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Eco-designing the use phase of products in sustainable manufacturing: the importance of maintenance and communication-to-user strategies

Esther Sanyé-Mengual, Paula Pérez-López, Sara González-García, Raul Garcia Lozano, Gumersindo Feijoo, Maria Teresa Moreira, Xavier Gabarrell, Joan Rieradevall

Address Correspondence to:

Esther Sanyé Mengual, Esther.Sanye@uab.cat

Sostenipra (ICTA-IRTA-Inèdit) – Institute of Environmental Science and Technology (ICTA), Universitat Autònoma de Barcelona (UAB), Campus de la UAB s/n, 08193, Bellaterra (Barcelona), Spain

Abstract

Recently, principles in sustainable manufacturing have included the Design for the Environment (DfE) methodology with the objective of improving the environmental performance of products over their entire lifecycles. Current EU Directives on eco-design focus on the use phase of Energy-related-Products (ErPs). However, the maintenance of various household non-ERPs is performed with ErPs; therefore, the environmental impacts of product maintenance have an important role in the lifecycle of non-ErPs.

This article presents two eco-design studies where the implementation of improvement strategies for the use and maintenance phase of products had relevant results. Moreover, environmental communication-to-user strategies were important to ensure the commitment of users towards eco-efficient behaviors. First, a knife was eco-designed according to strategies focused on materials, processing, maintenance and communication-to-user. By applying eco-design in a cradle-to-consumer scope, improvements in environmental impact of the eco-designed product accounts for 30%. However, when accounting for eco-design of the product's entire lifecycle, environmental impacts could be reduced by up to 40% and even up to ≈93% (depending on the cleaning procedure), due to large improvements in maintenance strategies. Second, a woman's jacket was eco-designed following multifunctionality, recycled materials and efficient maintenance strategies. The new Livingstone jacket reached environmental improvements between 32% and 52% in the indicators analyzed. In this case, maintenance contributed between 40% and 80% of the reduction.

As shown in this study, maintenance behavior and communication-to-user strategies are crucial to the eco-design of different household products (traditional vs. flexible design) and can account for between 40% and 80% of environmental improvement.

Keywords: eco-design, communication-to-user, innovation, Energy-related Products (ErPs), eco-efficiency, industrial ecology.

<Heading level 1> Introduction

Eco-design is defined as "the integration of environmental aspects into product design with the aim of improving the environmental performance of the product throughout its whole life cycle" (Directive 2009/125/EC) (European Council 2009a). During the last decades, eco-design has played an important role in sustainable manufacturing because numerous environmental burdens of a product are determined at the design stage (European Council 2009a; Clarimón et al. 2009). Moreover, there has been a growing concern in policy making about the environmental impact of products and services, particularly since the Integrated Product Policy (IPP) was implemented (European Comission 2003), which emphasized the contribution of the entire life cycle of a product to its environmental impact.

Eco-design has been applied to different types of products, some of which now have guidelines for their effective eco-design; some examples are urban furniture (e.g., streetlight, bin, bench) (Fundació La Caixa 2007), household products (e.g., appliances) (Rieradevall et al. 2003), electric and electronic devices (Rodrigo and Castells 2002) and packaging (Rieradevall et al. 2000). Moreover, the application of DfE in some sectors has been thoroughly analyzed in the literature, such as wooden products (González-García et al. 2011a, 2012a, 2012b, 2012c, 2013), electronics industry (Unger et al., 2008; Mathieux F et al., 2001; Aoe, 2007), lighting sector (Gottberg et al., 2006; Casamyor & Su, 2013), automotive (Alves et al., 2010; Muñoz et al., 2006), packaging (Almeida et al., 2010) and printing industry (Tischner & Nickel, 2003).

Applying eco-design offers the following benefits to companies (Borchardt et al. 2011; Clarimón et al. 2009; Plouffe et al. 2011; Rieradevall et al. 2005): improved environmental footprint (i.e., emissions, waste) while complying with current regulations and anticipating more restrictive ones; improved product quality; reduced economic costs of both material inputs and outflows (e.g., cleaning treatment), while optimizing inputs and minimizing leftovers; and reduced energy consumption because of improved energy efficiency. Therefore, by following eco-design criteria, companies achieve sustainable environmental and economic indicators (Rupérez et al. 2008), which offers the opportunity to differentiate themselves from competitors, entrance into new markets and development of new products (Knight and Jenkins 2008). However, two additional areas can be improved: application of environmental issues in marketing and superior corporate image (Rieradevall et al. 2005).

<Heading level 2> Labeling, the consumer role and eco-design

Environmental labeling shows the environmental performance of a product to a consumer as an additional decision-making criterion in the purchase of a product. It also promotes the adoption of sustainable strategies by the companies (e.g., EPD of furniture by ARPER, http://www.arper.com/it/chi-siamo/sostenibilita). Most of the certification schemes are based on lifecycle schemes (ISO 14040 (2006), PAS 2050 (BSI 2011)), which contains all lifecycle stages. Some examples are the Carbon Footprint (BSI 2011), EU Ecolabels (depending on the product) (European Council 2009b) and Environmental Product Declarations (EPDs) (ISO 14025/TR) (ISO 2006a). Finally, enterprises can obtain global certifications while having an Eco-design Management System, such as ISO 14006 (2011) (e.g., see case study of m114 (2012)).

Because the use phase plays a key role in the performance of some products, it is considered when developing labeling for some products. Energy-related Products (ErPs) (e.g., televisions, computers, light bulbs) labels use this strategy to demonstrate environmental friendliness: Eco-label (European Council 2009b), EU Energy label (European Council 2010), US Energy star (http://www.energystar.gov/). In these cases, the consumer can also evaluate the performance of the product during the use stage when making a purchasing decision. However, environmental labels usually only consider cradle-to-gate stages for non-ErPs products due to the difficulties for modeling the use stage (Kota et al. 2013) and lack of information about this phase.

Communication-to-user can be done in two main ways. First, the producer can indicate information of the product: reporting the environmental impact of the product (e.g., Carbon Footprint) or indicating the average consumption during the use phase (e.g., EU Energy label), this can be done from a cradle-to-gate or a cradle-to-cradle perspective. Second, the producer can extend their responsibility and promote best practices in order to involve the customers for improving the environmental performance of the product. This type of communication can be applied to the use and maintenance phase or to the end-of-life one. For example, a case study of the Carbon Trust for Coca-Cola in 2008 (http://www.carbontrust.com/media/5888/cts287-coca-cola.pdf) highlighted the importance of the packaging and the company started communication-to-user campaigns about recycling in order to reduce the Carbon Footprint up to 40%. However, no case studies were found with communication-to-user about best practices regarding the use and maintenance phase and, therefore, there is a need of promoting these strategies in cases were the use stage has an important role in the lifecycle.

<Heading level 2> Eco-design and non-ErPs

The current eco-design directive focuses on Energy-related Products (ErPs) (formerly Energy-using Products, EuPs) and aims to improve energy efficiency, particularly in the use stage of the lifecycle. This fact has its origins in the development of the first Directive on Eco-design 2005/32/EC (European Council 2005) that replaced former directives about energy efficiency for hot-water boilers (Directive 92/42/EEC) (European Council 1992), household appliances (Directive 96/57/EC) (European Council 1996) and fluorescent lighting (Directive 2000/55/EC) (European Council

2000). Moreover, the 2005 eco-design directive was also encouraged by the European Climate Change Program (ECCP), where saving energy, particularly reducing electricity demand, and decreasing energy dependence were key points for achieving the objectives of Greenhouse Gas (GHG) emissions.

Household appliances are mainly ErPs that cover different functions (table 1). However, most maintenance and cleaning ErPs have a direct relation to other products, such as clothes and kitchenware. This relation means that resource consumption of the ErP during its use phase is also an input into the maintenance of non-ErPs (table 1). Therefore, the assumption that non-ErPs have low consumption during their use phase may be wrong for those products that need an ErP for maintenance. Accordingly, eco-design directives should also focus on non-ErPs products, as the potential environmental impact of the use and maintenance lifecycle stages may be significant when an ErP is involved.

The environmental labels of a majority of non-ErPs do not include the use or maintenance phases in their information, even if they require high levels of maintenance (ErPs) (table 1). Therefore, as the environmental burdens related to the use and maintenance of non-ErPs depends on the user behavior and habits and labels currently lack of communicating about best practices to perform the most environmentally friendly maintenance of the product, both qualitative (i.e., symbology) and quantitative (i.e., indicating average consumption values per maintenance options). In this sense, there is a need of enhancing communication-to-user tools about these lifecycle stages as well as to integrating them as eco-design strategies.

Table 1. Main household ErPs by function and by direct relation to non-ErPs. Application of eco-labels is indicated by superscript letters.

Household **ErPs**		Maintenance of **non-ErPs**
Maintenance & cleaning	Clothes washers[b,c,d], Dryer, Iron	Clothes
	Dishwasher[b,c,d]	Kitchenware
	Vacuum cleaner, Steam cleaner	
Food	Refrigerator[b,d], Freezer[b,d], Cooker, Oven[c,d], Water boile[d]r, Coffeemaker[d], Microwave[d]	
Lighting	Light bulbs[a,b,c], Lamps[b,c,d], Luminaries[b,c,d]	
Acclimatization	Dehumidifiers[c], Air cleaners & purifiers[c], Heat pumps[a,c], Air conditioners[b,c]	
Others (electronics)	Television[a,b,c,d], Personal computers[a,c,d], Portable computers[a,c,d]	

[a]EU Ecolabel, [b]EU energy label, [c]U.S. Energy Star, [d]Blue Angel

In this context, this article shows the application of eco-design methodology in two non-ErPs. A knife and a woman's jacket were chosen to represent items that received daily use, that were personal household products and that had a wide presence in the market. Moreover, this article aims to show the contribution of maintenance to the environmental impact of a product lifecycle and to show potential eco-design strategies and communication-to-user tools for improving the product's environmental profile.

<Heading level 1> Methods

A combined DfE-LCA methodology was used for the eco-design process (Figure 1), adapted from González-García et al. (2011b). The product is defined in the first stage (I) based on the following main criteria: company representativeness, production relevance, novelty and low degree of complexity. Then, a product evaluation (II) is performed through the application of a quantitative life cycle assessment (LCA). Thirdly, an ecobriefing (Smith and Wyatt 2006) (III) is created by compiling the critical points of the lifecycle. As a result, the proposal of eco-design strategies (IV) can be defined and selected by the company after a technological, social and economic assessment. Finally, the selected strategies are integrated into the design of the prototype and the product is validated (V) through an LCA.

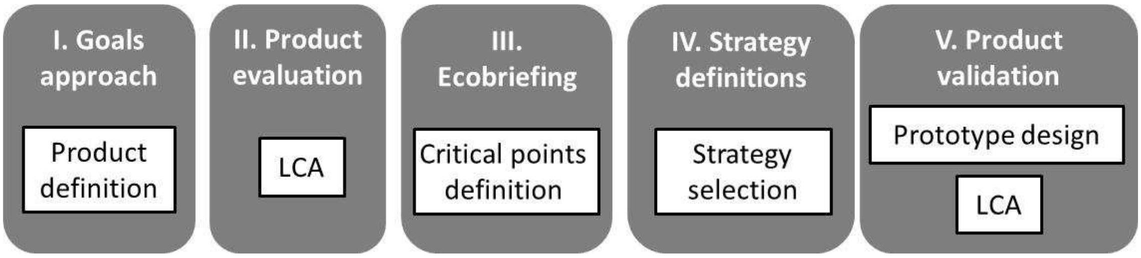

Figure 1. Combined DfE and LCA methodology, adjusted from González-García et al. (2011)

The LCA (ISO 2006b) quantifies the environmental burdens of the system and highlights the hotspots of the lifecycle. The CML method (Guinée et al. 2002) was used for the classification and characterization stages. The potential impact categories assessed were abiotic depletion (AD, kg Sb eq.), acidification (AC, kg SO_2 eq.), eutrophication (EP, kg PO_4^{3-} eq.), global warming (GW, kg CO_2 eq.), ozone layer depletion (ODP, kg CFC-11 eq.), human toxicity (HT, kg 1,4-DB eq.), freshwater ecotoxicity (FE, kg 1,4-DB eq.), marine ecotoxicity (ME, kg 1,4-DB eq.), terrestrial ecotoxicity (TE, kg 1,4-DB eq.) and photochemical oxidant formation (PO, kg 1,4-DB eq.).

However, only three indicators were selected for communicating the environmental profile of the products to stakeholders (i.e., companies involved in the project). The indicators were therefore the basis in the decision-making steps along the eco-design process, where companies decide the eco-design strategies that may be applied for the new product. First, the normalized CML environmental potential (Pt.) was used for showing the global profile. Second, the global warming potential (IPCC 2007) was selected as one well-known and understandable indicator for companies (i.e., use of carbon footprint, CO2 trade). Finally, the cumulative energy demand (CED, MJ) showed the global energy consumption (Hischier et al. 2010).

The selection of these three indicators was based on the following criteria: (a) previous experience on eco-design projects with companies, (b) stakeholders' understanding (e.g., GWP), (c) connection to common environmental indicators in companies (e.g., energy), (d) comprehensive indicator of the environmental burdens (e.g., CML Normalized) and (e) relation to current eco-labeling (e.g., CO2 and energy). Finally, the indicators resulted also of great interest for the present research, where the energy consumption and the associated GWP became a key issue in the eco-design of non-ErPs due to the important contribution during the use and maintenance step.

<Heading level 1> Eco-design of a knife

A 900 series kitchen knife was selected in the first step (I). Its fabrication is based on the following regulations: UNE-EN-ISO 9001 (2008) regarding quality management, UNE-EN-ISO-8422/1 (1997) regarding materials in contact with food products and NSF (National Sanitation Foundation) certification (http://www.nsf.org/) concerning hygiene. Additionally, knife production follows an HACCP (Hazard Analysis and Critical Control Points)-based system. Moreover, the handle of the knife is color-coded to avoid cross-contamination.

The knife is composed of a stainless steel blade and an overinjected copolymer polypropylene (PP) handle, both of which come from Spain. Eight percent of the PP is recycled in an internal closed-loop from leftovers of the overinjection process, while steel leftovers are sold for external recycling.

The 11-step production process is performed internally by the same company, while the packaging process is external. Steel sheets are cut into small pieces; then, semiautomatic die stamping is performed, followed by polishing the back side. The blade is tempered in an electric oven (1030-1070ºC) before undergoing smoothing, polishing and washing. Once the blade is manually finished, the handle is overinjected, and the cutting edge sharpened. Finally, brand and product details are added to the blade through electrolytic marking. The percentage of the electric consumption during the process that is from renewable resources (photovoltaic panels) is 4.05%.

Primary packaging is composed of the following 3 items: a PVC cover, information cardboard and a flange. Secondary packaging consists of a 6-knife cardboard box and a cardboard box for shipments (90 knives). The product is distributed by truck for both national (35%, 500 km) and international (65%, 2200 km) sales.

<Heading level 2> LCA data and method

The functional unit considered for the LCA was a knife for a domestic use (household) with a lifespan of 10 years. The lifespan responds to company data (i.e., experience, market studies) and entails the whole lifecycle, including maintenance of the product (both cleaning and sharpening processes). The resulting eco-designed knife must also accomplish this functional unit and the corresponding lifespan. Primary data was obtained from the company and complemented by background data from databases. These data were compiled in the Life Cycle Inventory (LCI) (Supporting information 1).

Regarding use and maintenance, two different scenarios were modeled considering the most common cleaning options: hand washing (environmentally friendly scenario) and dishwasher (environmentally unfriendly scenario), which allowed the assessment of potential maintenance habits and different patterns of user behavior. For both scenarios the amount of cleanings was considered the same (one use per day) and data was obtained from field work (i.e., water and soap amount for the hand washing option) and from producers (i.e., water, soap and energy consumption from dishwasher producers; and soap composition from soap producers). Regarding the dishwasher, data was allocated assuming a complete filling of the machine, in order to avoid an overestimation of its environmental burden. Finally, since the company does not make recommendations to the user regarding the end of life management, it is assumed that the fate of the knife at the end of its life cycle is landfill together with Municipal Solid Waste (MSW).

<Heading level 2> Product evaluation and ecobriefing

At first, the lifecycle was assessed while excluding the use phase, which was later analyzed by maintenance procedure. The material consumption during this process is the biggest contributor to environmental impact, representing between 45.2% and

68.7% of the potential impact of the categories analyzed, mainly due to the stainless steel (76.7 – 96.5%), which reaches nearly 100% in the toxicity categories (due to Cr^{6+} emissions into the air and Ni and Be emissions into the water). The processing stage represents approximately 35.4% to 50.1% of the environmental burdens (mostly due to electricity consumption), excluding human toxicity (-31.1%) and terrestrial ecotoxicity (-23.7%), which have positive impacts due to the recycling of the leftover steel material. The transportation and packaging stages have similar environmental impacts of 7.0% and 4.2%, respectively. Finally, the end-of-life treatment has the lowest environmental impact (<0.31%), with the exception of eutrophication (4.7%) and water ecotoxicity (9.8 – 12.8%) (Figure 2) (Supporting information 2).

However, the use phase varies substantially between users due to associated resource consumption (water, energy and soap). For a domestic user with a knife lifespan of 10 years, hand washing maintenance represents between 16.1% and 25.1% of the environmental burden, excluding the ecotoxicity and human toxicity categories (<12%), which increases the burden to 33% of the normalized CML indicator (Figure 2). Although materials (34.7 – 73.8%) and processing (32.7 – 42.1%, excluding HT (-81.9%) and TE (-43.0%)) are still the main contributors, strategies regarding knife maintenance can offer significant improvements. As an alternative, dishwashers are commonly used for kitchenware maintenance. When considering this scenario (Figure 2), maintenance becomes the largest environmental burden in the product's lifecycle (>91.2%), and HT (31.2%), FE (82.5%) and ME (89.9%) are still largely affected by the toxicity of steel.

According to the LCA results, strategies should focus on the materials (steel), processing (electricity consumption) and use phases (maintenance communication).

These critical points were assessed by the technical team in the ecobriefing (table 2) to perform a basis for the improvement strategies.

Table 2. Ecobriefing results for the 900 series knife by product stage: concept (C), materials (M), processing (P), transport and packaging (T&P), use and maintenance (U&M) and end-of-life (EoL).

	Lifecycle stages					
Critical points	***C***	***M***	***P***	***T&P***	***U&M***	***EoL***
Ecoinnovation strategies are not shown in the knife (function)	●					
Lack of visibility of the consumer's environmental impact	●				●	
Little use of recycled materials (handle and blade)		●				
High energy consumption during processing			●			
High amount of leftovers from die cutting (handmade process)	●		●			
High-impacting mode of transport				●		
Single-use packaging from steel suppliers				●		
Lack of recycled materials in the product packaging				●		
Insufficient environmental communication about maintenance	●				●	
High consumption of resources (water and energy) during maintenance	●				●	
Great difficulties for disassembling					●	
Insufficient environmental communication about end-of-life treatment	●					●

<Heading level 2> Strategy definition and product validation

Prototype design included 7 strategies that focused on the concept of the knife, materials, processing and use: (a) optimization of the amount of metal by reducing the blade's thickness, (b) co-injection of the handle with a core of recycled PP, (c) automatic die stamping with computerized systems (leftover reduction by 10%), (d) elimination of 6-knife secondary packaging, (e) supply of accessories to users to optimize maintenance, (f) communication-to-user about the environmental profile of the product, and (g) communication-to-user about maintenance.

The new design of the 900 series knife is mainly based on improvements in materials and communication. At the material level, both the steel blade and the PP handle were modified. Steel input was reduced by 25.0%. First, the thickness of the blade was reduced from 3 to 2.5 mm, which decreased steel input by 16.7% while maintaining knife properties. Second, computerization of die stamping decreased the amount of leftover steel by 10%. Furthermore, co-injection of the handle with a recycled PP core (up to 70% of handle) (Figure 2) practically reduced PP leftovers to 0. New technologies applied to the processing also positively affected this stage by reducing total electricity consumption by 7%.

At the communication level, strategies were applied at the concept and the use stages. First, the environmental performance of the product is communicated to the user through an environmental indicator with a large media projection: the Carbon Footprint (BSI 2011), which was stamped on the steel blade. This strategy aimed to differentiate the product in the market as well as to offer a decision-making criterion to consumers. Second, as shown in the product evaluation, the maintenance of the knife had an important contribution to its environmental impact due to its lifespan; therefore, the user is encouraged to apply eco-efficient cleaning and maintenance in water consumption. Environmental communication is used to promote cleaning with minimum water consumption by recommending dry cleaning instead of using the dishwasher or hand washing. To enable users to follow these recommendations, the knife is accompanied by a microfiber cloth and printed with symbols and instructions for eco-efficient cleaning to motivate their use in cleaning.

According to the environmental indicators for the validation of the design, the CML-normalized punctuation of the prototype was 33% lower than the original product, while the CO_2 equivalent emissions were decreased by 17.8% and the energy consumption by 21.5%. When considering the complete lifecycle (maintenance and end-of-life), improvements of 44.3% were made in the normalized CML, 35.0% in the GWP and 38.7% for the CED. Finally, when comparing the new 900 design to a conventional knife that is cleaned 100% by dishwashing, the application of a dry cleaning could further reduce the environmental burdens by up to 93% (Figure 2). This large reduction mostly relies on avoiding the energy consumption during the maintenance step related to the dishwasher use. For example, energy consumption is reduced from 653 to 37 MJ, as the electricity consumption of the dishwasher accounted for much of the energy consumption of the original knife.

The efficiency of the communication-to-user strategies regarding the maintenance best practices was assessed through a sensitivity analysis. Comparing to a dishwasher user, an effectiveness of 25% showed benefits between 24.6 to 25.9% in the different environmental indicators, while an effectiveness of 50% would represent a reduction of the environmental burdens from 47.8 to 48.2%. Comparing to a hand-washing user, benefits may be from 20.7 to 30.3% when assuming an effectiveness of 25%. Therefore, important environmental benefits can be achieved even with low efficiency rates (25%) for the both types of maintenance.

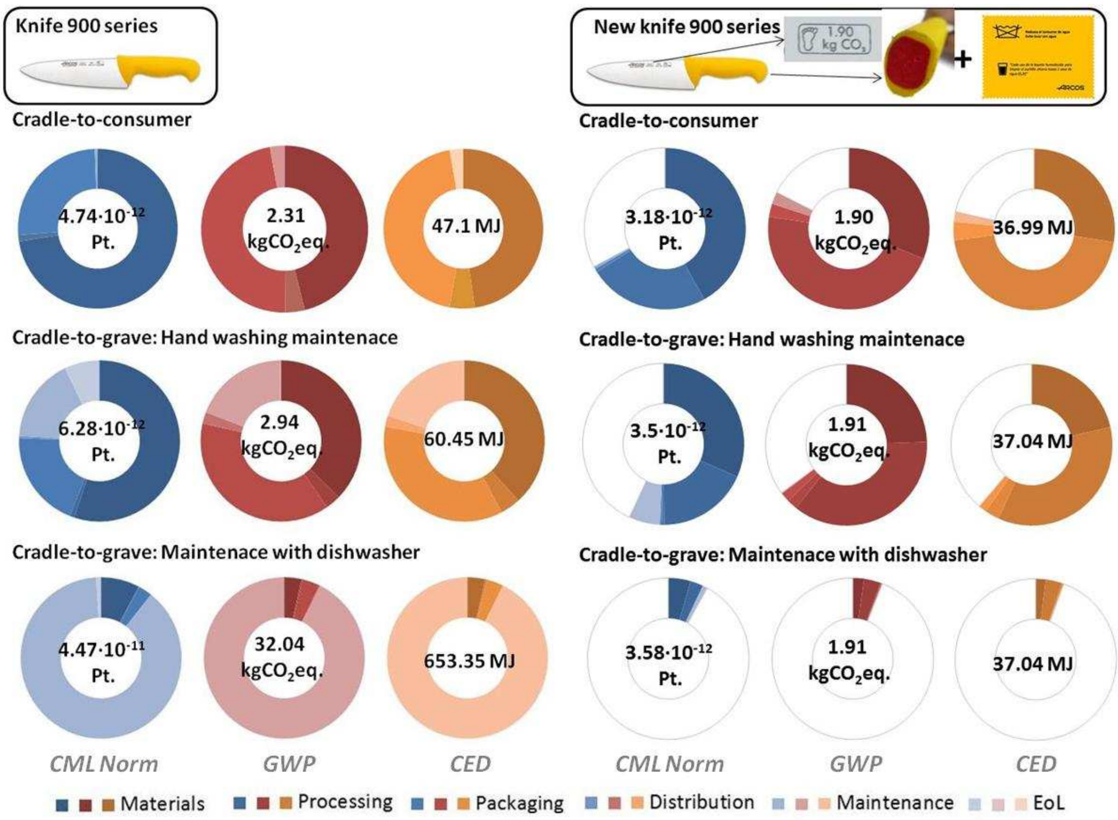

Figure 2. Environmental impact indicators: normalized CML, GWP and CED of the 900 series knife and the new eco-designed product that shows cradle-to-consumer and cradle-to-grave considerations (hand washing and dishwasher maintenance). Figures show environmental improvement by circle completeness.

<Heading level 1> Eco-design of a woman's jacket

The woman's Blazer jacket is a lightweight jacket made of nylon (50% of which is manufactured with recycled fishnets), polystyrene and cotton. The jacket is composed of 7 components: fabric, cotton label, cardboard label, buttons, hanger, fabric bag and potato fiber bag. The main components come from Korea (fabric), China (label) and Spain (buttons, hanger). The jacket processing stage consists of 3 steps: design, fabric dye and finishing, and dressmaking. Finally, the product is packed in a bag of potato fiber with a plastic hanger. Trucks are used for national distribution (72.5%, 485 km), and planes are used for international distribution (27.5%, 4500 km).

<Heading level 2> LCA data and method

The functional unit considered for the LCA was one Blazer jacket with a life span of 5 years, according to company data (i.e., experience, market studies). The resulting eco-designed jacket must also accomplish this functional unit and the corresponding lifespan. The whole lifecycle of the product was analyzed: materials extraction, processing, transportation, use and maintenance and disposal. Primary data was obtained from the company and complemented by background data from databases. These data were compiled in the Life Cycle Inventory (LCI) (Supporting information 3).

Two maintenance scenarios were considered for the use stage in order to show the environmental impact of a wide range of potential maintenance habits and different patterns of user behavior. A low maintenance scenario assumed 15 washing cycles (washing machine and drier) during the lifespan. A high maintenance scenario increased the washing cycles up to 25 and included an ironing step after the washing process (washing machine, dryer and iron). Data regarding the energy, water and soap consumption of the different appliances was obtained from producers. Finally, like in the previous case study, it is assumed that the jacket is landfilled together with MSW due to a lack of end-of-life recommendations from the company.

<Heading level 2> Product evaluation and ecobriefing

A cradle-to-consumer analysis showed the material usage is the biggest contributor to the environmental burdens of the Blazer jacket, representing between 66.21% and 94.53% of the different potential impact categories, except for ODP, where transportation accounts for 63.33% of the potential impact. The hanger and the potato fiber bag (packaging) are the highest contributing materials. The transportation contributes 2.51% to 26.17% to the environmental burden of the rest of the categories, largely due to the distribution of the product. Finally, the processing and energy consumption cause the least environmental impact (5.58 – 16.15%) in the different categories (Supporting information 4).

Nevertheless, the results significantly vary when performing a cradle-to-grave analysis and the use phase becomes the greatest contributing stage of the lifecycle in the different categories (36.20 – 62.36%), excluding the TE category (21.73%). The electricity consumption of appliances used for the maintenance of the jacket, such as ironing (67%) and drying, is the most important contributor, while the water consumption (<0.1%) is a minimal contributor. In the cradle-to-grave analysis, the materials represent a contribution between 9.02% and 44.80% (apart from TE, which contributes 74.00%), while the transportation (1.03 – 25.75%) and processing (2.14 – 6.07%) are the other main contributors. Finally, the end-of-life treatment of the jacket is the lowest impacting stage (<0.1 – 5.36%), which is largely affected by its contribution to ecotoxicity (Supporting information 4).

The product evaluation highlighted the importance of developing eco-design strategies for the use and the materials stages, which contributed the most to the environmental burdens of the product. These critical points were assessed by the technical team in the ecobriefing (table 3) to allow an analysis of improvement strategies.

Table 3. Ecobriefing results for the Blazer woman's jacket, broken down by product stage: concept (C), materials (M), processing (P), transport and packaging (T&P), use and maintenance (U&M) and end-of-life (EoL).

	Lifecycle stages					
Critical points	***C***	***M***	***P***	***T&P***	***U&M***	***EoL***
Limited functionality for a particular purpose	●					
Comfort problems related to breathability of the material	●	●				
Recycled Nylon		●				
Use of raw materials from a distant origin			●	●		
Long transport distances of the product				●		
Overpacking of the product	●		●	●		
Multimaterial packaging	●			●	●	
Undetermined management for the processing wastes			●			●
Non-identified materials and difficulties in end-of-life management					●	●
Lack of environmental communication about end-of-life management					●	●

<Heading level 2> Strategy definition and product validation

The prototype design included 5 strategies regarding the concept, materials and use stages: (a) change the product into a multiseasonal jacket with an increase of the potential lifespan, (b) require environmental data from suppliers, (c) use recycled materials, (d) use regional materials and (e) implement communication-to-user strategies about jacket maintenance.

The new woman's jacket, called Livingstone, is a detachable multiseasonal jacket composed of the following four pieces: external shell, internal vest, sleeves and skirt. This concept makes the jacket a multifunctional product with a wider use period during the year as it can be transformed from a summer vest to a winter coat. However, both products were designed for the same lifespan: 5 years. In this sense, although the new Livingstone model has a more intensive use when compared with the original Blazer jacket, it also has a higher material consumption in order to ensure its durability.

For this new model recycled and regional materials were promoted. First, the cotton label was changed into a recycled PET label from Portugal (500 km). Second, the new internal vest is made of recycled cotton, also from Portugal (500 km), which also offers more breathability that reduced the need for maintenance. Finally, the zippers are made of recycled POM and PET, although the supplier is from Japan. Moreover, because the jacket can be separated into separate parts, a single detachable part can be washed to limit the environmental burden of maintenance.

Furthermore, environmental data are now required from suppliers to increase the knowledge about the environmental performance of the materials used in their products. Therefore, the availability of data can reduce the environmental impacts related to the supply chain, increase the quality of suppliers, improve the environmental image of the company and facilitate the entrance of the product into more demanding markets.

Finally, the environmental communication-to-user strategy about maintenance is focused on avoiding the use of a dryer and an iron. This strategy aims to increase the user awareness of the importance of rational use of energy as well as to reduce the environmental impact during the use phase.

The new Livingstone jacket has an overall higher environmental impact compared to the original Blazer jacket from an eco-design cradle-to-consumer perspective; normalized CML and global warming potential are two times higher in the new product, while CED is 80% higher. Nevertheless, the eco-efficient maintenance strategies had a positive effect when analyzing the whole lifecycle of the products. For a high maintenance scenario, normalized CML is only 4% higher, and the CO_2 equivalent emissions are 17% higher, while the Livingstone jacket has a lower impact from an energetic point of view (reduction of 6%) (Figure 3).

However, these results are due to an increase in the amount of materials needed to offer a multiseasonal design with detachable pieces. The Livingstone model can be used during the entire year, unlike the original Blazer jacket. Notwithstanding its more intensive use, the new model was designed for the same lifespan of the former design: 5 years. Therefore, a final comparison was made to assess multifunctionality of the new model, and this product was compared to a combination of the Blazer jacket plus a winter jacket. In this context, environmental impact reductions were 53% for the normalized CML, 32% for the global warming potential and 36% for CED (figure 3).

Within these benefits, the maintenance strategies represented 40% (normalized CML), 71.7% (CO_2 equivalent emissions) and 86.8% (CED) of the environmental reduction, considering a user that applies eco-efficient procedures. Finally, a sensitivity analysis was carried out to assess the efficiency of the communication-to-user strategies for efficient maintenance. When considering 75% of effectiveness, the environmental benefits range from 22.5% to 43%, while 50% effectiveness would still yield positive results for the new design (impact reductions between 8.8% and 34%).

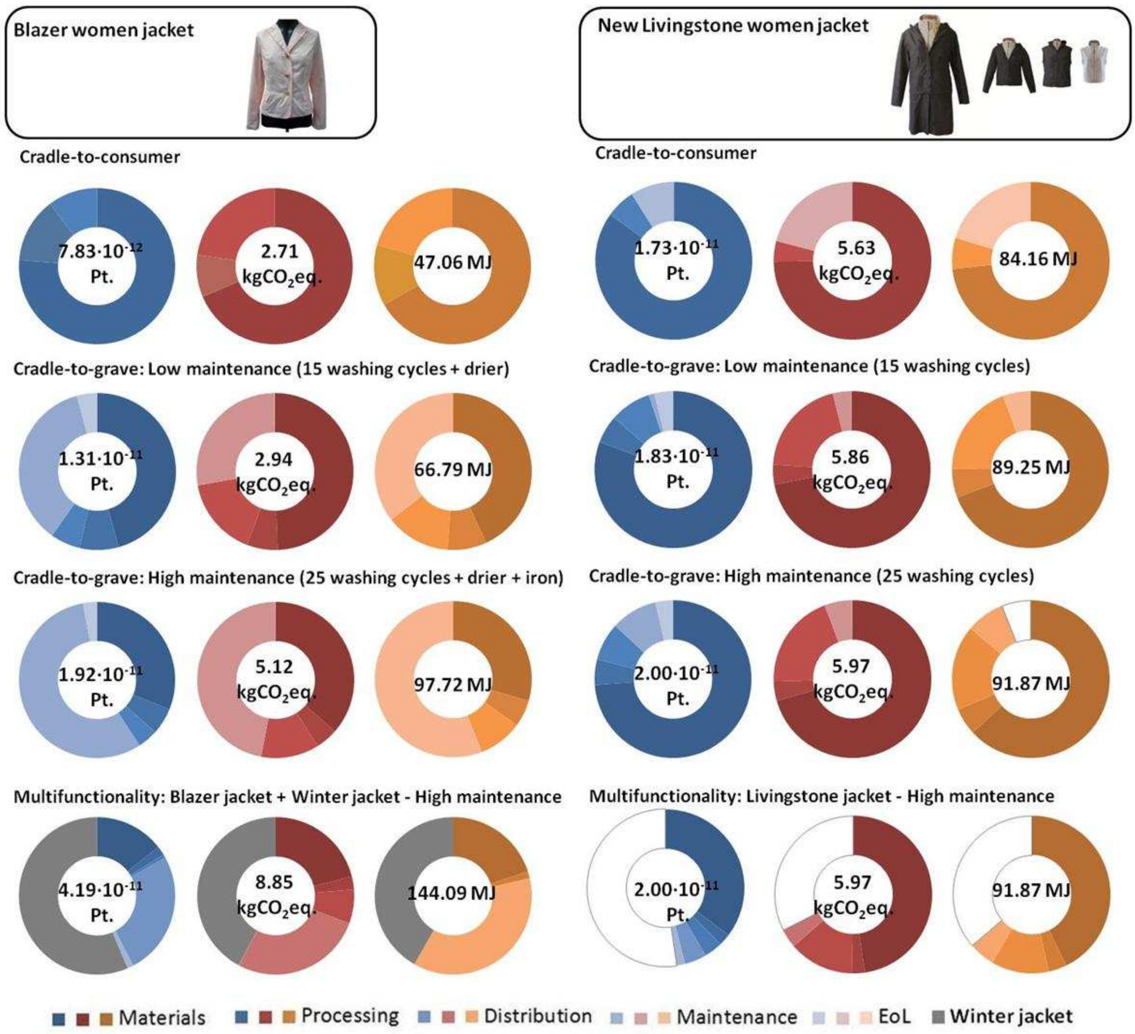

Figure 3. Environmental impact indicators: normalized CML, GWP and CED of the Blazer jacket and the new Livingstone jacket. Analysis for the cradle-to-consumer and cradle-to-grave scenarios (low and high maintenance) and for the multifunctional assessment between the new Livingstone jacket and a combination of the Blazer jacket and a winter jacket. Figures show environmental improvement by circle completeness.

<Heading level 1> Discussion and conclusions

As defined in the Eco-design Directive 2009/125/EC (European Council 2009a), a consideration of the entire lifecycle of a product is important in eco-design implementation. Although legislation has focused on the improvement of the use phase of ErPs, some non-ErP household items have a direct relation to ErPs and their resource consumption during the use and maintenance stage of their lifecycle. Therefore, strategies regarding use and maintenance as well as proper communication-to-user efforts are needed to include the consumer as contributor to the environmental responsibility of a product.

Two non-ErP eco-design studies showed the relevance of considering the entire lifecycle due to the achievement of greater outcomes when considering a cradle-to-grave scope instead of cradle-to-consumer scope. For both products (knife and jacket), the resource consumption (water, energy) during the use phase turned out to be the key points of the environmental burdens because the maintenance was performed with an ErP. Therefore, the prototype design included communication-to-user strategies for enhancing eco-efficient maintenance practices.

The series 900 knife was also improved in at the materials selection, processing and maintenance phases. Eco-design at the cradle-to-consumer level showed considerable reductions in the environmental burdens of the knife (≈30%). However, the inclusion of maintenance strategies resulted in environmental improvements up to 60% higher than when considering only the cradle-to-consumer stages.

The Blazer jacket was changed into a new multiseasonal model with detachable pieces, while also improving maintenance, communication-to-user efforts and use of recycled materials. An eco-design validation from a cradle-to-consumer perspective showed higher environmental impacts of the new model due to the higher material consumption. However, consideration of the whole lifecycle showed lower differences between the two models. Furthermore, the new model can be used during the entire year, and a multifunctionality assessment noted that the new model could cover the function of the Blazer jacket and a winter jacket and could reduce the environmental burdens by ≈40%, where the maintenance improvements contributed between 40% and 80% of this reduction.

Two aspects are relevant to the evaluation of the maintenance of a product during the eco-design process. First, quantitative evaluation (i.e., LCA) should include maintenance scenarios for evaluating the best and worst consumer behaviors. In the case of the knife, washing could be performed by hand or with a dishwasher, which would have a significant effect on environmental impact because a dishwasher is related to an ErP. In addition, the use of different ErPs for the maintenance (i.e., drier and/or iron) can vary the impact contribution of the maintenance of a jacket. Therefore, the assumption of only one scenario could result in completely different outcomes, which may not show the real performance of the product.

Second, analysis of the efficiency of the proposed strategies is relevant to include the different user's behaviors that can result from communication. Therefore, different efficiency rates should be considered to assess this issue. In the case of the jacket project, this analysis showed that even with low efficiency rates (50%), the new eco-product would have lower environmental burdens than the original one.

Communication-to-user strategies were performed both for communicating the environmental performance of the product and for promoting an environmentally friendly maintenance behavior of the user. For the second purposes, strategies were performed in different ways (figure 4). First, the new knife design included a microfiber cloth to give the user a maintenance accessory for an eco-efficient practice (i.e., dry cleaning) while encouraging its use. Second, both ecodesigned products included washing symbols for clothes to indicate which practices the user should avoid to achieve a low impact on the environment. For example, for the eco-designed jacket, washing symbols were incorporated to caution the user against the use of a dryer or iron (ErPs) in the maintenance stage. Despite not being actual environmental symbols, popular symbols are a way to stimulate environmentally friendly behaviors by using already well-known, common and understandable symbols by consumers. However, these may be complemented by other company-user environmental communication channels, such as website, packaging or manuals. Finally, the environmental benefits of the use of the accessory were illustrated in terms of avoided water consumption.

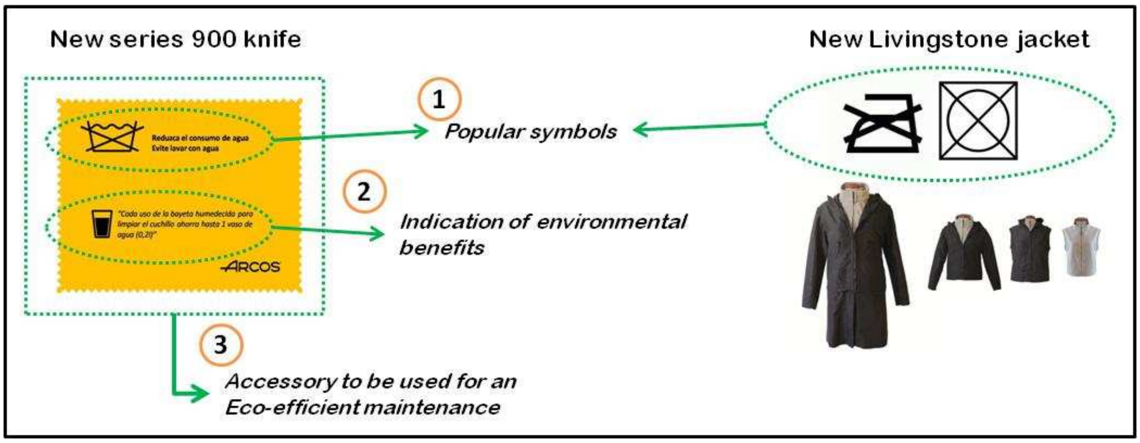

Figure 4. Environmental communication-to-user strategies for promoting efficient maintenance procedures.

Environmental communication has been carried out in the domestic sphere over the past several years through best-practices campaigns from public administration (e.g., resource efficiency, *see* EU Generation awake campaign: http://www.generationawake.eu/en) and the education system (e.g., water consumption in schools). Moreover, domestic campaigns often achieve considerable results, such as increasing recycling rates (e.g., Grodzińska-Jurczaka et al. 2006). In this sense, communication to domestic users, which are used to receiving advice about best practices, seems to be a potential effective tool to improve the environmental performance of household products.

Secondly, environmental communication about the product performance (e.g., labeling) result in an important tool to stimulate the consumer choice among different products. Environmental concern is growing in the market while becoming an important role as a decision-making criterion (Laroche et al., 2001). By informing about environmental properties, the producer is contributing to overcome barriers identified for green purchasing (Kollmuss and Agyeman, 2002) as, for example, environmental information may contribute to the environmental knowledge of the user contributing positively to increasing the environmental responsibility of the consumer (Jordan et al. 2006).

Although the economic aspects can be a barrier (e.g., investment) or a source of skepticism (e.g., doubts in the cost-benefit balance), some authors have analyzed the economic performance of ecodesign in enterprises with positive outputs (e.g. Borchardt et al. 2011, Johansson et al. 2001, Plouffe et al. 2011). The eco-design strategies implemented in both projects were selected by the companies and, therefore, the economic aspect was considered. Some of the strategies were free of cost, such as internal recycling of production waste (for the knife) or require environmental data from suppliers (for the jacket). Some of them had a little cost (e.g., maintenance accessory of the knife), while other strategies require an investment due to new machinery (e.g., coinjection of the handle of the knife). However, for the knife case the payback time of the new machineries was lower than 3 years. Moreover, environmental benefits regarding reduction of resources consumption (i.e., energy and material input) as well as increasing of internal recycling resulted into direct economic benefits for the enterprise and into a reduction of the cost per unit (comm. verb. ARCOS).

In this sense, and according to the literature, ecodesign entails not only environmental but also economic positive outcomes. Therefore, companies may be encouraged for assessing their products from an eco-design and life-cycle perspective. Although eco-design projects may need personnel and training investment, cost reductions per unit can be achieved through sustainable strategies. Moreover, some of them are transversal strategies that can be applied to most of the production chain (e.g., investment in more efficient machinery will affect all the products involved in that process).

The analyzed case studies demonstrate the eco-design of two products with different design considerations. The knife is a traditional product with a long lifespan, with a determined function and with a restrictive hygienic regulation (i.e., restricted contact of certain materials with food). As a result, the implementation of innovative design and environmental strategies are limited. In contrast, the jacket is part of the clothing market, where the design and application of new materials is continuously evolving. Regardless, for both cases, eco-design showed environmental improvements and highlighted the role of maintenance in a product's lifecycle, where the environmental burdens could be reduced by 40% to 80%.

In this sense, maintenance became a key stage in the eco-design of two non-ErPs due to their close relation to ErPs during this stage. Strategies applied to other stages (i.e., materials and processing) resulted in environmental improvements for the new 900 series knife, although the burdens reduction could be three times higher when considering maintenance. Furthermore, eco-design of the use phase was essential for obtaining better results in the case of the Livingstone jacket, which had a worse environmental impact in a cradle-to-consumer perspective than the initial jacket. Methodologically, maintenance scenarios are important to show how much the environmental burdens can be reduced as well as evaluate how effective communication-to-user strategies are in encouraging users to minimize environmental impacts in their use of the product.

Communication-to-user efforts should be concise and indicative of the environmental improvements to motivate users. The use of popular symbols (e.g., washing symbols) could simplify the messages from the producer to the consumer. The products presented here are household products, where environmental communication has developed during the last several decades and where effectiveness has been demonstrated.

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About the authors:

Esther Sanyé-Mengual is a PhD student at the Sostenipra (UAB-IRTA-Inèdit) research group of the Institute of Environmental Science and Technology (ICTA) (Universitat Autònoma de Barcelona, UAB) in Bellaterra (Barcelona), Spain.

Paula Pérez is a PhD student at the Department of Chemical Engineering of the University of Santiago de Compostela (USC) in Santiago de Compostela, Spain.

Sara González-García is a post-doctoral researcher at the CESAM. Department of Environment and Planning. University of Aveiro (Portugal)

Raul Garcia is the product manager of Inèdit Innovació, S.L., a spin-off of the UAB Research Park, in Cabrils (Barcelona), Spain.

Gumersindo Feijoo and Maria Teresa Moreira are professors at the Department of Chemical Engineering of the University of Santiago de Compostela (USC) in Santiago de Compostela, Spain.

Joan Rieradevall and Xavier Gabarrell are professors at the Departament d'Enginyeria Química (XRB) of the Universitat Autònoma de Barcelona and senior researchers of the Sostenipra (UAB-IRTA-Inèdit) research group of ICTA in Bellaterra (Barcelona), Spain.