Integrated Environmental Assessment and Management — Volume 11, Number 3—pp. 373–382

Beyond the Throwaway Society: A Life Cycle-Based Assessment of the Environmental Benefit of Reuse

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(Submitted 5 June 2014; Returned for Revision 24 September 2014; Accepted 12 December 2014)

Special Series

EDITOR'S NOTE:

This paper represents 1 of 7 articles in the special series "LCA Case Study Symposium 2013," which was generated from the 19th SETAC LCA Case Study Symposium "LCA in market research and policy: Harmonisation beyond standardization," held in November 2013, in Rome, Italy. This collection of invited papers reflects the purpose of the symposium and focuses on how LCA can support the decision-making process at all levels, that is, in industry and policy contexts, and how LCA results can be efficiently communicated and be used to support market strategies.

ABSTRACT

In the context of a circular economy, sustainable consumption is often seen as the antithesis of current consumption patterns, which have led to the definition of the so-called throwaway society. Reuse may provide a preferred alternative to other waste management options, because it promotes resource efficiency and may significantly reduce environmental impacts. To appraise the environmental benefits related to reuse of goods, a methodology adopting life cycle assessment (LCA) has been developed. A standardized procedure has been developed, identifying reference products within product category subject to reuse, and collecting reliable inventory data as a basis for calculating environmental impact through LCA. A case study on a second-hand shop is presented, and the avoided impacts are quantified. Inventory data were taken both from the literature and directly from sales and surveys submitted to customers. The results are presented, highlighting: 1) for each product category, the average avoided impacts for 1 unit of reused product considered; and 2) for the overall activities of the second-hand shop, the cumulative avoided impacts in 1 yr. In the case study, the higher contribution to avoided impacts comes from the apparel sector, due to the high amount of items sold, followed by the furniture sector, because of the high amount of environmental impacts avoided by the reuse of each single item. *Integr Environ Assess Manag* 2015;11:373–382. © 2015 SETAC

Keywords: Reuse   Life Cycle Assessment   Second-hand shops   Circular economy   Avoided waste

INTRODUCTION AND STATE OF THE ART

An efficient and sustainable use of resources is at the heart of sustainable production and consumption strategies and policies (EC 2011). A culture of sustainable consumption and lifestyles is seen as the antithesis of current modes of consumption, which have led to the so-called throwaway society (Evans 2012). In fact, statistics from the Organization for Economic Cooperation and Development have shown a steady increase in waste production over time (OECD 2013); according to projections for the year 2020 (OECD 2008), 45% more waste is expected to be generated compared to 1995. Within current consumption patterns, many products become waste when there is still a potential for reuse.

At the international level, it is considered crucial to strengthen 3 R policies (reduce, reuse, recycle) and to bring life cycle-oriented assessment into the mainstream—to increase resource productivity (OECD 2008, 2011). The European Union Waste Framework Directive (EU WFD) (EC 2008a) aims at targeting policy interventions toward the 3 R hierarchy, while requiring that moving up in the hierarchy is mediated by both technical efficiencies and economics.

Reuse (which is at the top of the hierarchy) is defined by the EU WFD as "any operation by which products or components that are not waste are used again for the same purpose for which they were conceived." Reuse and sharing economy ("using instead of owning") have been gaining more mass media attention recently. Indeed, the number of economic activities, either formal or informal, related to reuse is constantly increasing (Han 2013; Guiot and Roux 2010). In the present study, we consider the definition of reuse as applying mainly to the consumer waste sector, although examples of reuse in an industrial context also exist (e.g., Schraven et al. 2012). These activities include car boot sales, charity shops, vintage shops, pawn shops, specialist second-hand retail chains, online auctions (e.g., eBay), and the integration of online selling (e.g., Amazon), as well as manufacturing and wholesale and retail activity involving reused products (Gregson et al. 2013).

Second-hand shopping is also a system in competition with traditional retail outlets (Hibbert et al. 2005), which implies

All Supplemental Data may be found in the online version of this article.

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Published online 30 December 2014 in Wiley Online Library (wileyonlinelibrary.com).

DOI: 10.1002/ieam.1614

the existence of retail expectations that traditional channels cannot satisfy (Guiot et al 2010). Surveys of consumers' purchasing attitudes as well as the quantity and types of goods have been conducted. In the United Kingdom, Gregson et al. (2013) focus on car boot sales; in Australia, Lane et al. (2009) confirm the importance of both formal and informal channels for the circulation of second-hand goods. Cervellon et al. (2012) analyze the determinants behind the choice of a second-hand product. A Eurobarometer report (Gallup 2011) states that 72% of Austrians are willing to buy second-hand products, and online exchange is booming.

Actually, the reuse benefits may involve all the sustainability pillars. Socioeconomic benefits may complement environmental avoided impacts. The environmental benefits of reuse are mainly associated with the fact that reuse requires fewer resources, less energy, and less labor, compared with recycling, disposal, or the manufacture of new products from virgin materials (WRAP 2011). This explains why reuse is at the top of the waste hierarchy as a preferred alternative compared to other waste management options. Indeed, reuse promotes resource efficiency and reduces air, water, and soil pollution because of the production stage. In addition, the product categories (such as textile products, furniture, etc.) and the quantities that are possibly suitable for reuse are significant. For example, in US landfills, 4% of the waste consists of unrecovered textiles that are almost 100% recyclable, whereas only 15% of US clothes are currently recycled. In the EU, clothing accounts for between 2% and 10% of consumers' environmental impacts (EIPRO project, Tukker et al. 2006); therefore, the impact associated with unrecovered textiles may be relevant. Other studies report that 50 to 60 000 tons of goods annually are exchanged through car boot sales in England. Baby- and child-related goods are the primary category exchanged by number of purchasers and by weight (Gregson et al. 2013).

Reuse may also confer socioeconomic benefits. On the one hand, reuse provides disadvantaged segments of populations with second-hand goods that are cheaper than new ones. On the other hand, many reuse centers are engaged in programs for the handicapped or at-risk youth programs and on the job training programs (ReDO 2012). Increasingly, reuse also represents a relevant new niche of business beyond "charity and thrift shops" and a fundamental element of the circular economy. For example, Gelbmann and Hammerl (2014) described an innovative business model based on reuse, considering that ecologically oriented work integration social enterprises focusing on reuse may constitute a novel kind of Sustainable Product–Service System (SPSS). This may also involve international trade (Brooks 2013).

Given the potential relevance of the phenomenon, the analysis of environmental benefits of waste reduction and prevention options requires the identification of specific methodologies of appraisal. Among the possible environmental impact assessment methodologies, life cycle assessment (LCA) is considered more suited to assess reuse given its ability to cover comprehensively product life cycle stages. Life cycle thinking (LCT) represents the backbone of several policies at the European level (e.g., EC 2005, 2011, 2008a,b) and at the international level (e.g., UNEP 2004, 2012). Life cycle-based methodologies (LCA, life cycle costing, and social life cycle assessment) are recognized as the most appropriate methodologies to assess the environmental, economic, and social benefits of sustainable production and consumption practices (Sala et al. 2013).

State of the art: the environmental assessment of reuse

Some attempts to assess the environmental benefits of reuse have been made in recent years. So far, the studies have adopted several appraisal approaches: 1) a purely mass-based approach, assessing the tonnage diverted from disposal (or landfill), based on the weight of goods estimated to be flowing through the system; 2) energy balance and carbon footprint assessment; 3) composite indicators (e.g., ecological footprint); and 4) LCA. Comprehensive approaches using LCA have been quite limited. A purely mass-based approach has been most widely used (e.g., Gregson et al. 2013).

Energy balance and the carbon footprint have been assessed for several products. Krikke (2011) studied reuse of personal computers and laptops and showed a 50% reduction of 50% reusing a hardware, and Williams et al. (2008) assessed the environmental, economic, and social implications of global reuse of personal computers. Other studies have focused on the reuse of household textiles and clothing (e.g., McGill et al. 2010; Woolridge et al. 2006 who assessed cotton and polyester), furniture (Alexander et al. 2008), toys, and baby clothes (Waight 2013 who used the ecological footprint approach). Tsiliyannis (2012) considered reuse from an industrial perspective. Reused or remanufactured products become multiple cycle products when they are returned for reuse or remanufacturing by the manufacturer at the end of each cycle (e.g., printers, mobile phones, etc).

More comprehensive LCA studies are now limited to the following: Farrant et al. (2010) who assessed the reuse benefit associated with a cotton T-shirt and a pair of polyester (65%)/cotton (35%) trousers (in terms of global warming potential, acidification, eutrophication, ozone depletion, and photochemical ozone formation); and Ljundgren Soderman et al. (2011), who compared reuse with various recycling options (accounting for climate change, acidification, eutrophication, and energy demand).

An LCA-based evaluation of a variety of products (clothing, furniture for household and office, electronic devices) has been conducted in the United Kingdom (WRAP 2011). Different reuse scenarios were assessed focusing on environmental, social, and economic impacts of reuse within the United Kingdom. The indicators selected were global warming potential, resource consumption, and cumulative energy demand related to environmental issues. In addition, in terms of the social impact, the number of employees involved in the reuse sectors has been assessed, and, in terms of the economics, a cost–benefit analysis of reuse practice has been conducted.

There are limitations to the current assessment of reuse benefits. The present study aims to present a methodology for systematic assessment of reuse practices, based on a life cycle approach and using LCA methodology to quantify the associated overall environmental benefits. Methodological challenges to such an assessment are also discussed.

The present study was developed within a project promoted by a nongovernmental organization (NGO), the Cooperativa Mani Tese, which has a long experience in the collection and reselling of used objects, with the aim of reducing the environmental burdens associated with household consumption and promoting socially sustainable networks.

In the next section we explain our methodology as well as the assumptions adopted for the case study, involving product selection, life cycle inventories, shop sales data, percentage of product substitution, and the life cycle impact assessment adopted.

METHODOLOGY

In the present study, we evaluate the potential environmental benefits related to reselling and reuse of second-hand products through a case study of a second-hand shop in Italy. The methodology builds on WRAP guidelines (2011) and integrates 2 crucial aspects: 1) a different method is used to consider the rate of substitution (i.e., direct survey of customers instead of modeling several possible scenarios based on the life length of the items); and 2) a broader range of impact categories is considered, including impacts not directly associated with material or energy resource depletion (e.g., toxicity-related impacts). The case study stemmed from the RIUSI-AMO project, which was developed in cooperation with Cooperativa Mani Tese. The aim of the project was the quantification of avoided impacts as a result of 1 yr of activity of the second-hand shop located in Gorgonzola, Italy, and managed by the Cooperativa Mani Tese.

The Mani Tese shop receives used items as donations from private people. The items are sold in the shop at a low price and are usually bought by people who cannot afford new items. The revenues are used to finance international cooperative projects developed by the Mani Tese NGO. The shop is interested in both socioeconomic and environmental benefits.

To quantify the environmental benefits of shop activities, an LCA methodology was adopted according to International Organization for Standardization (ISO) guidelines 14040 and 14044.

An LCA was considered the most valuable method (of several options) for the scope of the present study because it allows identification of benefits associated with reuse in a comprehensive fashion, as requested by the European Commission Waste Directive (EC 2008).

Evaluation of the environmental benefits was based on the LCA for estimating the avoided impacts. This consists of 2 phases: 1) calculation of average avoided impacts for 1 unit of reused product in each product category considered; and 2) calculation of the cumulative avoided impacts generated during 1 yr by a second-hand shop, through the selling of second-hand products, as partial or total substitution of new ones. The cumulative avoided impacts are estimated by multiplying the avoided impact for a single product by the number of products sold during 1 yr and subtracting the impacts that were a result of reuse activities (only through transport of goods from the users' homes to the second-hand shop, as there is no impact after sale (see *Phase 1: Inventory* section for details). Figure 1A and B illustrates the 2 phases, and Table 1 reports the methodological assumptions.

Each methodological step is described below, with details on specific assumptions for the case study application.

Phase 1

Categorization of products. Second-hand shops usually sell several kinds of products, and, because of the nature of the shops, there can be high variability among products in the same category in terms of shape, weight, and material. Therefore, a selection of some representative products for each product category sold is needed.

Representative products were selected during a visit to the Mani Tese second-hand shop and a meeting with the shop managers. The products were chosen considering first, quantity sold in 1 yr (e.g., T-shirts and sweaters are the items of apparel most sold in the Gorgonzola shop) and second, the potential environmental impact (e.g., among household items, wine glasses can have high impact because of the glass)

The objects selected for the case study were thus T-shirts and sweaters for the apparel sector, sofas and sideboards for the furniture, glasses for furnishing accessories and fancy goods, and books for recreational objects.

Inventory. For each of the representative products selected, inventory data were collected through a literature review (Supplemental Data, Tables S1–S6). The system boundaries considered were the same for all representative products. They include extraction and transport of raw materials and auxiliary materials, energy consumption and emissions attributable to the stages of production, waste production, transport from the production site to the user, and finally the transport user at the Mani Tese shop in Gorgonzola. The only impacts associated with reselling are those related to the transport of the products from the first owner's home to the Mani Tese shop. The reason is that the shop does not prepare any items for reuse (e.g., washing of clothes, repairing of furniture) and only accepts items that can be directly resold; therefore, the storehouse has negligible energy consumption (no heating and very little energy consumption as a result of cash registers and lighting).

Therefore, the inventory for each product category was as follows: the life cycle stages related to the first life of an item (i.e., from raw materials through manufacturing to distribution to the end user) are considered as avoided impacts, whereas the only additional impact associated with the reuse is the transport from the user to the second-hand shop. This transport was assumed to cover an average distance of 10 km (based on information provided by the shop managers) and to be carried out by private car, the only exception being transport of furniture, which is by a van. The system boundaries are shown in Figure 2.

The life cycle of these objects was built using average data from the literature. An overview of the data collected and the assumptions made for the inventory of each product category is provided in the Supplemental Data.

Average avoided impacts. An LCA for reference products can be performed with data collected in the inventory phase (the main data source for inventories is Ecoinvent 2.2, integrated with data from the literature; details available in the Supplementary Data). In the case of complete substitution of new products by second-hand ones, LCA results can be considered as a proxy of avoided impacts conferred by the action of buying second-hand products instead of new ones.

For assessment of avoided impacts, according to WRAP (2011), we assumed that in case of complete substitution, 100% of the impact of extracting resources from the environment, manufacturing, and transporting a product shall be allocated to the first life of the product. However, this assumption applies only to products that effectively substitute for new ones. In fact, as already pointed out by previous studies (e.g., Farrant 2010), in some cases the purchase made at a second-hand shop is an additional buy rather than a substitution for a new item.

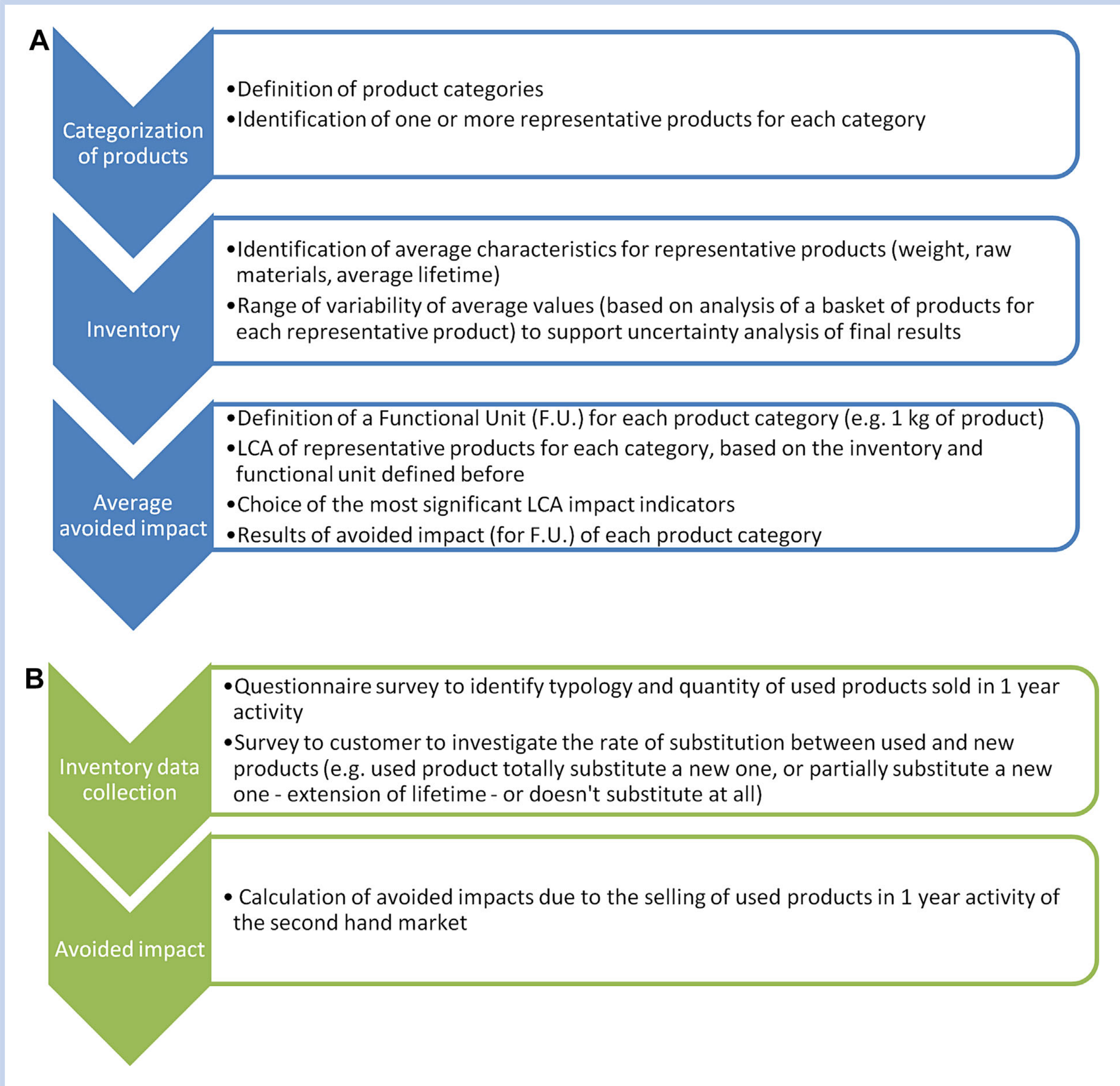

Figure 1. (**A**) Flowchart of methodology for calculation of average avoided impacts because of reuse of products (for F.U.) (phase 1). (**B**) Flowchart of methodology for calculation of avoided impacts as a result of 1 yr of activity of second-hand shops (phase 2). LCA = life cycle assessment.

Therefore, in the present study not all the products sold by the second-hand shop are supposed to substitute for new one. The rate of substitution of the total amount of products sold in the shop is derived by direct survey of customers (see *Phase 2* section for details and Table 3 for survey results). Hence, only a portion of the total amount of products sold is considered for assessment of avoided impacts that can be attributed to the activity of the shop.

The Joint Research Centre of the European Commission has launched the International Reference Life Cycle Data System (ILCD) to develop technical guidance that complements the ISO Standards for LCA and provides a basis for greater consistency and quality of life cycle data, methods, and LCA studies. Within this system, recommendations for a best practice characterization framework, models, and factors have been published. Therefore, the methodology adopted for life cycle impact assessment is the ILCD 2011, as recommended by the Joint Research Centre (EC-JRC 2011; Sala et al. 2012), because this system represents a reference methodology for product evaluation in an EU context (Wolf et al. 2012). In addition, we focused on energy resources, using the cumulative energy demand method.

The quantification of potentially avoided impacts (in case of 100% substitution) for each representative product was done using SimaPro 7.3 (PRé Consultants, The Netherlands), starting from the inventory data collected in the previous phase and using the life cycle impact assessment (LCIA) methods ILCD 2011 Midpoint and Cumulative Energy Demand v. 1.07.

Phase 2

Data collection from the Mani Tese second-hand shop. The case study was performed by undertaking extensive data collection to calculate the cumulative avoided impacts (i.e.,

Table 1. Basic methodological assumption related to the calculation

LCA phase	Assumptions
Goal and scope	According to WRAP 2011, we assumed that 100% of the impact of extracting resources from the environment, manufacturing and transporting a product shall be allocated to the first life of the product. However, not all the items sold by the second hand shop are assumed to substitute a new one. The rate of substitution of the amount of products sold is derived by direct survey to customers. The impact is calculated using a bottom-up LCA approach instead of a top-down (input-output) because of the source of data (not economic data at regional level, but specific data coming from assessment of single products). All products are considered to be reused without any preparation for reuse (as defined in the European Waste Framework Directive, 2008/98/EC).
System boundaries	Local supply of items to be reused is assumed. The transport phase of items delivered to the charity shops is considered negligible as the items usually come from municipalities close to the shop location (max 10 km).
Inventory - data quality	The hierarchy of data sources requires the collection of primary data as much as possible. Secondary data come from the ecoinvent database v.2.2.
Life Cycle Impact Assessment	ILCD (EC-JRC 2011) impact assessment method is used for all the product categories

the cumulative benefit). We aimed at assessing the overall benefit of reuse by collecting information on:

- The type and quantity of second-hand objects sold by the shop in a defined period (1 yr, in the Mani Tese case study)
- The rate of substitution between used objects and new ones. There can be 3 options when a second-hand item is bought: 1) the second-hand product totally substitutes for a new one; 2) the second-hand product partially substitutes for a new one, but will not cover its whole lifespan (i.e., there is an extension of lifetime for theproduct); and 3) the used product doesn't substitute for other products (i.e., there is no impact avoided).

Processing of survey data allowed us to identify the percentages of replacement for each product category. As it was not possible to obtain reliable data about any rate of substitution below 100%, in the present study only the first option (100% substitution) is considered. If customers stated that the item bought at the shop would not substitute totally for a new one, then that item was not considered in the study. Therefore, the results obtained should be considered conservative in terms of environmental impacts avoided.

Data on the quantity of items sold by the shop were retrieved from sales receipts. A sample period of 4 mo (January to April 2013) was used. The sample period can be considered representative for the whole year, because there is no variability in the quantity sold during the year (the variability is higher within the same month, because the average customers of the shop usually have low income, so people have more money to spend at the beginning of the month rather than at the end).

Data from sales receipts need to be elaborated because the categories used for sales receipts are slightly different from the ones used for the present study. First, the item "bicycle" is grouped with furniture and needs to be subtracted from the total furniture revenues before counting the pieces of furniture sold. Second, within the category "objects," several types of objects are included. We considered only the item "glasses," which accounted for 1% of the total revenues in this category, so only 1% of the revenues in this category has been considered for the next step.

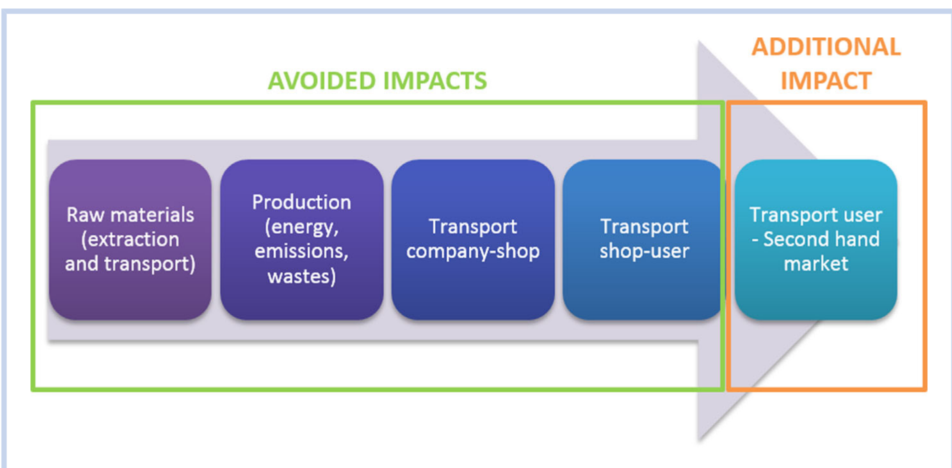

Figure 2. System boundaries considered for each item included in the study.

In addition, some assumptions were made about the representativeness of the selected items with reference to the whole product category.

Among the total of apparel items sold, 50% were supposed to be T-shirts and 50% sweaters. The actual percentage of T-shirts and sweaters sold among apparel items was 20% (10% each); the upscale was done considering the representativeness of the materials used (cotton, in the T-shirt category, and wool and viscose in the sweater category) with reference to the other apparel items (e.g., wool and viscose coats and trousers, cotton shirts and skirts)

After the 5% of bicycle revenues were subtracted, the remaining 95% of furniture revenues was assumed to be represented by sofas (50%) and sideboards (50%). The percentage for sofas is close to the actual percentage of sales, whereas sideboards were assumed to represent all the other pieces of furniture sold (medium and small furniture items, made of medium-density fiberboard, laminated timber, and glass)

Because the variability (in terms of types of products and materials used) among the furnishing accessories and fancy goods sold in the shop is very high, this category was partially excluded from the evaluation. The item "glass" was considered representative only for a portion of the category, and therefore only the percentage of glasses sold (1% of the sales from this category) was considered for the accounting of the substitution.

After these corrections, the revenues for each category of products were compared with the average price of the items in that category, to obtain an estimation of the total number of units sold over 1 yr.

Collection of data on the rate of substitution was made from January to February 2013 through a survey questionnaire administered to 414 customers of the Mani Tese second-hand shop (Supplemental Data, Annex 1). Customers interviewed were asked: 1) to indicate the type of item purchased; 2) whether the item(s) purchased at the shop replaced one or more items purchased at another store; 3) whether the second-hand item completely replaced a new one, or whether it was just a temporary delay of a new purchase, and 4) the hypothetical lifetime of the used object purchased (months or years).

Avoided impacts of the second-hand shop. As explained previously (Figure 1A and B), the second-phase of the study involved calculation of avoided impacts attributable to the existence of the second-hand shop Mani Tese, during 1 yr of activity. Data on the number of items replaced in each category during 1 yr of activity of the second-hand shop, collected in the previous step, were multiplied per the average avoided impact per unit of item, to get the average avoided impacts for each product category as from the results of phase 1. Cumulative avoided impact values for the case study were obtained.

RESULTS

The results obtained in each phase of the methodology are presented below.

Inventories

All inventory data for the representative products (i.e., T-shirt, sweater, sofa, sideboard, book, and glass) are summarized in the Supplemental Data, Tables S1–S6. Data include raw materials, energy, emissions, and transports to the first user.

Average avoided impacts for representative products

Figure 3 illustrates the potentially avoided impacts (in case of 100% substitution) conferred by the substitution of 1 unit of the representative items selected. In all cases, impacts from transportation of the item to the second-hand shops was already added to the avoided impacts related to the first life of

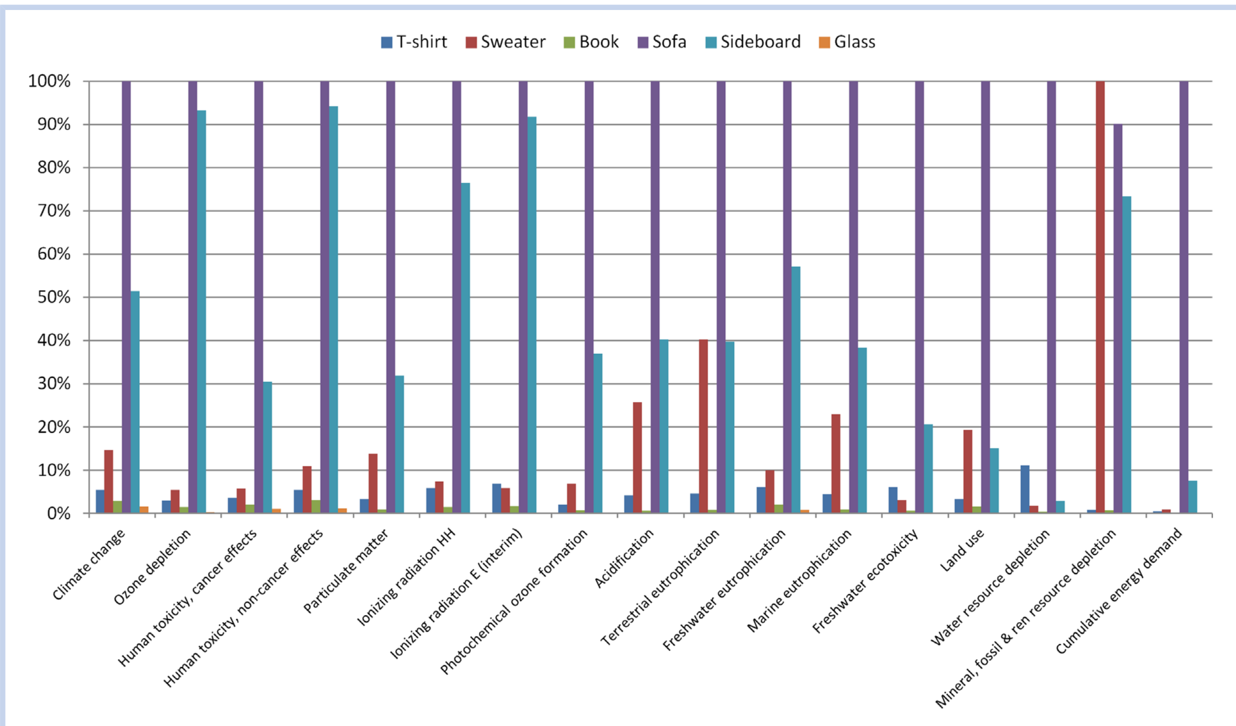

Figure 3. Relative impact results for 1 unit of each representative item selected (methods ILCD 2011 Midpoint and Cumulative Energy Demand v. 1.07).

the item. Therefore, the results presented in Figure 3 can be considered the net benefit associated with 1 unit of each representative product sold for reuse. Detailed data are reported in the Supplemental Data, Table S7. Furniture, primarily the sofa, has the highest impact in almost all the impact categories. The only exception is for the category "mineral, fossil, and renewable resource depletion," for which the sweater has the highest impact. This is mainly because of the production of feed (i.e., agricultural activities) for the sheep that provide wool. This aspect should be further explored in the future to obtain more detailed information.

Regarding energy consumption, there is a huge difference between the sofa and the other items considered, because of the high amount of electricity needed to produce each of the components of the sofa and to process them during production. The book and the glass generate environmental impacts that are negligible compared with the sofa and sideboard impacts. This is mainly the result of the amount of materials needed to produce the item: because a relevant fraction of the impacts comes from the production of raw materials, the lower the amount of materials used, the lower the impacts attributed to the final product.

It is worth noting that comparison among the different items is intended only with reference to their contribution to the environmental benefits generated by the second-hand shop. A deeper analysis aimed at comparing the relevance of the items in absolute terms should also consider the differences in weight and lifespan among the items considered.

Shop data

Tables 2 to 4 illustrate shop sales data, the percentage of substitution of new items declared by the customers interviewed, and the amount of items replaced during 1 yr of shop activity, which was calculated accordingly.

Avoided impacts for the shop

As noted before, data for the amount of new items that were 100% replaced by second-hand items and bought by customers of the Mani Tese shop during 1 yr were multiplied to get the avoided impact conferred by each single item replaced. The results represent the cumulative amount of avoided impacts conferred by 1 yr of activity at the shop. The results are illustrated in Figure 4. Absolute values are reported in the Supplemental Data, Table S8.

The activity of the Mani Tese second-hand shop can contribute to a reduction in environmental impacts from the production of goods, for example, through the saving of approximately 160 tons of CO_2eq, of 7 000 000 MJeq of energy, the avoided emission of 170 kg of $PM_{2.5}$eq, the reduction in acidification and eutrophication potentials, and many other impacts. The highest contribution to avoided impacts comes from the apparel sector, due to of the high amount of items sold, followed by the furniture sector, because of the amount of items sold but also the high amount of environmental impacts avoided by the reuse of each single item.

DISCUSSION AND CONCLUSIONS

The results on the potential avoided impacts for each type of item considered would suggest promotion of the sales of larger items, such as furniture, which would generate the highest benefits for units sold. This, however, could raise management issues (e.g., the need for a larger storage space) and could limit the total sales of the shop—because the sales records of the Mani Tese shop demonstrate that small items like T-shirts, sweaters, and glasses can be sold more easily—and so could reduce the total benefits generated. Moreover, the cumulative results over 1 yr of shop activity show that if small items (such as apparel) are sold in large quantities, they can provide relevant benefits in absolute terms.

The Cooperativa Mani Tese used the results obtained from the present study with a 2-fold aim. First, the Cooperativa aimed at a better understanding of how to manage the shop to maximize the social, economic, and environmental benefits of its activity. This has been made possible not only by the results showing the amount of environmental benefits generated by the items sold, but also because for the first time the Cooperativa had the opportunity to analyze sales records and identify the relevance (in terms of economic revenues and environmental benefits) of the different types of items received and sold by the shop.

Second, the Cooperativa aimed at communicating the environmental value (in addition to the social one) of the shop activities, through communication campaigns addressed to customers and local policy makers. Customers can be gratified by the fact that their purchase is not only a way to save money, but also an environmental action, that is, a way to contribute to the sustainability of the community.

Table 2. Amount of items sold by Mani Tese second-hand shop in the sample period (January-April 2013) and in 1 year

Product category		A. Revenue January-April (€)	B. Adjusted revenue (€)	C. Average price (€)	D. Items sold in January-April 2013 (B/C)	E. Items sold in one year (D/4 * 12)
Furniture	Sofa	14 597	13 868	75	93	278
	Sideboard				93	278
Apparel	T-shirts	15 801	–	5	4740	4740
	Sweaters				4740	4740
Books		3574	–	2	1787	5361
Furniture accessories (including glasses)		15 000	150	0.5	300	900

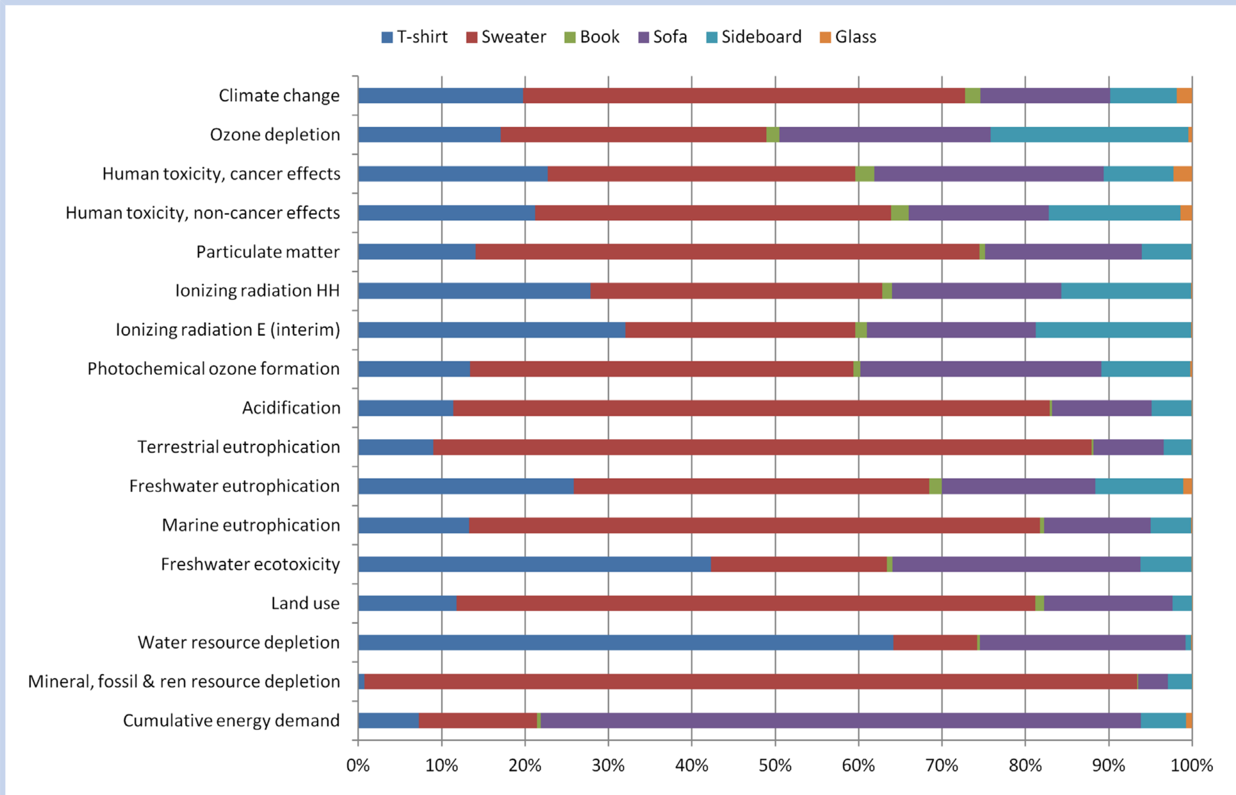

Figure 4. Avoided impacts for 1 yr of activity of the second-hand shop. The contribution of each product category is highlighted in percentages.

As for the methodology, the amount of environmental impacts avoided through the Mani Tese shop may be underestimated, for the following reasons: 1) only total substitution was considered in the accounting, including the impacts avoided by partial replacement would increase the benefits generated by the shop; and 2) the LCIA methods applied include elementary flows and impact factors for only a limited number of resources; in addition, biotic resources were completely ignored (Klinglmaier et al. 2014), for example, the avoided wood cut for the production of furniture is not accounted for in the evaluation.

Integrating the evaluation with a purely mass-based analysis, such as Material Flow Analysis or Total Material Requirement, for example, could help us to better understand the overall resource efficiency (in terms of amount of resources used for a unit of product) associated with reuse, even if such analyses are methods of resource accounting and do not take into account resource scarcity. Conversely, the choice of representative items for each category is an approximation in terms of materials and energy used, which contributes to the uncertainty of the cumulative results. Indeed, the possibility of reducing the potential impacts should be based on different strategies, namely, expansion of the product categories and selection of different reference products for each category. This may support the identification of best and worst cases (i.e., minimum and maximum values in the inventory) for each product category.

As mentioned before, published studies on LCA of the reference products could differ in terms of the system boundaries, the assumptions made (e.g., inclusion or exclusion of packaging materials or transport operations, consideration of transport distance) and the LCIA method used, that is, the methods may not be directly comparable. Therefore, the main aim of the present study was to define a standardized methodology based on identification of reference products for each product category that has to be evaluated, so as to be able to collect reliable inventory data and to perform fully comparable LCA studies. In this context, the existence of product category rules can help to identify the baseline scenario for reference products.

The results highlight the need for future research aimed at reducing uncertainties. This entails expanding our current

Table 3. Rate of substitution of the items, as resulting from the survey

The item purchased in this second-hand-shop replaces the purchase of a new one (100% rate)?				
Product categories	**NO**	**YES**	**Answers**	**Replacement rate (%)**
Furniture	53	28	81	34.57
Apparel	48	43	91	47.25
Books	37	3	40	7.5
Glasses	4	21	25	84

Table 4. Amount of items replaced during one year of activity of the Mani Tese second-hand shop

Product category		E. Items sold in one year (D/4*12)	F. Replacement rate (%)	G. Total items replaced in one year (E*F)
Furniture	Sofa	278	34.6	96
	Sideboard	278	34.6	96
Apparel	T-shirts	4740	47.3	2240
	Sweaters	4740	47.3	2240
Books		5361	7.5	402
Furniture accessories (including glasses)		900	84	756

basket of reference products, including best and worst case in terms of product performance and exploring various logistic options .

- In terms of the LCA implementation, there is a need to improve both the inventory and the impact assessment phase: for the inventory, better results may be achieved by: 1) having data on more products, including not only the average but also the range of their environmental profile (from best to worst performers); and 2) modeling inherent processes of the reuse practice (e.g., transport to and from the reseller).
- In terms of the impact assessment, future research may show even more favorable aspects of reuse, as current LCIA methods sometimes lack comprehensive coverage of all the possible impacts and avoided impacts (Sala et al. 2012). For example, the number of chemicals or resources covered by current methods is only part of those actually used in producing a product. Hence, the reuse of those products may imply even more benefits.

Nevertheless, the proposed methodology has proved to be useful to evaluate comprehensively the environmental benefits of reuse of goods, especially in light of the emerging market of second-hand products, not only for charity purposes but also as a growing commercial segment. Indeed, the study can serve as a base for future replication of the project in other areas, within and outside Italy, and in similar contexts (e.g., to quantify the environmental benefits of retail chains of used items). The application of the methodology in other contexts may also support the use of the results for policy support on a larger scale.

The systematic assessment of environmental benefits associated with reuse may support and steer prevention and reuse policies at various levels, especially in the context of resource efficiency and circular economy interventions. The methodology presented (along with its application) is considered a crucial step toward multi-impact- and evidence-based policy support. To increase the robustness of the results in future studies, the following measures may be taken: 1) increasing the number of product categories; 2) selection of several reference products for each product category, to highlight variability in impacts; 3) a sensitivity analysis of the results of the avoided impacts considering different end of life scenarios for the reference product (e.g., reuse of a book to be checked against book landfilling, or incineration, or paper recycling; 4) extension of the modeling of the reuse-related process (impact associated with selling spaces, energy, linked activities); and 5) further integration of market analysis, to properly assess the extent of substitution of products. In addition, recognizing that reuse may play a significant role in protecting the environment and ensuring an efficient use of resource, specific policies are needed to support waste prevention practices, for example, the realization of sites outside the municipal waste platforms where citizens can donate or sell items that can be reused instead of discarding them as waste. This implies a strengthening of private–public synergies and fostering of consumers' awareness around their role in resource efficiency.

Acknowledgment—The authors thank Renato Conca, Fabio Salomoni, and all the staff of Cooperativa Mani Tese for their contribution to the development of the present study and the data collection. The work was partially funded by the NGO Mani Tese within the project "Grabbing Development—Toward new models of North/South relations for fair exploitation of natural resources," DCI NSA-ED/2011/239–451.

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