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Variables that affect the environmental performance of small electrical and electronic equipment. Methodology and case study

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ABSTRACT

This paper provides a methodology to identify the variables that affect the environmental performance of the life cycle of small electrical and electronic equipment (EEE). Different environmental indicators were contemplated as response variables, and five covariates were considered to potentially affect the life cycle of equipment: material weight, distribution, power, frequency of use and end-of-life. Different values per covariate were assumed. For material weight, power and frequency of use, three different levels were considered for each one: low, average and high. For distribution, three different distances were taken by simulating national, European and international distribution. For end-of-life, different scenarios were considered: using the equipment until the end of its life span, repairing it (assuming different repair types) or replacing it with a new one if it breaks before the end of its life span. The environmental impacts of each scenario obtained by combining these covariates were calculated by applying the Life Cycle Assessment (LCA) methodology using mid- and end-point impact assessment methods. The obtained environmental indicators were modelled by Integrated Nested Laplace Approximation (INLA) to identify the variables that affect the environmental performance. The methodology was applied to a sample of 10 categories of small household EEE. The results revealed that one general pattern was associated with all these categories: the covariates that statistically more affected the environmental impact of their life cycle were, in this order, frequency of use and power, followed by end-of-life strategies and material weight.

1. Introduction

Recently, European directives and legislation address the circular economy principles (The Ellen Macarthur Foundation, 2013), which aim to ensure that products, materials and resources are maintained for as long as possible in circulation, while reducing the generation of waste by applying strategies to extend their useful life, such as repair and reuse (COM 33, 2017; COM 614, 2015). This approach is particularly relevant for electrical and electronic equipment (EEE) given its rapid innovation and substitution cycles, the accelerated growth of its waste, and the variety of components and materials in its composition (Cui and Forssberg, 2003).

In this context, many EEE life cycle aspects can be assessed from an environmental point of view, but those generally related to both its end-of-life (EoL) alternatives and energy efficiency have been the most analysed ones in the literature.

According to Maurer and Pachl (2015), measures should aim to, among others, systematically model replacement scenarios to calculate the optimal time at which replacing an EEE makes sense from an environmental and cost perspective for consumers. With this approach, several studies have focused on determining the environmental performance of different EoL strategies for energy-using products, and this emerging research area derives from recent and continuous legislative developments in the fields of waste electrical and electronic equipment (WEEE) (Directive, 2012/19/EU), energy efficiency (Directive, 2010/30/EU) and eco-design (Directive, 2009/125/EC).

For example, Allwood et al. (2011) concluded that for EEE to have a significant impact on use, it may be better to replace it with more energy-efficient alternatives. While referring to large appliances like refrigerators, Kim et al. (2006) also concluded that their

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premature replacement could be an effective environmental strategy. Tasaki et al. (2013) identified the best replacement age for equipment, such as TVs, air conditioners and refrigerators, from the reducing energy use viewpoint. (Prakash et al., 2012a,b and Yu et al. (2010) concluded that for equipment such as laptops or mobile phones, early replacement would probably not be the optimal environmental strategy given their relatively low energy use. Bakker et al. (2014a) and Pérez-Belis et al. (2017) also analysed the effect of consumer use behaviour when selecting the best EoL scenario for EEE.

Apart from energy efficiency and EoL aspects, other studies have focused on material efficiency (Allwood et al., 2011; Chancerel et al., 2017) or resource efficiency (Ardente et al., 2012). However, there is no study in the literature that simultaneously considers all the aspects that affect the environmental performance of the life cycle of EEE.

With this approach, this study focused on identifying the variables that affect the environmental performance of the life cycle of EEE by conducting a sensitivity analysis in which the effect of variables, such as material weight, distribution, equipment power and frequency of use and different alternatives of end-of-life, were considered.

2. Methodology

In order to provide a methodology to identify the variables that affect the environmental performance of the life cycle of EEE, the stages shown in Fig. 1 and described below were proposed.

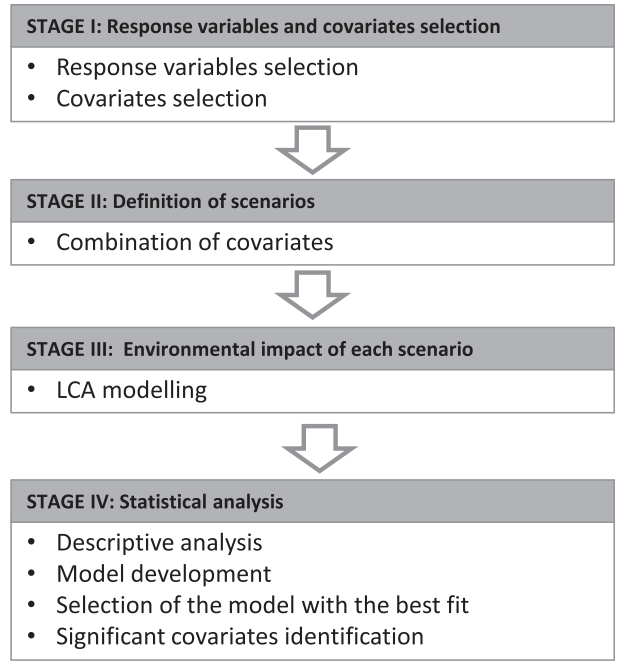

Fig. 1. Methodological approach.

2.1. *Stage I: response variables and covariates selection*

The response variables and covariates that characterise the environmental performance of EEE need to be selected according to a literature review. Response variables have to quantify the environmental impact of the life cycle of EEE, while covariables are parameters that affect the life cycle of EEE.

The environmental impact of EEE can be obtained by applying the Life Cycle Assessment (LCA) methodology (ISO 14040, 2006; ISO 14044, 2006). This tool is able to assess the potential impacts of a product or service over its whole life cycle. The environmental impact obtained from an LCA study can be measured in different units depending on the life cycle impact assessment (LCIA) method applied. If mid-point LCIA methods are applied, an environmental indicator for each considered impact category is obtained, as indicated in ISO 14040 (2006) as a mandatory element. Different impact categories and various methods for weighing factors can be applied (CML (Guinée et al., 2002), EDIP (Potting and Hauschild, 2004; Wenzel and Hauschild, 1998), etc.). However if end-point LCIA methods are applied, a unique environmental indicator is obtained for the analysed system, as proposed in ISO 14040 (2006) as an optional element. Different impact assessment methods have been developed for this purpose, such as Eco-indicator'99 (Goedkoop and Spriensma, 2000), ReCiPe (Goedkoop et al., 2009; Huijbregts et al., 2017), etc.

A review of LCA studies applied to assess the environmental performance of EEE was conducted to facilitate the selection of the commonest LCIA methods and impact categories applied to define response variables (Table 1).

The results show that the literature considers a wide range of impact categories. However, the commonest ones are those highlighted in grey in Table 1: abiotic depletion (AD), global warming (GW), ozone layer depletion (OLD), photochemical oxidation (PO), acidification (AC), eutrophication (EU) and human toxicity (HT). Eco-indicator'99 method (Goedkoop and Spriensma, 2000) is the most widely applied end-point LCIA method, although this method is no longer used since the ReCiPe method (Huijbregts et al., 2017) has been more recently developed and built on the Ecoindicator'99 method (Goedkoop and Spriensma, 2000). We can observe in Table 1 that a combination of primary and secondary is commonly used for modelling LCI, where the Ecoinvent database is the commonest source for secondary data.

In reference to covariates selection, there is a wide range of parameters that may affect the life cycle of EEE. To select them, a literature review was done to identify the most commonly analysed parameters (Table 2).

2.2. *Stage II. Definition of scenarios*

The definition of scenarios has to be done by combining the values that each covariate can take, as Fig. 2 shows. Each combination of values per covariate creates a scenario to be analysed by applying the LCA methodology.

2.3. *Stage III. Environmental impact of each scenario*

Environmental indicators (response variables) can be obtained for each scenario based on the application of the LCA methodology. According to the ISO 14040, (2006) guidelines, the following stages and general aspects in each need to be considered:

- Objective and boundary definition. This study aimed to obtain the environmental performance of the life cycle of the different scenarios for the life cycle of EEE. To this end, the life cycle stages detailed in Fig. 3 were proposed to be included in the boundary of the study: materials acquisition and production, distribution, use and end-of-life.

  The functional unit recommended for the LCA study corresponds to the use of each equipment during the entire lifespan that corresponds to the EEE category to which it belongs, from its raw material acquisition and manufacturing to its end-of-life treatment.