A tool for detailed analysis and ecological assessment of the use phase

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Abstract

The use phase in Life Cycle Analysis is normally calculated considering both an average use and user. This limits the effectiveness of any strategy aimed at reducing the environmental impact of the product use. To tackle this problem, a tool to model use in detail by differentiating user and product contributions is proposed. It can be coupled coherently with existing environmental assessment approaches. Its application is illustrated with a case study (refrigerator). The proposed works is complementary calculation tool to improve the environmental assessment.

Keywords: Eco-design; LCA tools; Product Use Phase

1. Introduction

Life cycle assessment considers the environmental impact evaluation from the moment the product most basic components are obtained (raw materials), up until the product is discarded or no longer used (end of life).

In general terms, software to perform LCA generally consists of a database, a modelling module and a set of assessment methods for environmental impacts. The data are handled and modelled on an interface. The modelling consists mainly of associating product aspect to existing life cycle inventory of processes or materials. The combination of processes and materials represents a stage in life cycle and is defined by its environmental input and output.

The use phase of a product modelled under a traditional LCA is a representation of the average conditions. This can be illustrated by the example of the New European Driving Cycle [1] which considers two types of driving styles (urban and extra-urban) in a 1200 second cycle. The procedure used for testing is usually under controlled conditions such as a flat surface and/or absence of wind. This is a generalization that is not close to reality, neither in terms of the driving conditions, nor in terms of the driving style.

It could be argued that all phases of the product life cycle are represented as average conditions. Nevertheless, human relationship with objects, especially when using them is determined by cultural and physical environment, habits and cognitive operations in their minds. When a product design is confronted to a group of users who differ widely in these, each one of them will have a different behavior with the product [2]. So, it is misleading to consider the middle point as valid representation of the group’s heterogeneity. The use phase of the refrigerator, for example, requires opening and closing the door with external temperatures that vary depending mainly on the geographical location and season (physical background of the user). The cooling system of a fridge is designed to work at an average external temperature of 25ºC, with a tolerance of +/- 10ºC, to maintain the internal temperature of the fridge constant. The energy required to handle variations in external temperature throughout a year, is not the same under conditions where the average temperature has a small standard deviation vs. conditions where the standard variation is important. The same could be said for the total number of times the door is opened and closed (cultural background, habits and cognitive processes). Having an average number of...
times will not reflect equally the two uses represented in Fig. 1 (data for temperature record taken from [3]).

Moreover, the number of times a fridge’s door is opened and closed is one action within the whole use phase. It becomes untraceable under a classical LCA approach because it is modelled as energy consumption over the use phase, without any reference to frequency of the user actions (details in paragraph 2).

As a result of these modelling limitations, the design strategies that could be taken in order to reduce the impact in use cannot have a clearly defined aim. Since the specific actions that result in important environmental impacts are indiscernible under current LCA approaches, only very general guidelines (such as “motivate the driver to keep a constant speed whenever possible” in the case of the car) can be given.

In the first section, an overview of the LCA tools and how they deal with the use phase is presented. Then a formalized proposal is presented. Following that, along with the case study, the transformation of the proposal into a calculation tool is presented. Finally, a brief discussion and future works perspective is included.

2. LCA tools and use phase modeling

A review of three different software applications has been done: SimaPro7 [4], OpenLCA [5], and BilanProduit [6].

The first one is one of the most popular in industry, with several paying options. The second one is a freeware that can nevertheless offer users the possibility to model large systems. The third one is a very simplified and free tool for environmental assessment sponsored by the French Environmental Protection Agency (ADEME). These three tools can be representative in terms of how a traditional LCA approaches the use phase of a product.

2.1. LCA software and circumstances of use.

When modelling a product life cycle model, environmental expert proposes an average model associated to the product model and the defined functional unit. As explain in introduction, with the same product design, different use circumstances can happens. All the reviewed software proposed to model use as an average. A difference in the circumstances of use can, in the best case, be modelled as an uncertainty around this average value or a completely different life cycle scenario.

2.2. SimaPro.

For SimaPro in its latest version 7 [4], the use phase is not understood as an independent phase of the product life cycle (like the assembly and the phases of end of life). It is included in the product life cycle and can be modelled as a process (energy for example) and/or the replacement of an assembly part (for maintenance).

To account for the different use circumstances, an entire alternative product lifecycle with different process intake (like “Electricity” or replacement) should be modelled.

2.3. BilanProduit.

Despite the fact that it is a very simplified tool, the use phase is specified in a separate label and it is modelled in terms of any energy or materials consumed during the use phase. Different scenarios of use could be modelled by generating different lifecycle model, yet the same problem as in Simapro with the relation to the functional unit persists.

This could be circumvented by modeling the different use scenarios as different products, yet it would be, just like in SimaPro, an artificial fix that could become very long if the different scenarios vary a lot. This variation is discussed further in the conclusions of this section.

2.4. OpenLCA

The interface for OpenLCA is strongly based on impact assessment of processes rather than what is defined within the software as “product systems”. The construction of a product system is in itself rather difficult. Whereas it is more evident to model phases such as extraction, manufacturing, and distribution, the use phase and its related processes have a relatively limited scope.

2.5. Conclusions

Those three examples of LCA software show that use phase is one of the most difficult phase to model. In one of them, it is not even specify separately, but only as an event in product lifecycle.
One of the reasons for this difficult integration is that it is not easily related to product structure. Unlike, pre and post use phases, the mere decomposition of product in terms of materials and industrial processes is not enough to provide useful information to improve product environmental impact. Modelling use phase as consumption (energy, water, consumables) over lifetime will provide results that cannot be used directly to improve product impact.

Even if all structures are well suited to compare different product lifecycle scenarios, no specific configuration can support the evaluation of the same product over different use circumstances. Under the current approach, to define a new use scenario does not highlight the fact that one product design must support a variety of use circumstances.

In this work, a formalization and computational tool that could be complementary to the classical LCA tools is proposed. The main objective of the interface is to provide designers with information on product environmental impact during use phase, over a variety of use circumstances.

3. Theoretical definition of use phase environmental impact

In an ecodesign context, the identification of product related parameters to environmental impact is central. The ambition of this use phase model is to be able to illustrate the contribution of different product parameters under the influence of different type of user behaviour.

In order to do so, a model of the use phase is proposed that defines environmental impact in use phase based on product and user related parameters (Fig. 2).

![Fig. 2. Model of the use phase.](image)

The model proposed is based on the evaluation of environmental impacts during use phase depending on:

- Product parameters -PP- that will be demanded over the use phase, for example “Door opening for two seconds” or “Seal”. Those product parameters are defined by behavioral model, in the first example by the thermic model and in the second example by material resistance model. The behavioral model can be associate to life cycle inventories-LCI (§ 3.1)
- Intensity of practice of product parameters by user during a specific action, for example the action -A- “Extract aliments from the fridge” demands the product parameter “Door opening for 2 seconds” with an intensity of 4, equivalent of a door opening of 8 seconds.
- Grouping of action into moments - M- [7] that can occur multiple times over use phase. For example, “Extract aliments from the fridge” will happen during the moment “Breakfast” which occurs every day over ten years of product use.

The environmental impact of the use phase - EI can thus be described as:

$$ EI = F_n (PP(LCI); Intensity of A; Occurrence of M) $$

3.1. Associating a Life cycle inventory to product parameters

A product parameter, in this proposal, is a behavioural model of component that is associated to the realization of a product function. For example, the product parameter “Door opening for two seconds” is the thermic behaviour of the refrigerator component associated with the cooling of room temperature air that can enter in the product over two seconds. And for the “Seal”, the mechanical behaviour of the refrigerator sealing material is used to define it.

For the environmental assessment, a product parameter can be associated to the life cycle inventory (LCI) of a process. In the first example, an electricity process LCI can be associated to the consumption calculated for the thermic behaviour of the product. In the second example, the quantity of refrigerator sealing is associated to the material LCI of EPDM, the sealing material.

Equation (1) represents the environmental impact Pj of a product parameter associated to the function j:

$$ P_{Pj} = \sum a_p \times LCI_p(A) $$

With ap representing the quantity needed to realize the function according to product components behavioural model of processes A and LCI(A), the life cycle inventory of the process A.

3.2. User: evaluating the intensity of actions and occurrence of moments

In order to evaluate the impact of the use phase, user behaviour should be added to the equation. The contribution of the user is based on the frequency and intensity of activation for each of the product parameters.

The intensity of the action i on a product parameter $n_i$, in $n_{i,C}$, can be evaluated by observing user actions...
when activating the function. The assessment of intensity of user practice can be done by analysing the realization of a task.

The frequency can be evaluated by observing in which moments it can take place. Then the occurrence of the moment over the use phase can be assessed. The assessment of the moment’s occurrence is based on the projection of product use over it useful life.

This clear differentiation between product contribution and user related parameters enables to generate multiple assessment of the use phase with the same product model but with different users profiles, i.e., different intensities of action and occurrences of moments.

3.3. Environmental assessment of use phase

The environmental assessment of the use phase is a sum of the assessment of the moments. And moment’s environmental impact is based on the sum of its actions. The environmental assessment of the action $i$ is defined as:

$$Action_{(i)} = \sum_{n} in_{a,n,i} \times PP_i$$

For a product with $n$ product parameters, and the associated $PP_i$ environmental impacts.

The environmental assessment of a moment is:

$$Moment_{(i)} = Occurrence_i \times \sum_{m} \sum_{n} in_{a,m,n} PP_i$$

For a moment with $m$ actions.

The environmental assessment of the use phase is:

$$IE = \sum_l \sum_m \sum_i occurrence_i \times in_{a,m,n} \times PP_i$$

For a use phase with $l$ moments, $m$ actions over $n$ product parameters.

This formalization of product environmental impact during use phase helps identifying the contribution of the product (its $PP_i$), the user (occurrence and intensity), and the combination of the product with user.

4. A tool for use phase environmental impact evaluation during design

The tool developed to model a detailed use phase has a comprehensible interface for the product development team, including the environmental expert. It needs to associate product parameters to Life Cycle Inventory and users’ behaviour in term of actions and moments in order to make an environmental assessment. It follows the formalization stated in the previous section.

4.1. General approach

The calculation tool is deployed in three general phases:

Phase 1. The Moments of use, the Actions, and the Product Parameters are defined and listed. The eco-design expert defines at this stage the environmental indicators to be considered for the assessment.

Phase 2. As a result of observations of real use, Moments and Actions are associated first, followed by the association of the Product Parameters to the first two. The occurrence is defined for the Moments. The intensity is defined when associating Product Parameters with the couple Moment-Action.

Phase 3. The calculation of the environmental impact is made, considering each of the indicators defined by the eco-design expert on Phase 1.

4.2. Case study

The case study for this work is a refrigerator, the product is considered to be used in France, and the information has been extracted from government sources as well as studies made by national statistical institutions. The details of the sources can be found in Table 1.

The phases explained in the previous subsection are applied by a mixed group of experts that includes both environmental assessment experts and human factors experts. They determine the contextual factors and the user habits that influence the environmental impact of the phase.

In this case study, the use scenario is limited to one user profile, the French user and one product model. It defines the list of actions and moments and the occurrence of moments. For the refrigerators, the list is illustrated in Table 1. Five different type of meal were defined: Breakfast, Lunch, Dinner, Snack, Munchies, and Refreshments.

| Type of information | Source |
|---------------------|--------|
| Kind of product, energy class, product park age, refrigerator’s average internal temperature | [8] |
| Population in France | [9] |
| Buying attitudes in France | [10] |
| French Dietary behaviour | [11] |
| House heating behaviours in France | [12] |
| End of life of refrigerators in France | [13] |

Then, the different product parameters are listed and characterized. A list of 23 product parameters was identified and some of them are reproduce in Table 2. They are modelled in the units that need to be used for the assessment. For example, Table 2 has 8 product parameters (n=5 in the table) that represent the cooling behavioural model for eight different food group that are defined by the energy necessary to cool one kg of this type of food for room temperature to fridge temperature (units kWh/(kg°C*K)). Parameters 9 to 12 represent the environmental impact by kg of what will happens depending on the trash used for the end of life of such components.
Next, all the actions that reflect the user behaviours when interacting with the product are also coupled with the product parameter that is used to realize it. The association is made by specifying the intensity of the action.

Table 2. Product parameters for the refrigerator and their associated units

| No. | Product parameters |
|-----|--------------------|
| 1   | Connecting the fridge (Text=25°C; Atmospheric) kWh |
| 2   | Overconsumption for 1°C (reference: 25°C) kWh |
| 3   | Side blocked by cold element kWh |
| 4   | Side blocked by hot element kWh |
| 5   | Food = Food group 1 kWh/(kg°C*K) |
| 6   | Open door < 5 seconds kWh |
| 7   | Open door >= 5 seconds kWh |
| 8   | Defrosting kWh |
| 9   | Recycling Packaging Type.kg |
| 10  | Recycling Refrigerator Type.kg |
| 11  | Domestic Waste Packaging Type.kg |
| 12  | Domestic waste: refrigerator Type.kg |
| 13  | Cleaning products kg |
| 14  | Seal kg EPDM |

Table 3. List of “moments” within the life of the refrigerator.

| Moment       | Actions associated          |
|--------------|----------------------------|
| Installation | Take out Remove packaging  |
|              | Connect the user manuals and guarantee |
| Learning     | Read the instruction manual Make analogies |
| Use Summer   | Connecting                   |
| Use Autumn   | Connecting                   |
| Use winter   | Connecting                   |
| Use spring   | Connecting                   |
| Shopping     | Establish the list Store the food |
| Meal 1 week  | Prepare Store               |
| Meal 1 weekend | Prepare Store        |
| Cleaning     | Disconnect                  |
|              | Take out the food Store    |
|              | Take out the shelves Store  |
|              | Use a cleaning product Store |
|              | Put the shelves back in Store |
|              | Connecting                  |
| Maintenance  | Disconnect                  |
|              | Disamount                   |
|              | Change the defective parts Dis aggregate |
|              | Remount                     |
|              | Connecting                  |

4.3. Tool interface

The different parameters are included in a database delivered to the use-phase modelling tool user through a friendly interface that can help him/her register the two pieces of information needed to complete the environmental assessment: the intensity of the “action” related to the product parameters, and the number of times the “moments” occurs during the product life time (named “occurrence”).

For the case study, an interface has been developed to facilitate the registration of the 3 lists (product parameters, actions and moments), as well as the intensity and the occurrence. This first step is illustrated in Fig. 3. The association of product parameters to LCI is made in external LCA software and documented in the tool.

Once all the fields are documented, the option to calculate is enabled and the environmental assessment is made, according to the formulations in the previous section.

4.4. Environmental impact calculations

The report given by the tool uses visual communication tools (rather than numbers) to guide the development team on which product parameters, which moments, and more specifically, which actions within each moment have the more important impact.

In this case (Figure 4), the environmental indicator is energy consumption, and the results are shown with color codes. Red reflects the first contributors to the environmental impact, deep green the last. As it can be seen:

- the most impacting Moment is “Use summer”, followed by the other seasonal moments of use.
- the most impacting action is “Connect”, followed by certain cases in which the action “Organise” impacts
- the most impacting product parameter is “Connecting” (Text=25°C; Atmospheric). The second most impacting product parameter if “Foods Liquids”.

Fig. 3. Interface for the use-phase modelling tool, version 1.0.
This information can give important guidelines for the product development team. It can then direct the design efforts to focus on improving, e.g., the product parameter “Connecting” (by redesigning the refrigerator’s compressor). It can also focus on the user’s behavior during the moment “summer” and associated action “connect”, by implementing for example, an eco-feedback devise [14,15].

The detail offered by the tool proposed is far from the single score offered by the traditional tools, and far from the averaged total consumption of energy (for the case study) usually accounted for under a classical view. It provides designers with information on product environmental impact and it repartitions between product and users. The possibility to assess, for a same case study, the single score offered by the traditional tool, is far far away from the detail offered for the work of this tool. It can then direct the design efforts, and far from the averaged total consumption of energy (for the case study) usually accounted for under a classical view.

The automation will consist on a direct connection of those LCI directly into the software. The association of life cycle models will require collaboration with LCA software developers, in order to harmonize their formalization of the product life cycle with our use phase model proposition.

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