A methodological approach to environmental impact assessment of reuse practices

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Introduction and state of the art

An efficient and sustainable use of resources is considered a crucial step towards sustainable lifestyles, implying sustainable production and consumption patterns. In fact, the transition towards sustainable production and consumption is recognized as one of the major challenges for sustainability, entailing waste prevention and reduction. E.g. by 2020, the OECD estimates, we could be generating 45% more waste than Europe did in 1995. And many of the items are often discarded when much of their potential lifetime is left and there is a reuse potential.

Worldwide, through volunteer efforts, for-profit businesses and charities, several forms of reuse exist including: thrift stores and charitable drop-off centers; reuse centers, equipment and materials; "drop & swap" stations at landfills; used equipment stores and salvage yards; local and regional material exchanges.

In the priority of the intervention for waste prevention and reduction, the re-use is considered crucial but usually neglected in term of methodologies for assessing the environmental benefit of its implementation.

Actually, the re-use may imply benefits on all the sustainability pillars as avoided impacts are not only at environmental level but also at socio-economic one.

At environmental level, many reuse programs have evolved from local solid waste reduction goals because reuse requires fewer resources, less energy, and less labor, compared to recycling, disposal, or the manufacture of new products from virgin materials. Therefore, reuse provides an excellent, environmentally-preferred alternative to other waste management methods, because it reduces air, water and land pollution, limits the need for new natural resources, such as timber, petroleum, fibers and other materials. At socio/economic level, for many years, reuse has been used as a critical way of getting needed materials to the many disadvantaged populations that exist. Reuse continues to provide an excellent way in which to get people the food, clothing, building materials, business equipment, medical supplies and other items that they may need. There are other ways, however, that reuse benefits the community. Many reuse centers are engaged in job-training programs, programs for the handicapped or at-risk youth programs (ReDO, 2012).

The product categories (such as textile products, furniture, etc.) and the quantities possibly involved in the reuse practice are significant. Just for example, approximately 4 percent of the contents of US landfills is made up of un-recovered textiles which is almost 100 percent recyclable. But only about 15% of US clothes are currently recycled. And the associated impact of this may be huge, e.g. in a report edited by the European Commission clothing is reported to account for between 2% and 10% of consumers' environmental impacts (EIPRO project, Tukker et al 2006).

Therefore, specific methodologies are needed in order to analyze the sustainability benefits of waste reduction and prevention, including the capability of policies, plans and actions to provide adequate solutions. This requires an integrated assessment of the different components of products' use along its life cycle from the extraction of raw materials to final waste disposal. In this context, Life Cycle Thinking (LCT) and, in particular, Life cycle-based methodologies (Life Cycle Assessment - LCA, Life Cycle Costing-LCC, Social Life Cycle Assessment - sLCA) may play a crucial role as recognized by several policies at European (e.g. CEC 2004, CEC 2005, CEC 2008, CEC 2010 and CEC 2011) and international level (UNEP, 2004 and 2012) in which LCT represents the backbone.

State of the art

In literature, there are still few studies that account for potential environmental benefit of reuse and most of them are not comprehensive evaluations (entailing different environmental impacts) but are limited to avoided CO2 emissions. So far, existing case studies showed that re-using a product can reduce CO2 emissions and carbon footprint by more than 50% relative to the complete product life cycle (e.g. Krikke, 2011). In the cited study, a scientific methodology has been developed to calculate how much CO2 emissions are reduced when buying used or second hand hardware versus new hardware, the so called durability greener network calculator. Another methodology was developed for consumer clothing and household textile (the Streamlined Carbon Footprint Analysis of post-consumer clothing and household Textile Reuse and Recycling by Mc Gill et al 2010).

Comprehensive approaches using LCA are still very limited, e.g. the case study on clothes by Farrant et al 2010 in which the environmental profile of cotton T-shirt and a pair of polyester (65%)/cotton (35%) trousers has been assessed assuming a reuse option. Only one attempt of a multi-product, environmental and economic assessment has been conducted and reported by WRAP (2011).

Project's objectives

Therefore, the objectives of this study are: to identify a methodology for the systematization of the evaluation of the environmental benefit related to reuse, based on LCA; to present and discuss methodological challenges in the evaluation.

The study has been developed starting from the experience of the Cooperativa Mani Tese, involved since long time in the collection and reselling of used objects, with the aim of reducing environmental burdens associated with household consumption and of promoting socially sustainable networks. A proactive exchange between the Cooperativa and the Research Group at the University of Milano Bicocca underpins the present study.

Methodology

In the present study, we propose a methodology for assessing the impacts and the benefits related to reuse, developed in collaboration with Cooperativa Mani Tese.
The basic idea is to identify the key drivers of impact highlighting the avoided impact due to the production of a certain good. For this purpose, methodologies such as Life Cycle Assessment (LCA) allow assessing the environmental implications of the whole supply-chain of products, both goods and services, their use, and waste management, i.e. their entire life cycle from "cradle to grave" has to be considered.

Life cycle assessment

LCA is an internationally standardized methodology (according to ISO 14040 and 14044) that allows to identify and quantify the environmental impacts associated with the production of goods or services and to identify environmental benefits, weaknesses and areas for improvement within of the production cycle.
LCA methodology is identified as one of the most reliable methodologies for evidencing and analyzing the environmental impacts of products and should be part of the decision-making process toward sustainability (Baumann and Tillman 2004). Therefore, LCA is considered the most valuable method for the scope of this study as it allows identifying the benefit associated to re-use in a comprehensive way.
LCA is successfully used in the private sector, e.g., for: continuous environmental improvement of products; internal strategic decision support; evaluating risks and opportunities along the supply chain; communication on strategic aspects with stakeholders at company and association level and communication with customers on products, e.g., via Environmental Product Declarations (EPD), carbon labels and footprints.
Despite the current use of LCA, a wider mainstream of life cycle thinking as key approach to environmental sustainability is still needed. This requires increasing the interaction among stakeholders involved in the development, application and use of the LCA results (such as the scientific community, business associations and policy makers) (Sala et al 2012)
LCA is distinguished from other environmental assessment tools by two main features:

- Life cycle perspective: all phases (“from the cradle to the grave”) of the life cycle of a product (good or service)—from the extraction and processing of the resources, over production and further processing, distribution and transport, use and consumption to recycling and disposal—have to be assessed with regard to all relevant material and energy flows.

- Cross-media environmental approach: a comprehensive analysis of environmental impacts is carried out, i.e., both on the input side (use of resources) and on the output side (emissions to air, water and soil, including waste). The analysis of input and output of each process is reported in the life cycle inventory (LCI). Within the, so called, life cycle impact assessment (LCIA) step, there is the characterization of the input and output presented in the LCI and the calculation of indicators for different impacts, such as climate change, ozone depletion, photochemical ozone formation, respiratory inorganics, ionizing radiation, acidification, eutrophication, human toxicity, ecotoxicity, land use and resource depletion.

Methodological steps

The methodology for evaluation of the environmental benefit associate to re-use is based on the adoption of life cycle assessment for estimating the avoided impacts. The procedure is divided into two main phases: the first one is aimed to the calculation of average avoided impacts for one unit of reused product in each product category considered. The second one is aimed at calculating the cumulative avoided impacts generated during one year by a second hand shop, through the selling of second hand products, as partial or total substitution of new ones. The steps of the two phases are illustrated in Figures 1-A and 1-B, whereas the basic methodological assumption are reported in the table 1.

Figure 1-A: Flowchart of methodology for calculation of average avoided impacts due to reuse of products (for F.U.) (phase 1)

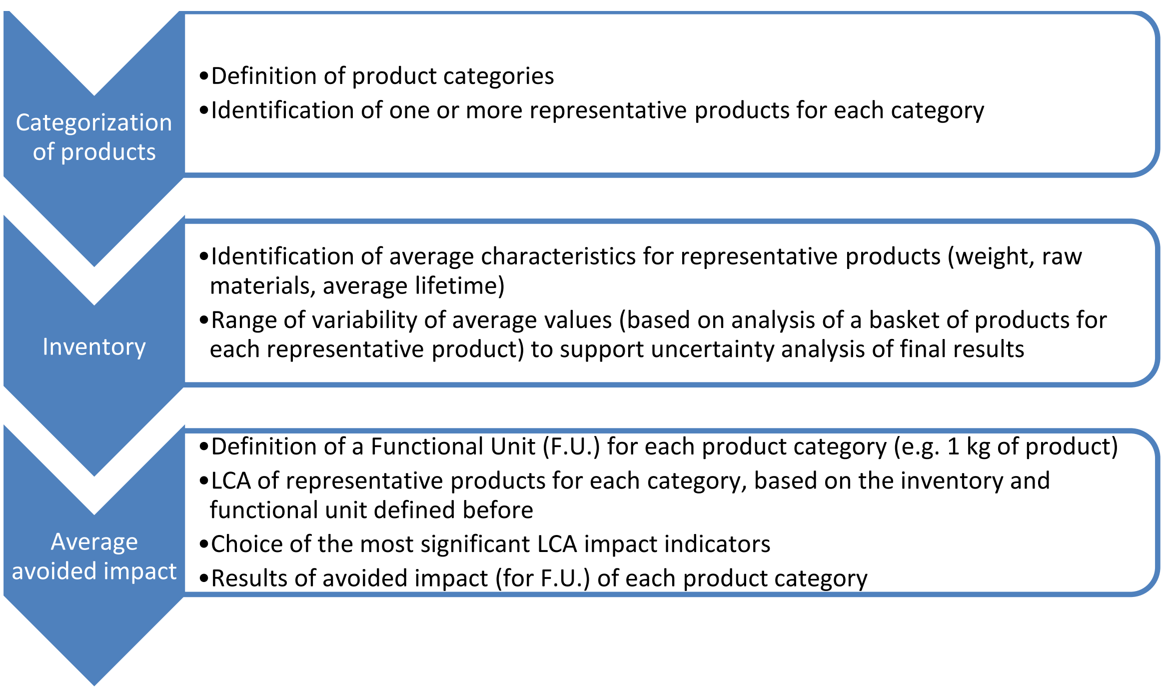


Figure 1-B: Flowchart of methodology for calculation of avoided impacts due to 1 year of activity of second hand markets (phase 2)

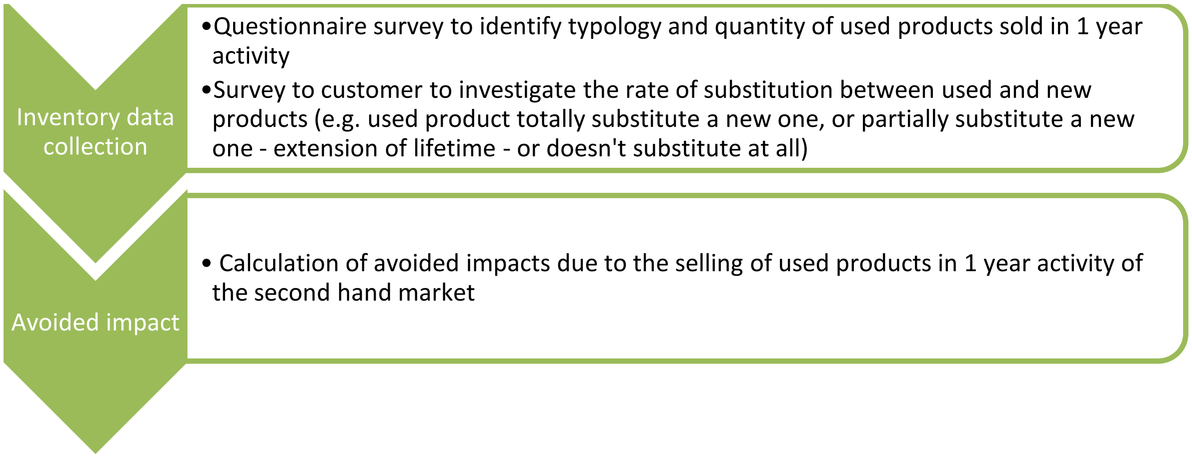


Table 1 Basic methodological assumption related to the assumptions

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. • 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 re-used 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.
Inventory - data quality	• The hierarchy of data sources requires the collection of primary data as much as possible.
Life Cycle Impact Assessment	• ILCD (EC-JRC 2011) impact assessment method is used for all the product categories

Detailed description of the methodological steps

In the following paragraphs a description of each methodological step (in phase one and phase two) is given. To improve clearness of description, the first part of the methodology is also illustrated through an example from the "Furniture" product category.

Phase 1

Categorization of products:

The product category is analyzed performing LCA of some representative products, different in term of shape, weight and materials, for which inventory information are available (from previous study published in the scientific literature or summarized in EPD declarations). Reliable and detailed inventory data for the reference products are needed to perform LCA of products with the same LCIA method (the method chosen is ILCD, for the reasons explained below), in order to ensure consistency in LCA data, i.e. comparability of avoided impact results. Data about avoided impacts due to reuse of products could be obtained also from a review of LCA studies of reference products; however, this cannot ensure that data are comparable, since different studies can have different system boundaries, different assumptions or use different LCIA methods.

The product chosen for furniture category are: wooden desk (data from BOMO project, a previous study of the authors, Mirabella et al 2012), Polypropylene (PP) chair (Environmental Product Declaration, Green's chair, EPD, 2012a) painted aluminum desk (Environmental Product Declaration, Ginger Round top and painted aluminum four-way base (H74), EPD, 2012b).

Inventory:

To obtain the inventory data needed to perform a LCA of an average product of the chosen category, it is necessary to define the basic characteristics of each reference product, such as its average weight, raw materials contained and average lifetime.

The following table illustrates the example of data available for the furniture reference products chosen.

Table 2: inventory data for reference products of the category “Furniture”

Product	**Weight (kg)**	**Raw materials (kg)**		**Lifetime (years)**
Wooden desk	8.25	Wood	8.47	15
		Iron	1.74	
		Glue	0.22	
		Pigment	0.24	
Polypropylene (PP) chair	4.6	PP	4.3	15
		PE	0.07	
		PA6	0.04	
		Pigment	0.18	
Painted aluminum desk	9.59	Polypropylene	5.38	15
		Aluminum	2.17	
		Glass fibre	1.27	
		Steel	0.63	
		Nylon	0.09	
		Glue	0.03	
		Paint	0.03	

Average avoided impacts

Using data collected in the inventory phase, LCA of reference products can be performed. In the light of the abovementioned assumptions, LCA results can then be considered as a proxy of avoided impacts granted by the action of buying second hand products instead of new ones (in the hypothesys of complete substitution).

The Joint Research Centre (JRC) 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 the basis for greater consistency and quality of life cycle data, methods, and LCA studies. Inherent to this goal is the development of recommendations of best practice characterization framework, models and factors. Therefore, the suggested methodology to be adopted for life cycle impact assessment is the ILCD 2011 as recommended by EC-JRC 2011, as this reflect the state of the art in impact modeling and should represent a reference methodology for product evaluation in a EU context (Wolf et al 2012).

Table 3 illustrates the results of LCA of the reference product “Wooden desk” (data from the above mentioned BOMO project), detailed for each manufacturing stage (the column “Total” represent the value of the avoided impact for each impact category considered; measured with an impact indicator defined by the LCIA method used for the assessment). Please note that, since this is only an illustrative example, the assessment is made with Recipe method instead of ILCD; in case of assessment made specifically for the evaluation of avoided impacts following the methodology illustrated before, LCA should be run using ILCD, to ensure comparability of results.

Table 3: example of LCA results – reference product “Wooden desk”, F.U.: 1 desk, Recipe method for Life Cycle Impact Assessment

Impact category	**Unit**	**SWP[1] manufacturing**	**Woodworking**	**Iron parts processing**	**Painting**	**Total**
Climate change	kg $CO_{2\ eq}$	9,56E+00	6,55E+00	3,43E+00	8,60E+00	2,81E+01
Ozone depletion	kg CFC-11 eq	7,69E-07	5,14E-07	1,68E-07	6,36E-07	2,09E-06
Human toxicity	kg 1,4-DB eq	1,17E+00	9,28E-01	3,49E+00	1,06E+00	6,65E+00
Photochemical oxidant formation	kg NMVOC	2,27E-02	1,57E-02	1,12E-02	1,97E-02	6,93E-02
Particulate matter formation	kg $PM10_{eq}$	1,01E-02	7,23E-03	1,03E-02	9,29E-03	3,69E-02
Ionising radiation	Kg U_{235} eq	2,19E-01	2,04E-01	4,84E-01	1,50E-01	1,06E+00
Terrestrial acidification	kg $SO_{2\ eq}$	3,29E-02	2,35E-02	1,29E-02	3,08E-02	1,00E-01
Freshwater eutrophication	kg P_{eq}	1,55E-03	1,21E-03	1,62E-03	1,43E-03	5,81E-03
Marine eutrophication	kg N_{eq}	7,20E-03	5,57E-03	3,28E-03	8,04E-03	2,41E-02
Terrestrial ecotoxicity	kg 1,4-DB_{eq}	4,96E-04	4,84E-04	7,11E-04	1,41E-03	3,10E-03
Freshwater ecotoxicity	kg 1,4-DB_{eq}	2,33E-02	1,93E-02	4,68E-02	2,21E-02	1,12E-01
Marine ecotoxicity	kg 1,4-DB_{eq}	2,54E-02	2,00E-02	4,97E-02	2,31E-02	1,18E-01
Agricultural land occupation	m^2a	2,50E+01	1,21E+00	7,43E-02	2,88E-01	2,66E+01

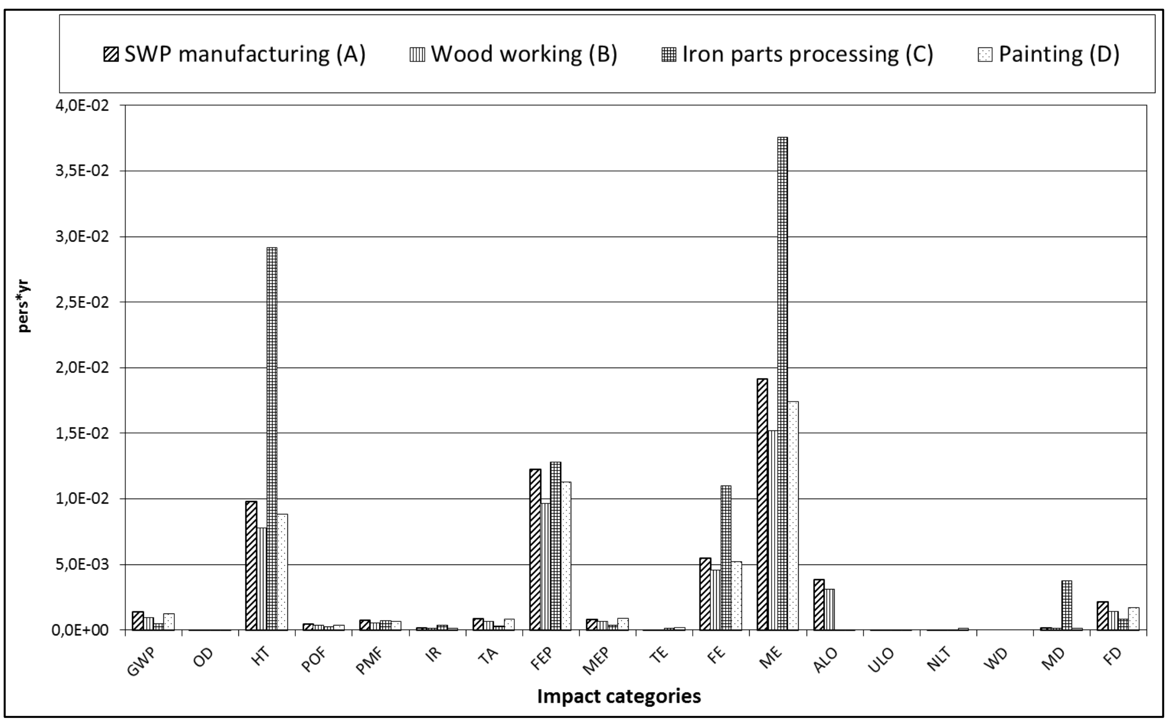
[1] SWP: Solid Wood Panels

Urban land occupation	m^2a	1,97E-02	3,41E-02	2,51E-02	2,14E-02	1,00E-01
Natural land transformation	m^2	1,51E-03	1,25E-03	5,03E-04	1,39E-03	4,65E-03
Water depletion	m^3	2,42E-02	2,46E-02	2,22E-02	1,97E-02	9,07E-02
Metal depletion	kg Fe eq	8,51E-02	7,09E-02	1,67E+00	6,52E-02	1,89E+00
Fossil depletion	kg oil eq	2,89E+00	1,87E+00	1,18E+00	2,35E+00	8,29E+00

As explained in ISO standards, the normalization phase can help to identify the most relevant impact categories affected by the product considered. It can also be useful in case of high uncertainty in some inventory data, because it helps to verify if those data refers to phases that determine important or negligible impacts (i.e. if the investigation need to be deepened or not).

Figure 2 illustrates the normalization results for the reference product “Wooden desk”.

Figure 2: results of normalization for the reference product “Wooden desk”



Phase 2

Inventory data collection

In order to calculate the cumulative avoided impacts (i.e. the cumulative benefit) of the reselling made by second hand markets, we need two kind of information:

- the typology and quantity of used objects sold by the market in a defined period (e.g. one year)
- the rate of substitution that should be hypothesized between used objects and new ones. We suppose 3 scenarios: i) used product totally substitute a new one, ii) used product partially substitute a new one (extension of lifetime), iii) the used product doesn't substitute other products, i.e. there is no impact avoided.

Data collection is made through questionnaire surveys to sellers and to customers of second hand markets.

Avoided impacts

Data collected in the previous step are multiplied for the average avoided impacts calculated for each product category at the end of phase 1, to obtain a set of values of cumulative avoided impacts from the selected case study (market where the data have been collected).

Discussion and conclusions

The proposed methodology has been developed in order to evaluate comprehensively the environmental benefits of re-use of goods, especially when the purchase of second hand products totally substitutes the purchase of new ones.

The need of a standardized methodology arises from the differences existing among published studies, such as the system boundaries, the assumptions made (e.g. inclusion or exclusion of packaging materials or transport operations; the distance of transport considered, etc) and the LCIA method used.

Therefore the main aim of the methodology is to define a standardized procedure based on the identification of reference products for each product category that has to be evaluated, in order to be able to collect reliable inventory data and to perform an LCA. In this context, the existence of product category rules is fundamental in order to identify the baseline scenario for reference products.

The current limitations that require further research are mainly focused on:

- at the inventory side: the availability of a wide range of studies on each product category for defining a realistic range of variability of the environmental profile of products; the modeling of the reuse inherent processes (e.g. the transport to and from the reseller)
- at the impact assessment phase: the fact that existing methods lack of comprehensive coverage of all the possible impact and avoided impacts (e.g. the resources to be considered are not only minerals and fossil fuels but also critical raw materials, not only abiotic but also biotic, not only mineral stock but also anthropogenic (Klinglmeier et al 2012)).

Moreover, recommendation for reduction of residual potential impacts should be further explored, also expanding the basket of reference products, including best and worst cases, i.e. minimum and maximum values in the inventory, for each reference product identified.

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