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ORIGINAL PAPER

Development of usage models for the ecodesign of products: the concept of usage ecodrift

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Abstract Usage ecodrifts, which refer to non-optimal use of a product by the users, create additional environmental impact generators: energy overconsumption (real-time impacts) and abnormal wear and tear of parts of the product (delayed impacts). The goal of this study is to demonstrate that these Usage EcoDrifts must be taken into account during the design stage to better the environmental performance of the use phase of the product. In this paper, we study the case of different usages of a vacuum cleaner and their environmental consequences. We first conducted a survey to gather information on how people use the product. Then, we conducted experimentations to measure the consequences of the usages. We also explored how the testers responded to feedback inviting them to adopt a more sustainable behaviour. Results show that most of the users do not use the product optimally and cause additional environmental impact. Several usage ecodrifts were identified, causing both abnormal energy overconsumption and wear and tear of the product. The calculations show that delayed environmental impacts, because their consequence is the early replacement of the whole product, are of much greater importance than real-time environmental impacts.

Keywords Usage EcoDrift · Use phase model · Ecodesign · Life cycle assessment · Users segmentation · Interactive design

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1 Introduction

The use phase of products is the source of a great share of environmental impacts at a global scale [1]. As showed by Tang and Bhamra [2], people often find their own ways of using products and risk deteriorating their environmental performance. These non-optimal usages generate both unnecessary electrical overconsumption [3,4] and abnormal wear and tear of products [5]. In this study, we call product usage which deviates from the best available environmental practices available "usage ecodrift" (UED). UEDs do not have yet a common shared definition among the scientific community. Given its importance on the environmental performance of products use phase, it appears necessary to clarify this concept. The UED concept has already been studied in the scientific community under other names. Studies have mainly focused on eco-driving and household sustainable practices regarding water and heating/cooling [6–10]. The goal of this study is to demonstrate that the UEDs can be modeled to be taken into account during the design stage of products. There, they can be dealt with to better the environmental performance of the use phase of the product. This underlines the fact that the ecodesign process has to be highly interactive with the users. Knowing the users and their practices is of crucial importance for the product to be environmentally efficient. Especially if the use phase has a high environmental impact, an interactive approach should be systematically employed when ecodesigning a product.

To evaluate the pertinence of the UED concept, we used the case of the wireless vacuum cleaner. We studied its usage by observing a panel of users and conducted several environmental evaluations of the product itself and of different usage scenarios.

In Sect. 2, the UED problem is developed, Sect. 3 details the research method, Sect. 4 gathers the results obtained during the field and laboratory experimentations. Finally the results are discussed and future research problems are suggested.

2 The behaviour-centered design challenge

Taking users behaviors into account during the design process is not easily done. For a given product, the diversity of users induces a diversity of usages and thus, a diversity of UEDs. This diversity is due to several factors such as need, culture, consent, etc. [11].

2.1 The UED concept

Our definition of the UED concept is based on a previous research conducted by Serna et al. [12]. Here, the UED concept takes into account both "real-time environmental impacts" (REI) (due to overconsumptions) and "delayed environmental impacts" (DEI) (due to abnormal wear and tear) [5]. The following definition is proposed: "For the usage of a product with a given functional unit, a UED is defined as a usage practice which, in comparison to a reference usage, causes: (1) an increase in energy consumption and/or (2) an increase in materials consumption and/or (3) abnormal wear and tear of the product (and so the need to replace it earlier), thus generating additional environmental impacts".

This definition underlines the fact that diverse behaviors can be associated with the diversity of users [13]. Hence, instead of considering only an "average user" and an "average usage" [6], the concept requires to study a wider panel of usages.

2.2 Considering users and usages

A first step of the problem concerns the way people learn how to use products. As products become more and more complex and user guides become heavier and heavier, it is not given that users will instinctively adopt a sustainable behavior. Later on, the usage pattern may evolve throughout the service life of the product. Usage patterns are likely to be influenced both by internal factors (ecological engagement, free time, health, culture, etc.) and external factors (energy cost, air quality, etc.) [14]. Scientific studies have shown up four constraints likely to lead to UEDs: habits, beliefs, comfort and time constraint.

User behavior is influenced by these four constraints simultaneously but some might be stronger than others. Grouping people according to their predominant behavioral constraints is a way to categorize users. Segment-specific technological solutions may then be developed to guide users towards a more eco-friendly behavior [15].

2.3 User awareness and design solutions

A product fulfils various different needs for various different users. Cor and Zwolinski [16] state that taking this diversity into account is essential for establishing an efficient eco-design strategy. Designers should use this diversity to design the technological solutions for the product. In the same time, the way users will interact with these technologies has to be thought through. An adaptive and interactive product is likely to be efficient and well accepted by the customers [17]. First, such a product encompasses the needs of a large variety of users [18]. Second, the interactive aspect, as it creates a dynamic relation with the user, allows an active influence of the product on the user's behaviour [12]. Hence, making products more interactive should permit guiding large user segments towards better usage practices while involving them in the process; thus making the change more durable and accepted.

If real usage differs notably from the ideal usage foreseen by the designer, the environmental impacts generated during the use phase may increase. To prevent this, the product itself can be a way to encourage a behavioral change since it is an interface between user and usage [19]. In the literature are found several "product to user" eco-usage mechanisms with different levels of enforcement [11,20,21]. They are usually labelled as "eco-feedback" (which is only informative), "behaviour steering" (which provides incentives or "forced functionality" (which is highly enforced).

Out of the four constraints listed in part 2.2 of this paper, we hold that *belief* is the most important. Indeed, a user who does not understand the relation between his actions and their environmental impacts may not be easy to guide towards more sustainable behaviour [3]. A sustainable frame of mind change is the prerequisite for inducing sustainable behavioral change [22–24]. According to the Theory of Planned Behaviour [25], knowing that the user has control over his/her actions (if the product is well designed) and that social norms are mostly in favor of sustainable behaviour, then only the user's attitude will influence their behaviour.

Informing users with eco-feedback seem to be an effective way of influencing their attitude [12]. However, a major eco-feedback drawback is the lack of certainty as to whether the user will get the information or will react in the desired way [15]. To improve the odds, designers must take into consideration the user's awareness process [26,27]. However, even when the behavioral change is accepted, it is necessary to ensure that the change is sustainable and will not fade over time [27,28].

3 Application of the UED concept

To evaluate the impacts caused by UEDs, we set up a six step research protocol: (1) definition of usage of reference (UoR), (2) users segmentation, (3) identification of UEDs, (4) experimentation, (5) modelling impacts and (6) environmental evaluation.

3.1 Step 1: Definition of the UoR

The UoR has been defined as the usage free of all UEDs. It is the one that offers the best environmental performance. The UoR is useful in two ways. First, to have a value to compare the environmental performances of the UEDs with. Second, to have a targetable goal that can be used to orientate users' behavior.

When the product is simple to use, common sense and discussions with users and with the designers should be enough to define the UoR. Otherwise, if finding the optimal use of the product is not trivial, techniques such as design of experiments should be employed to determine the best environmental usage patterns.

3.2 Step 2: User segments

A good way to establish different user segments is to explore directly the diversity of usages. To do so, a sufficient number of users and usage situations have to be observed. Data collection can be done in various ways. More important is the choice of the data collected and the ways of analyzing it. The data has to be pertinent to represent the diversity of usages. Then, using segmentation techniques allows establishing coherent users groups [29,30].

3.3 Step 3: UEDs identification

UEDs identification requires a broad and objective vision of the diversity of usages. Furthermore, when a UED is identified, it is crucial to know its level of occurrence among the population of users. A seemingly good way to have these broad and quantitative views of usages is to observe a large variety of users in a large variety of situations. Before observation, protocols have to be set up to define when a usage is out of the UoR boundaries.

3.4 Step 4: Experimentation

3.4.1 Feedback

Our experimentation consists in two use sessions separated by a feedback intermission and concluded by a debriefing. The feedback is given to the user directly to be sure that the information is heard. The second use session allows us to measure the reaction to the feedback. Finally, the debriefing is useful in order to know whether the user understood the feedback they were given and how they interpreted it.

3.4.2 UEDs

The use session is the occasion of confirming that the UEDs previously identified are really adopted by the users. It permits quantifying two of the UEDs negative consequences: overconsumption of energy and, also using information from the manufacturer, decreased lifetime (LT) of the system.

3.5 Steps 5 & 6: Impact models and environmental evaluation

In order to perform the environmental evaluation of the system, it is necessary to apply the results found during the experimentations to the whole of the product use phase. To do so, for each UED, we measure the electrical overconsumption and define, using inputs from the manufacturer, a value of LT decrease. These values are used to model the use phase of the product and calculate its impacts. First, the environmental impacts of each UED are calculated, then, the same calculations are conducted for several combinations of UEDs (each UED with a specific coefficient), defined to correspond to observed usage patterns.

4 Results

4.1 Case study

The case study concerns the usage of a household wireless vacuum cleaner (12V). The vacuum includes a dust canister (bagless system) and a dust filter. The control is a single three position slider button that can be moved by the user's thumb when grabbing the handle. The three positions are (1) Stop, (2) Run (low power) and (3) Run (max power). The battery LT is 500 cycles.

The results from this section were obtained following the method described in Sect. 3.

4.2 The UoR

The UoR has been defined by the research team using information provided by the manufacturer in the user's manual. When the information was insufficient, the best usage practices were arbitrarily determined after discussion. The UoR elaborated is summed up in the four following actions:

- Use low power vacuum on hard floors and max power on soft floors.

- Empty the canister once the marked level is reached.
- Clean the dust filter after 2 running hours.
- Unplug the battery charger when the charge is complete.

4.3 User segments

To identify user segments we conducted a survey among a population of users. We designed a questionnaire with 60 questions to characterize the respondent's usage practices. The questionnaire also allowed us to determine participants' environmental awareness. The survey provided us with 350 completed questionnaires. Analyzing the results allowed us to define three different user segments.

C1 *Hygiene* (40 %): They are not interested by how much electricity the vacuum cleaner needs. It is an everyday tool that must be efficient. People in this group are efficient and well organized for doing chores. Some know about the environmental consequences of their actions but they do not consider this as a priority.

C2 *Comfort* (51 %): Their priority is their well-being. Chores need to be done, the quicker the better. They favor easy-usage efficient products. Their choice tends towards silent and automatic products.

C3 *Eco-sensitive* (9 %): They are concerned about the consequences of their everyday actions. They often seek advice to improve their behaviour. They do not favor high product performances if this means consuming a lot of electricity.

4.4 UED identification

We chose to observe a panel of twelve persons while vacuuming "as usual" a 10 m^2 room. The experimentation was monitored so that users can be observed without being disturbed by the presence of a member of the research team. Usage practices that deviated from the UoR were marked and, if relevant enough, labelled as UEDs.

Observation of users and comparison with the defined UoR led us to identify 5 UEDs:

D1 Charging time management (battery left plugged in even when charged)

D2 Dust filter cleanness (vacuuming with an obstructed filter)

D3 Canister dust level (vacuuming even if the canister is already full)

D4 Vacuum power management (always vacuuming using max power)

D5 Preparing the room before vacuuming (moving furniture when vacuuming)

Table 1 UEDs distribution depending on user segment expressed in percentages of persons doing to the UED

	C1	C2	C3
D1	50	100	0
D2	100	100	50
D3	50	70	50
D4	50	70	50
D5	50	100	0

Not all users contribute towards these UEDs in the same proportions. The survey allowed identifying UED tendencies for each user segment. Proportions were established using the answers to the questionnaire. These proportions are approximated in the following Table 1 (meaning that 50 % of users from C1 is doing D1, 100 % is doing D2, etc.).

4.5 Experimentations: UEDs

Each of the UEDs was reproduced in the laboratory to measure and calculate their environmental consequences caused by energy overconsumption and/or abnormal wear and tear. The results of the measurements and calculations are listed in the following Table 2. The electrical overconsumption is the difference between the reference usage electrical consumption and the value measured when reproducing the UED. The value is given for 500 usage cycles. The LT decrease is estimated using after-sales data gathered by the manufacturer.

Table 2 UED consequences in terms of electric overconsumption and LT decrease of product parts

UED	Consequences	Overconsumption (kWh)	LT decrease
D1 : charge management	Charger plugged in 24/7	3.3	Battery LT down to 360 cycles
D2 : filter cleanness	Hard on the motor, more running time	1.3	Motor LT decrease of 10 %
D3 : full canister	Less vacuum power, more running time	2.6	–
D4 : power management	Accelerated battery aging	3.2	Battery LT down to 400 cycles
D5 : room preparation	More running time	3.1	–

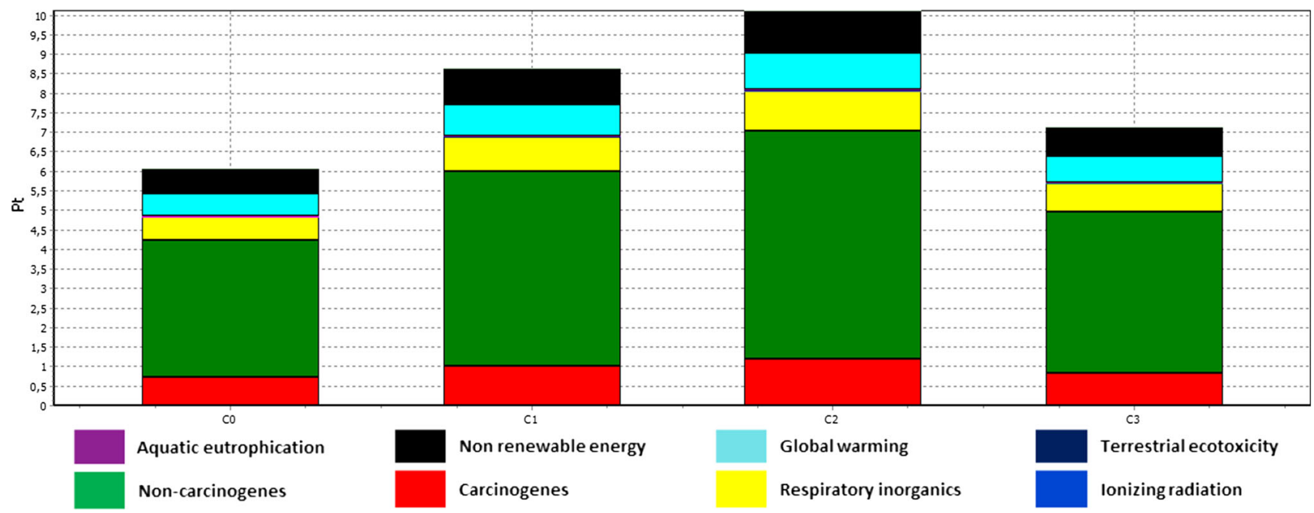

Fig. 1 Evironmental impacts of the UED sums corresponding to the pattern of each user segment

4.6 Models and environmental evaluations

The environmental evaluations carried out for this study were conducted using the SimaPro v8.0.4.30 software and the EcoInvent v3.1 database. The LCAs were performed accordingly to the ISO 14040 and ISO 14044 norms.

UED consequences, in terms of overconsumption and LT decrease, are translated into mathematical equations in order to calculate environmental impacts. We consider that the LT decrease of a product part induces the same LT decrease for the whole product. As said earlier, usages are in fact combinations of several UEDs. Taking into account UED distribution depending on user segments allows us to obtain results closer to reality. The results of Table 2 are used to create the UED coefficients of occurrence used in the calculation. The results of the calculation are displayed in Fig. 1 below. It shows that summing UEDs according to observed usages has heavy consequences. We can see that the score of segment 2 (C2 the one with the most UEDs) is 64 % (+4.1 Pt) higher than the ideal use score without UED (C0).

5 Conclusion

We conducted an experimentation to identify the UEDs from people of three different user segments (hygiene, comfort and eco-sensitive) when using a wireless vacuum cleaner. We showed that depending on their segment, users have specific usage tendencies associated with a specific combination of UEDs. We estimated that UEDs, when summed up, can cause a raise up to 64 must be taken into account that usage is often a sum of UEDs. Their weighting varies according to user behaviour. To counter the UEDs, designers must find a balance between considering the "average user" (which is inaccurate) or considering every type of user (which is impossible).

Creating several user segments based on their behavioral tendencies seems to be an effective way of addressing this issue. In order to increase products' LT, designers must anticipate UEDs and the wear and tear they generate. Technological solutions should be designed in this way.

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