Chapter 16
Environmental Lifecycle Hotspots and the Implementation of Eco-design Principles: Does Consistency Pay off?

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Abstract Structured approaches to diminishing products' environmental footprint include the identification of hotspots, e.g., lifecycle phases or aspects that feature criticalities in terms of environmental sustainability. Still in these approaches, measures are taken consistently by investing eco-design efforts to improve the situation in the identified hotspots. However, many products implement eco-design principles irrespective of hotspots, i.e., without taking into account the major sources of environmental footprint. A sample of products has been analyzed in terms of hotspots, and lifecycle stages are affected by the implementation of eco-design principles and achieved success. The study reveals that, while eco-design principles in the use phase of the product favor success, the consistency between the hotspot and the lifecycle stage does not modulate the relationship between implemented eco-design principles and success. As a result, while the identification of hotspots is a best practice as for the attempt to maximize environmental benefits brought on by eco-design initiatives, it plays a limited role in terms of customer's acceptability and appreciation of new products.

16.1 Introduction and Background

The need to design more sustainable products and encourage sustainable consumption practices is of anecdotal evidence. The variety of instruments to pursue this objective and the numerous eco-design principles (EDPs) available clarify that the

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paths to achieve more sustainable designs are various. Improvements can regard, among others, toxicity of materials, need for packaging, energy consumption, recyclability, and reusability. Every product is characterized by some of these aspects that, at the present stage, represent major environmental concerns. Formally, the term "hotspot" is used to characterize dimensions attributed to greater environmental criticalities and the circumstances in which they occur. Once identified, hotspots suggest which measures should be prioritized in order to minimize the product's environmental footprint. Despite their relevance, the definition and categorization of hotspots are not univocal; scholars attribute the term "hotspot" to phenomena that have a relevant negative impact on a system's environmental profile. In most of the cases, such a system is represented by a product or a family of products, while the hotspot is the lifecycle stage ensuing major environmental concerns [1]. Also in this case, the subdivision of the product life cycle into stages or phases is not universal.

In the literature, the identification of environmental hotspots represents a fundamental step when systematic design approaches are proposed [2], as they reveal major environmental aspects to take care of. Their identification has to take place in a continuous manner, as design modifications, product improvements and changes in the value chain can alter hotspots themselves [3]. Technological changes represent a considerable trigger for the need to reconsider hotspots [4]. The systematic identification of hotspots can also be seen as a checklist for visualizing redesign possibilities and deadlocks in the attempt to improve the environmental profile of the developed products, e.g. [5]. Furthermore, individual companies manufacturing akin products might find different hotspots in different sections of their process or the product life cycle [6]. Although hotspots are usually referred to environmental challenges, the social and economic dimensions should be also considered to target sustainability as a whole [7].

Traditionally, different design methods are normally chosen for tackling environmental issues belonging to different product lifecycle stages; the concept is extended to information management in [8]. In several contributions, different hotspots are linked with TRIZ or eco-design tools to disclose the most promising heuristics for obtaining improvements [9, 10]. The individuation of hotspots is relevant for the application of circular economy strategies within new product development initiatives too [11].

Lifecycle assessment (LCA) is classically used as a tool to identify hotspots; applications in different industries are illustrated in the literature. [12–16]. It is claimed that the information required to use LCA is often too complex to be available [17], especially in initial design phases [1, 7]. Actually, changes that are consistent with LCA outcomes and the identified hotspots are feasible also in late design stages, e.g., when performing geometric modeling [18], but the early design phases are susceptible of higher potential benefits [19]. Obstacles to an effective and quick execution of LCA are tackled by means of simplified procedures that allow for the determination of hotspots [20].

Despite the standard approach to investing design efforts in hotspots, i.e., where enhancements are supposed to provide the largest environmental benefits, these have to be considered also in terms of practicability and ease of interventions [6]. This aspect might lead product developers to channel eco-design resources in lifecycle stages irrespective of the major environmental burdens. The present study is concerned with the effects of the choice of lifecycle stages affected by implemented EDPs in relation to the presence of hotspots. These effects are evaluated in terms of products' market success. The research objectives are detailed in Sect. 16.2. Section 16.3 presents methods and materials required to investigate the research question. The results of the study are presented in Sect. 16.4, which is followed by discussion and conclusions (Sect. 16.5).

16.2 Research Objectives

Many products are developed and eco-design efforts can be recognized that have led from previous generations to the current one. More specifically, their design is featured by the implementation of one or more EDPs; a tentative list of these principles can be found in [21]. Details of the design process are generally not available; in particular, it is not known whether the changes brought on by new designs have been envisioned based on previous analysis of the products, e.g., including the identification of lifecycle hotspots. In principle, the application of EDPs that tend to minimize the environmental footprint in the most critical lifecycle stage (hotspot) results in larger environmental benefits and can be able to provide, as a consequence, greater customer value. This is supposed to take place if consumers diffusely recognize efforts aimed at improving products' environmental profile and contextually hotspots. As a result, those products capable of targeting hotspots by means of suitable EDPs are attributed of major success chances. This phenomenon, which can be hypothesized, has to undergo scientific verification. The research objective is therefore the verification of the following hypothesis.

> The selection of EDPs that affect the life cycle stages identifiable as environmental hotspots boosts the chances of new products success in the market.

In other terms, the consistency between EDPs and lifecycle hotspots is supposed to give rise to a (positive) effect in the relationship between the implementation of EDPs and market success.

16.3 Materials and Methods

In order to answer the research question, the following methodological steps have been considered necessary. At first, a set of products showing design efforts aimed to improve some environmental metrics has to be built (Sect. 16.3.1). All the products were then characterized in terms of:

- Lifecycle hotspots (Sect. 16.3.2)
- Implemented EDPs ascribable to product lifecycle stages (Sect. 16.3.3)
- Achieved success (Sect. 16.3.4).

16.3.1 Set of Products

A large set of products was identified by benefitting from established literature sources [21–24] that leverage examples to explain principles and techniques referable to eco-design, design for environment or design for sustainability. The authors selected products and services for the construction of the dataset, while stories about firms or trademarks were not relevant for the present study. These choices led to the determination of a product database including 178 unique products.

16.3.2 Lifecycle Hotspots

As mentioned in the introduction, the characterization of products in terms of environmental hotpots is not a standard process. The most common approach stands in the segmentation of the product life cycle into stages and the identification of the stage(s) where the most severe criticalities lie. In the present study, the authors required a taxonomy to subdivide lifecycles sufficiently general to be applicable to all the products. Based on the examples shown in the reviewed papers, the authors opted to schematize the lifecycle into:

- Raw materials and manufacturing (RMM);
- Distribution and packaging (D&P);
- Use phase (USE);
- End-of-life (EOL).

The attribution of the hotspots, i.e., one of the above stages, to products took place with a consensual technique. The starting point was the approach used in [1]; i.e., the reference hotspot is the one featured by the predecessor in a product family. This is appropriate for the present study, as it is here critical to compare previous criticalities (and not those ensuing after the introduction of the new design) with the actually implemented EDPs. All the authors analyzed the products separately and indicated what they deemed as hotspots. The results were compared and, in all those cases of misalignment, a discussion was carried out until an agreement was found. This eventually led to the attribution of the environmental hotspots for all the gathered 178 products.

16.3.3 Eco-design Principles

The authors used an established reference [21] to characterize the products in terms of EDPs. Here, a list of 31 EDPs is made available to readers and reported in Table 16.1. Although there is no shared taxonomy for EDPs, the mentioned source can be considered as the most acknowledged reference in this domain. In addition, the structuring of EDPs in terms of the lifecycle stage they affect eases the subsequent steps of the study, i.e., matching eco-design efforts with the lifecycle stages they have brought on benefits in (see Table 16.1).

The authors have attributed a number of EDPs to all the products by following an akin consensus technique. As for the products extracted from [21], a preliminary set of EDPs had been already considered. In any case, the authors added other EDPs by benefitting from the details provided in the description of the products and the EDPs. A new or additional EDP was assigned whenever the implementation of that EDP seemed reasonable. Particular attention was paid to the transformation of the product from the previous standard version to the new design.

16.3.4 Success

Also in this case, there is no universally recognized procedure to assess or evaluate a product's success, because the most established terms that feature success:

- Are predominantly of financial nature and are unknown to the public;
- Depend on companies' objectives related to the launch of a specific product, which represents another piece of information that is very difficult to obtain.

Given these obstacles, scholars devised a procedure to evaluate success based on available information accessible from the Web and the scientific literature [25]. They developed a seven-level success scale, articulated as follows.

- Level 1: information states that the product is a flop or it has never entered the marketplace after a large amount of time.
- Level 2: very scarce information is found about the product, which is then considered as an example of oblivion.
- Level 3: contradicting information about success and failure of the product has been retrieved.
- Level 4: success is suggested by information showing that some argued success indicators are fulfilled.
- Level 5: success is demonstrated by information showing that some undisputed success indicators are met.
- Level 6: information stating that the product was successful is found, but this takes place in Web sources only.
- Level 7: the same as level 6, but the information is accessible in the literature sources, i.e., more reliable sources, too.

Table 16.1 Eco-design principles extracted from [21] and used in the study; they are associated with affected lifecycle stage

EDP	Explanation	Lifecycle stage
01	Design for appropriate lifespan	EOL
02	Design for reliability (simplify, reduce number of component)	USE
03	Facilitate upgrading and adaptability	USE
04	Facilitate maintenance	USE
05	Facilitate repair	USE
06	Facilitate reuse	EOL
07	Facilitate remanufacturing	EOL
08	Intensify use (share, multifunction, integrated, on demand)	USE
09	Minimize material content or dematerialize, digitalize, miniaturize	RMM
10	Minimize scraps and discards	RMM
11	Minimize packaging (avoid, integrate, drastically reduce)	D&P
12	Minimize material consumption during usage (select more consumption-efficient systems)	USE
13	Minimize materials consumption during usage (engage systems with dynamic material consumption)	USE
14	Minimize energy consumption (during pre-production and production)	RMM
15	Minimize energy consumption (during transportation and storage)	D&P
16	Minimize energy consumption (select systems with energy-efficient operation stage)	USE
17	Select non-toxic and harmless materials	RMM
18	Select non-toxic and harmless energy resources	RMM
19	Select renewable and biocompatible materials	RMM
20	Select renewable and biocompatible energy resources	RMM
21	Adopt the cascade approach	EOL
22	Facilitate end-of-life collection and transportation	EOL
23	Identify materials	EOL
24	Minimize the overall number of different incompatible materials	EOL
25	Facilitate cleaning	USE
26	Facilitate composting	EOL
27	Reduce and facilitate operations of disassembly and separation	EOL
28	Engage reversible joining systems	EOL
29	Develop services providing added value to the product's life cycle	USE
30	Develop services providing "final results"	USE
31	Develop services providing "enabling platforms for customers"	USE

The attribution of success levels to the products of the dataset took place by following the designation procedure widely described in [25].

16.4 Elaboration of Data and Results

The gathered data have been organized as in Table 16.2. As it was one of the main objectives of the study, the authors determined if the implemented EDPs were consistent with the hotspot (last column of Table 16.2). The parameter *consistency* holds the value 1 (156 cases out of 178) if at least an implemented EDP belongs to the lifecycle stage that features the product hotspot, 0 otherwise. For instance, the value 1 is assigned to the second product in Table 16.2; the identified hotspot is USE and the EDP 16 belongs to the corresponding lifecycle phase USE; here, the EDP 18 (RMM) plays no role in the determination of *consistency*.

The data were then statistically analyzed with the software Stata 13.0 in order to address the research question. In the first step, the direct relationship between *success* and *consistency* was investigated through a regression in which the former is the dependent variable and the latter is the regressor. This regression and the others that follow are all ordered logistic, due to the ordinal nature of the dependent variable. According to the output of the regression, *consistency* tends to diminish the value of *success* ($\beta = -0.380$), but this indication is not reliable due to the high level of the *p*-value (0.343). Subsequently, the authors investigated the moderating role of *consistency* for each specific lifecycle stage. Four new regression analyses (one for each lifecycle stage) were performed, in which *success* is kept as a dependent variable, while the regressors were:

1. The presence of EDPs affecting the lifecycle stage (0/1), designated as Reg1;
2. The lifecycle stage being the hotspot for the product family (0/1), Reg2;
3. The multiplication of the two factors above (0/1), Reg3, which makes it possible to discover if the latter is a moderator for the former.

The results of the regressions are presented in Table 16.3, which includes, for each lifecycle stage (first column), the regression coefficients β and the corresponding p-values for the above three regressors. The data show that the sole coefficient featured by a p-value minor than 0.05 is the presence of EDPs ascribable to the use phase. The effect of this variable on success is positive.

16.5 Discussion and Conclusions

The main finding of the study is the rejection of the hypothesis formulated in Sect. 16.2. This means that the matching between environmental hotspots and the lifecycle phases in which EDPs are implemented does not result in greater success chances. It follows that eco-designed products can achieve success irrespective of

Table 16.2 Illustrative set of products, for which the following designations are indicated: success level (Sect. 16.3.4), hotspot of the product family (Sect. 16.3.2), implemented eco-design principles (numbered as in Table 16.1) separated according to the affected lifecycle stage (Sect. 16.3.3)

Product	Success level	Hotspot	EDPs RMM	EDPs D&P	EDPs USE	EDPs EOL	Cons
Tiles made of cement and mussel shells by Jan Velthuizen	1	RMM	10, 17, 19	–	–	–	1
Fria refrigerator designed by Ursula Tischner	1	USE	18	–	16	–	1
Whirlpool Green Kitchen	2	USE	20	–	08, 16	21	1
Edible packaging for chocolates, Eckes	2	D&P	10, 17	11	–	01	1
Refillable glue stick, Henkel	3	RMM	–	–	–	06, 24	0
Procter and Gamble toothpaste	3	RMM	09	11	02, 08	01, 24	1
Tupa bamboo beds	4	RMM	14, 17, 19	11, 15	08	01, 06, 24, 26	1
Pedal-powered washing machine	4	RMM	18	15	16	–	1
The Klippan sofa by Ikea	5	RMM	–	–	03, 04, 05, 25	07, 27	0

(continued)

Table 16.2 (continued)

Product	Success level	Hotspot	EDPs RMM	EDPs D&P	EDPs USE	EDPs EOL	Cons
Solar-powered mower, Husqvarna (Electrolux)	5	USE	–	20	–	–	1
gDiapers	6	EOL	17, 19	–	01, 03, 04, 05	06, 26, 27, 28	1
Hire Fitness equipment	6	RMM	–	–	03, 04, 08, 29, 31	06	0
Nested chairs	7	RMM	–	15	–	27	0
Patagonia common Threads Garment Recycling Program	7	EOL	10, 17, 19	–	–	06, 07, 21, 22, 23, 24	1

The parameter "consistency" is consequently determined (Cons in the last column)

Table 16.3 Outcomes of the regressions (regression coefficients β and p-values) investigating the moderating role (Reg3) of the consistency between hotspots (Reg2) and lifecycle phases affected by eco-design principles (Reg1) in the relationship between the latter and the success achieved by products

Lifecycle stage	β Reg1	p Reg1	β Reg2	p Reg2	β Reg3	p Reg3
Raw materials and manufacturing	−0.066	0.851	0.017	0.971	−0.481	0.415
Distribution and packaging	0.265	0.401	0.013	0.976	Omitted by the regression because of the limited number of data	
Use phase	1.28	0.030	1.18	0.447	−1.28	0.416
End-of-life	−0.389	0.168	13.2	0.976	−12.4	0.977

the individuation of the principal environmental criticalities. From this result, it is inferable that consumers have limited interest or experience problems in recognizing the effectiveness of and the benefits emerging from a product development process that starts with the identification of priorities in the environmental sense.

Another phenomenon could be ascribable to people's perception of value and benefits. One of the side results of the study is the fact that eco-design efforts involving the use phase of products, differently than all the other lifecycle stages, affects success chances—the effect is positive. Changes in this stage might result straightforward to consumers, as opposed to lifecycle phases they have more limited sensitivity toward and control over. Consequently, the easily recognized (sustainability-related) advantages can be seen as a source of value with positive repercussions on market success. This gives rise to a relevant research issue; i.e. the need for a better understanding about the importance of the effective perception of value is enabled by eco-designed products.

Although the main output of the study, i.e., the poor relevance of environmental hotspots in products' success, emerges clearly, some limitations have to be laid bare in order to consider possible sources of bias.

- The sample of selected products is large, but resulted insufficient to establish strong statistical relationships (see Table 16.3). This is also due to the uneven distribution of hotspots and lifecycle phases affected by EDPs. The authors benefitted from products described in the literature sources to create a sample of convenience and did not force the process toward a better balance among involved lifecycle phases;
- All the designations of the parameters attributed to products are featured by some extent of subjectivity, although performed with consensual techniques;
- The study assumes that greater environmental advantages are achieved when EDPs' corresponding lifecycle stages match the hotspots. This effect is intuitive, but cannot be demonstrated in the chosen case studies. At the same time, the relatively large number of implemented EDPs (average 4) represents a potential source of unbalance also for the parameter *consistency*, which features a predominant number of values equal to 1.

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