals the ratio between VLR and the value of intra-sectoral transactions of the aggregate activity branch. Paper recycling is a sub-sector of NACE 17, plastic recycling of NACE 22, glass recycling of NACE 23 and metal recycling of NACE 24. The net effect on GVA results in −58 million €.

The overall effect of these different factors is a net reduction of GDP of 71 million € in the alternative scenario (absence of packaging waste separation and recycling).

4.2. Uncertainty analysis

An uncertainty analysis was performed using Monte–Carlo integration. It was assumed that the aggregate values (vector **x**) are error-free while interior points (matrix **Z** and vectors **y** and **v**) have errors given by:

$$e(t)/t = at^{-b}, \tag{7}$$

where $e(t)$ is the error, t is the datum, and $a = 0.165518$ and $b = 0.05160$ are parameters determined so that the relative error of the smallest datum is 30% and the relative error of the largest datum is 10%. The choice of this functional form reflects the empirical observation that there is a decrease in uncertainty with the magnitude of the datum (Lenzen, 2001) and the choice of the limit-values is taken from a study performed for Portuguese official data in 1995 (Nhambiú, 2004), and is consistent with international studies (Bullard and Sebald, 1977; Lenzen et al., 2010).

Errors were generated assuming a normal and independent distribution for each datum (Lenzen et al., 2010). To ensure that no negative number is generated but that the expectation is the datum t, only realizations in the range between 0 and $2t$ were accepted. After an initial configuration was obtained, it was balanced using the RAS method (Lahr and de Mesnard, 2004).

Using Monte–Carlo integration, for each configuration the desired multipliers were calculated and the uncertainty estimates were obtained using the descriptive statistics:

$$E[m] = \left(\sum_j mj\right)/n; \tag{8}$$

$$Var[m] = \left(\sum_j (m_j - E[m])^2\right)/n, \tag{9}$$

where E[m] and Var[m] are the expected value and variance of a multiplier, m_j is a realization of the multiplier and n is the number of realizations. Finally, the multiplier uncertainty is:

$$e(m) = (Var[m])^{0.5}. \tag{10}$$

The largest uncertainty for each type I multiplier calculated was 13% for GVA, 19% for wages and 8% for total revenue. The corresponding values for the disaggregation of SIGRE multiplier are 28%, 30% and 25%. Finally, for the case of leveraging, these values are 29%, 30% and 26%.

5. Social impacts – employment

While at the global level, UNEP estimates that at least 20 million jobs in activities related to waste management and 15 million people in the developed world depending on garbage for their livelihood (UNEP, 2011), there are very few studies that focus on specific waste streams, as the one presented here, which includes an analysis both at the firm and the worker levels.

In the Portuguese case study, the number of companies associated with SPV has increased significantly over the last decade (2000–2009), independently of their typology. While in 2000, there were 87 companies with a formal connection to the SPV; in 2009 the number rose to 138 companies, which translates into a growth of about 60%.

Companies associated with SPV have, on average, higher initial capital than companies not associated with the SPV from the same sectors of economic activity. Typically, companies associated with SPV have a higher percentage of foreign capital than other firms in the Portuguese economy; the same holds true for public participation in initial capital. Regarding company size – measured in both number of employees and sales turnover – it can be concluded that companies associated with SPV are larger than their counterparts (i.e., the same sectors of economic activity) not associated with the SPV. Companies associated with SPV employ between six and seven times more workers than other companies in the Portuguese economy. In financial terms, results point to a relationship of five to six times higher sales turnover among SPV partners compared with non-SPV partners. This difference is more pronounced in 2002 and 2009, where the ratio is seven times higher than in 2000 and particularly where the difference reaches a ratio nine times higher.

Typically, a SPV partner company employs about 20% of female workers, while a non-SPV partner company employs roughly the double. However, the most relevant aspect of comparing the profiles of workers in “SPV partner companies” with “non-SPV partner companies” relates to the compensation of employees, which are considerably higher in the former. One factor that may explain this difference is that the employees from SPV partner companies have greater seniority. From this comparative analysis other aspects can be recognized as being relevant for the economy and labor market dynamics; namely, the fact workers from SPV partner companies are older and possess more educational attainment (measured in years of schooling) than workers from non-SPV partner companies. The owners of the SPV partners have an average number of years as employer rather inferior to non-SPV partners. The data show that, over time, SPV partners have been slightly increasing the hiring of foreign workers and women and there is a significant decrease in the average number of workers per firm.

Between 2000 and 2009, there was a decrease in the average number of workers for the case of RPP’, while MWS’ and WMO’ showed a reverse trend. The latter tended to hire more women and, in recent years, there was also a greater recruitment of foreign workers. REC’ seem to favor older workers and especially workers with higher seniority, i.e. years of experience in the company. In terms of qualifications, in 2000, the average number of years of education was higher in WMO', and by the end of the last decade, this aspect has changed significantly since, for example, in 2009, workers employed by REC' are those with higher qualifications.

6. Conclusions

This paper provided a comprehensive methodological framework to quantify the net environmental, economic, and social impacts a dedicated waste management system. This methodology was applied to the case study of the Integrated waste packaging management system (SIGRE), managed by Sociedade Ponto Verde (SPV).

In the case of the environmental dimension, it was found that SIGRE contributes to decrease the impacts of the various categories. For example, the functioning of SIGRE in 2011 avoided the emission of 116 kt CO_2 equiv., which is an amount equivalent to the carbon sequestered by 386.000 pine trees for 30 years. Its contribution becomes even more evident when compared to alternative scenarios of energy recovery and landfilling – it is the only alternative that presents a positive environmental outcome in all impact categories For example, SIGRE would avoid the emission of 396.240 ton CO_2 equiv. in 2011, when compared to a scenario where packaging waste is collected indiscriminately with other waste and sent for energy recovery (see Table 7).

At an economic level, considering the companies that operate within SIGRE, it was found that, on average, they had in 2009 a capital of 2.3 million € and generated an average sales volume of 11.7 million €. In the latter aspect, this means that these businesses have a 6.4 times greater turnover than the average value added of the economic sectors to which they belong. Also, it was concluded that for each Euro of value added generated in SIGRE, 1.25 € are additionally generated in the rest of the economy; for each Euro of wages 1.30 € are additionally paid in the rest of the economy; and for each Euro of total revenue 1.04 € additionally circulate in the economy.

The total leverage of SIGRE, understood as the monetary value of the indirect effects of the various industries that comprise SIGRE in other sectors of the economy, is 147 million € in GVA, 80 million € in salaries and 391 million € in turnover.

It is estimated that the level of direct employment associated to SIGRE amounts to more than 2300 jobs, which is equivalent to 0.08% of employment in non-financial companies in Portugal. Of these, 83% work in the management of municipal waste packaging (in particular in the activities of selective collection and sorting), 15% are work in the management of non-municipal packaging waste and only 2% work for SPV.

In conclusion, this paper presents a quantitative indication of the EEA (2011) conjecture: at least in the Portuguese case-study of packaging waste, moving up the waste hierarchy – from landfilling to recycling – does indeed create jobs and boost the economy.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.resconrec.2013.10.020.

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