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Life Cycle Thinking and Eco-Design: An Overview

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Abstract

Life cycle thinking is increasingly recognized as a crucial component of environmental management, particularly within product-based environmental management systems that often incorporate eco-design principles. Eco-design can be applied to various aspects of product management, yet small and medium-sized enterprises frequently face challenges in implementing these activities due to their unique operational constraints. This paper proposes a simplified approach to eco-design, tailored specifically for small and medium-sized enterprises, by introducing a life cycle-based environmental classification of products. This classification serves as a starting point for small and medium-sized enterprises to enhance the environmental performance of their products through more informed design decisions. The primary objective of the paper is to present this classification system and discuss its potential role in improving product sustainability within the context of small and medium-sized enterprises operations. The study involved analyzing 50 products, which were classified according to selected environmental criteria. In the initial phase, a cluster analysis was conducted to categorize products into passive and active groups based on their environmental characteristics. However, the findings suggest that relying solely on this cluster analysis may not provide sufficient information for comprehensive eco-design strategies. To address this limitation, a second classification was performed using selected environmental impact indicators, specifically global warming potential and cumulative energy demand, calculated across three life cycle stages: production, use, and final disposal. This refined classification highlights the environmental hotspots for each product, offering a more detailed understanding of where improvements can be made. The final product classification provides valuable insights into the environmental impacts of different products, offering small and medium-sized enterprises a practical tool to support the implementation of life cycle-based eco-design processes. By adopting this approach, small and medium-sized enterprises can better navigate the complexities of eco-design, ultimately leading to more sustainable product outcomes and enhanced environmental performance.

Keywords: Eco-Design, Life Cycle Assessment, Environmental Management, SMEs, Product Sustainability
JEL Codes: Q56, L25, O32

1. INTRODUCTION

Eco-design is defined as "the integration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout a product's life cycle" (EN ISO 14006, 2011: 2). This concept is often referred to by other terms such as Design for the Environment, green design, life cycle design, and environmentally conscious design. While ecodesign and the development of green products may seem like contemporary concerns, they are not entirely new. As noted by Baumann et al. (2002), attention to this issue first emerged in the early 1970s and gained significant momentum, particularly throughout the 1990s. Over the past two decades, numerous initiatives aimed at advancing ecodesign methodologies and tools have been introduced (Lewis et al., 2001; Wimmer et al., 2004; Dostatni and Karwasz, 2009; Pigosso and Rozenfeld, 2011; Birch et al., 2011; Poudelet et al., 2012). One such initiative is the development of the Ecodesign Maturity Model, which consists of practices designed to enhance an organization's processes in the context of ecodesign (Pigosso and Rozenfeld, 2011). This model helps organizations evaluate their current ecodesign practices and identify areas for improvement to better incorporate environmental considerations into product development. Another significant contribution is the creation of the Business Process Reengineering (BPR) methodology, which aids in the development of Decision-Support Systems tailored for ecodesign. These systems help organizations make informed decisions that align with sustainable design principles (Poudelet et al., 2012).

In addition to these theoretical advancements, there has been considerable practical experience gained in the field of ecodesign. Various studies and initiatives have documented the application of ecodesign principles in real-world contexts, demonstrating the viability of integrating sustainability into product development processes (Tukker et al., 2001; Jincheng, 2003; Wimmer et al., 2010; Ribeiro, 2013). These practical experiences have provided valuable insights into how organizations can reduce their environmental impact while maintaining economic viability and product innovation. Over the years, the growth of ecodesign has been driven by increasing awareness of environmental issues, coupled with regulatory pressures and consumer demand for more sustainable products. This has led to the creation of new tools and frameworks that assist organizations in embedding environmental considerations at every stage of the product life cycle—from conception and design to disposal and recycling. The evolution of ecodesign highlights the critical role that product development plays in addressing global environmental challenges, such as resource depletion, pollution, and climate

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change. Ecodesign methodologies encourage designers and engineers to adopt a holistic view of their products, considering not only functionality and aesthetics but also the environmental impact of materials, manufacturing processes, energy use, and end-of-life disposal. By incorporating these aspects into the early stages of product development, companies can minimize waste, reduce energy consumption, and use more sustainable materials, leading to products that have a smaller environmental footprint throughout their life cycles.

Ecodesign has evolved into a robust discipline that integrates environmental concerns into the core of product development. It offers a framework for creating products that are not only functional and marketable but also environmentally sustainable. The combined efforts of academic research and practical implementation have resulted in a variety of methodologies and tools that help organizations adopt ecodesign principles, contributing to a more sustainable future. As environmental challenges continue to grow, the importance of ecodesign in shaping responsible and eco-friendly product development will only increase. It is plausible to anticipate that interest in ecodesign from the perspective of business practice will increase significantly in the near future. This growing interest is likely to be particularly noticeable among small and medium-sized enterprises (SMEs), many of which have either implemented environmental management systems on their own or have become part of supply chains where larger organizations require suppliers to comply with pro-environmental practices. As environmental concerns become more prominent across industries, SMEs are increasingly being drawn into the broader movement towards sustainability, driven by both regulatory pressures and market demand for greener products.

However, a key issue remains: is ecodesign "methodologically ready" to be implemented on a larger scale within business practice, particularly in SMEs? The question arises because many advanced ecodesign tools—such as detailed environmental life cycle assessments (LCAs)—are often seen as difficult to implement for smaller companies with limited resources. Various scholars have pointed out that while LCA and other sophisticated ecodesign methodologies can offer valuable insights, they are frequently too complex, time-consuming, and costly for SMEs to adopt effectively (Masoni et al., 2004; Le Pochat et al., 2007; Chevalier, 2009; Arana-Landin and Heras-Saizarbitoria, 2011; Buttol et al., 2012; Arzoumanidis et al., 2013). Given these challenges, this article seeks to contribute to the ongoing discussion by exploring an alternative approach: a life cycle-based environmental classification system for products that can serve as a starting point for ecodesign in SMEs. The idea behind this approach is to simplify the process for SMEs by classifying products into groups that share similar environmental impacts throughout their life cycles. By creating distinct product classes, designers can identify the environmental "hotspots"—the stages or aspects of the product's life cycle that generate the most significant environmental burdens—without the need for a full-scale LCA.

The primary goal of this article is to propose a classification system that meets the needs of designers, particularly in the context of defining environmental product classes and identifying critical points in their life cycles. By allocating a product to a specific class, designers should be able to pinpoint the environmental hotspots associated with that class and formulate an appropriate ecodesign strategy. This approach allows for the application of ecodesign principles without the necessity of conducting a detailed quantitative life cycle assessment, which can be both costly and resource-intensive for SMEs. This product classification approach has the potential to serve as an accessible tool for SMEs, enabling them to incorporate ecodesign into their processes without needing advanced technical expertise or significant financial investment. By focusing on the environmental characteristics of specific product classes, SMEs can more easily identify areas where improvements can be made, such as reducing resource consumption, minimizing waste, or selecting more sustainable materials. This, in turn, can help them meet the growing demand for eco-friendly products and contribute to broader sustainability goals without overwhelming their operational capacities. Moreover, this simplified ecodesign strategy could foster greater adoption of sustainable practices among SMEs by providing a practical, scalable solution that aligns with their capabilities. While large corporations may have the resources to implement comprehensive LCAs and sophisticated environmental management systems, SMEs often require more tailored approaches that reflect their unique constraints. By offering a product classification system that highlights environmental hotspots, this article aims to bridge that gap, making ecodesign more accessible to a broader range of businesses. As the demand for environmentally sustainable products grows, it is crucial to develop ecodesign tools that are both effective and feasible for SMEs. A life cycle-based product classification system offers a promising solution, enabling SMEs to engage in ecodesign without the need for advanced assessments or significant resource investments. By empowering smaller businesses to take meaningful steps toward sustainability, this approach has the potential to drive widespread adoption of ecodesign principles, benefiting both the environment and the companies that implement them. The first step in the analysis involved conducting a cluster analysis, where selected products were classified based on criteria such as mass, longevity, intensity of use, energy requirements, water consumption, and environmental impact indicators, including Global Warming Potential (GWP) and Cumulative Energy Demand (CED) across the entire product life cycle. Following this, a more detailed classification of these products was performed by comparing the aforementioned environmental impact indicators across three key life cycle stages: production, use, and final disposal. The data used for this analysis were drawn from the author's own research and supplemented by findings from life cycle assessment (LCA) case studies documented in existing literature. The LCIA (Life Cycle Impact Assessment) calculations were performed using the Impact 2002+ method (Jolliet et al., 2003), which allowed for a more comprehensive evaluation of the environmental impacts across the product life cycle.

The integration of ecodesign principles into traditional design processes has long been a subject of debate in academic and industry circles. Incorporating environmental considerations into the design and development of products is a complex task, and researchers have highlighted several challenges. One common issue is that, although many ecodesign

guidelines align with traditional design rules, the language and concepts of ecodesign often remain unclear or inaccessible to conventional designers (Lofthouse, 2005; Millet et al., 2007). This disconnect can hinder the practical application of environmental principles in the design process. Another critical point of discussion involves determining at which stage of the design process environmental aspects should be introduced. Researchers have debated whether these considerations should be incorporated during the strategic phase, the functional phase, the conceptual design phase, or later in the architectural or detailed phases (Millet et al., 2007). Each stage presents unique opportunities for embedding ecodesign, but it is essential to identify the most effective entry point for environmental considerations to achieve optimal results.
Additionally, there is an ongoing conversation about which specific ecodesign tools—such as environmental LCA, matrix methods, Material Input per Unit Service (MIPS), or Embodied Energy assessments—are most useful for different types of designers (Lofthouse, 2005). For example, conceptual designers, core designers, and design engineers may each require different types of information to integrate environmental aspects into their work. The usability of these tools varies depending on the designer's role and the design phase they are working in, further complicating the adoption of ecodesign in practice. One of the most frequently discussed challenges in ecodesign is the technical complexity and expertise required to effectively use many ecodesign tools. Without the assistance of external specialists, companies often find these tools too complicated to implement, especially when they lack in-house expertise in environmental assessments (Le Pochat et al., 2007; Reyes and Rohmer, 2009; Pamminger et al., 2013). This issue is particularly pronounced for small and medium-sized enterprises (SMEs), which typically have limited access to specialized resources and support.
All of these challenges are especially significant for SMEs. Multiple studies, including those by Van Hemel and Cramer (2002), Masoni et al. (2004), Le Pochat et al. (2007), Chevalier (2009), and Witczak et al. (2014), have demonstrated that SMEs often struggle to adopt ecodesign practices due to resource constraints. These constraints can be financial, human, or technological in nature. SMEs frequently lack the manpower, funding, or technological infrastructure necessary to implement comprehensive ecodesign strategies, which can put them at a disadvantage compared to larger firms with greater resources. Additionally, decision-making structures within SMEs can further complicate the adoption of ecodesign. In many small organizations, executive authority is concentrated in the hands of the owner, who is responsible for making decisions across a wide range of areas, including technology, production, purchasing, and marketing, as well as product design and development (Witczak et al., 2014). This centralized decision-making process can make it difficult to integrate ecodesign principles, particularly if the owner lacks awareness or expertise in environmental issues. In conclusion, while ecodesign offers significant potential for reducing environmental impacts, its successful integration into business practices—particularly within SMEs—requires addressing several critical challenges. These include simplifying ecodesign tools to make them more accessible, identifying the optimal stages in the design process for introducing environmental considerations, and overcoming resource limitations within smaller firms. By addressing these challenges, SMEs can more effectively incorporate ecodesign into their operations, contributing to more sustainable product development and environmental stewardship. A recommended best practice for implementing ecodesign in organizations is to establish cross-functional teams, drawing from staff across various departments. In the context of SMEs, this cross-functional approach involves integrating the competencies of individuals who are often responsible for a wide range of tasks. On the one hand, this can streamline decision-making, offering more flexibility and agility in adopting ecodesign strategies. However, on the other hand, overburdening employees with multiple responsibilities may lower their motivation to take on additional, unfamiliar tasks, such as those related to ecodesign. Furthermore, engaging an external expert in ecodesign—often essential for utilizing advanced tools—can be prohibitively expensive for SMEs. The issue is compounded by the fact that initial training and experience gained from working on a single project are typically insufficient for SMEs to independently continue implementing ecodesign without external support (Masoni et al., 2004).
The critical question, then, is: what can motivate SMEs to engage with ecodesign activities? Van Hemel and Cramer (2002) conducted an empirical assessment of 77 Dutch SMEs to explore the internal and external barriers and drivers for adopting ecodesign. They found that the most significant internal drivers were environmental benefits, cost reduction, and image improvement. These benefits directly align with SMEs' strategic goals of efficiency and sustainability. External drivers included customer demands, government regulations, and developments initiated by suppliers. These external pressures further push SMEs toward adopting sustainable practices, making ecodesign an attractive option. Among the external drivers, governmental policies play a particularly influential role. Green public procurement initiatives, for example, present opportunities for SMEs to access the public procurement market by competing not just on price, but on environmental credentials. Such initiatives allow environmental considerations to be factored into competitive bidding processes, providing SMEs with a distinct advantage if they can demonstrate their commitment to ecodesign. Another source of motivation for SMEs is integrating ecodesign as part of their Environmental Management Systems (EMS), where it can be used to identify and assess the environmental impacts of products throughout their entire life cycle (EN ISO 14006, 2011; Lewandowska and Matuszak-Flejszman, 2014). This practical application is aligned with the POEMS (Product-Oriented Environmental Management System) concept, which is especially relevant for SMEs that have already implemented EMS according to ISO 14001 (Rocha and Silvester, 2014; Ammenberg and Sundin, 2005; Donnelly et al., 2006).
Another external source of motivation may come from competitive pressures. If competitors are successfully implementing ecodesign, SMEs may feel compelled to follow suit to remain competitive. In such cases, it is likely that the department or individual responsible for environmental management within the organization would take the lead in initiating ecodesign activities. Given that small companies often lack separate departments for design, research, and

development, and frequently operate with limited financial and technological resources, the question arises: how can SMEs effectively manage ecodesign? Several approaches have been proposed in the literature to address this challenge. One suggestion is to use generic ecodesign guidelines, also known as "golden rules," which provide simplified principles for integrating environmental considerations into product design (Luttropp and Lagerstedt, 2006). Another approach is the "Trojan horse method," where ecodesign is subtly introduced into existing processes without requiring large-scale changes (Reyes and Rohmer, 2009).

For SMEs looking for more structured yet still manageable methods, semi-quantitative or qualitative tools like the ERPA matrix and MECO methodology offer practical ways to assess environmental impacts without requiring complex calculations (Hochschorner and Finnveden, 2003; Hur et al., 2005). Additionally, some studies advocate for simplified versions of LCA (Life Cycle Assessment) to make ecodesign more accessible to SMEs (Soriano, 2004; Pamminger et al., 2013; Okrasinski et al., 2013). These simplified tools allow businesses to assess their products' environmental impacts without needing the full expertise or financial resources required for a comprehensive LCA. Further support for SMEs can come through the development of ecodesign strategies tailored to specific product classifications. This approach enables organizations to focus their efforts on the most relevant aspects of product development, helping them implement ecodesign more efficiently (Sousa and Wallace, 2006). By categorizing products based on their environmental impacts and resource needs, SMEs can prioritize areas for improvement and align their design processes with sustainable principles. While SMEs face unique challenges in adopting ecodesign due to resource limitations and organizational structure, there are multiple strategies available that can facilitate this process. From simplified tools and guidelines to external pressures such as regulations and market demands, SMEs have a range of potential motivators to adopt ecodesign practices. By leveraging these resources and integrating environmental considerations into their operations, SMEs can not only reduce their environmental footprint but also improve competitiveness and align with broader sustainability goals.

2. THE ENVIRONMENTAL CLASSIFICATION OF PRODUCTS

Several analytical models are available that offer designers a product classification system that highlights critical product features while taking consumer needs into account (Mahmud et al., 2014; Xu, 2009). These models help guide designers in creating products that align with market demands and functional requirements. However, it is increasingly recognized that product designers need tools that not only cater to consumer preferences but also support pro-environmental decision-making (Chandrasegaran, 2013). In response to this need, various product classification approaches have emerged in the literature, each based on different environmental criteria. One of the primary challenges in the realm of ecodesign is to equip designers with tools that strike a balance between consumer focus and environmental impact reduction. Many traditional product classification models prioritize marketability and functionality, but integrating environmental considerations requires a more nuanced approach. This becomes particularly important when designers are tasked with minimizing a product's environmental footprint while maintaining its appeal to consumers.

In this context, the environmental classification of products offers a valuable framework, especially for small and medium-sized enterprises (SMEs) that often face resource limitations. Compared to other, more complex approaches, environmental product classification simplifies the design process by grouping products into disjoint classes based on clearly defined characteristics. This method allows designers to quickly and confidently categorize a product, reducing ambiguity during the design phase. More importantly, it helps identify environmental "hotspots"—areas in the product's life cycle that have the most significant environmental impacts—thereby providing a practical starting point for implementing ecodesign strategies. The advantage of an environmental classification system lies in its ability to simplify decision-making without sacrificing environmental integrity. For SMEs, which often lack the financial and human resources to engage in extensive life cycle assessments or other advanced environmental evaluations, such a system provides a practical alternative. By clearly defining product categories and associated environmental impacts, designers can focus their efforts on the most critical areas of improvement, thereby making meaningful contributions to sustainability without overwhelming their operations.

In light of the constraints faced by SMEs, the use of environmental product classification as a decision-making tool becomes particularly appealing. It offers a structured yet flexible approach, allowing SMEs to implement ecodesign strategies even in the absence of extensive expertise or resources. By providing a straightforward method for classifying products and identifying environmental priorities, this approach empowers designers to integrate sustainability into their work more effectively. While more complex models exist for product classification, the environmental classification of products represents a significant simplification that makes it especially valuable for SMEs. It allows designers to identify key environmental impacts and prioritize them in the design process, thereby fostering pro-environmental decision-making without the need for specialized tools or extensive training. This approach strikes a balance between practicality and environmental responsibility, making it a suitable option for organizations looking to integrate ecodesign into their product development processes.

3. METHODOLOGY

The primary objective of cluster analysis is to divide a collection of n objects, each characterized by a number of features, into two or more distinct, homogeneous groups (Stanisz, 2007; Norusis, 2012; Sarstedt and Mooi, 2014). This process requires creating a set of diagnostic variables that include factors deemed significant for distinguishing between objects. In the current study, an evaluation of these variables' discriminating potential was conducted, taking into account factors such as the completeness of data, the internal variability of features, and their mutual correlation. This evaluation helped in identifying distinct clusters within the data. Several environmental impact categories are relevant to product classification, and their importance can vary depending on the specific product under consideration. However, two key categories—Global Warming Potential (GWP) and Cumulative Energy Demand (CED)—were selected for this study. GWP measures the emissions generated throughout a product's life cycle, making it an output-oriented impact category, while CED accounts for the energy resources consumed, representing an input-oriented category. Together, these indicators cover both sides of the environmental impact spectrum, making them highly representative of a product's total environmental footprint. Additionally, GWP and CED are widely recognized in the field of life cycle analysis (LCA) and are frequently included in reports, which allowed for the collection of more research objects for this analysis.

The selected data set comprises products from a wide range of categories, including packaging. The life cycle of packaging products is particularly notable because packaging serves a critical function in trade and distribution. Packaging involves two primary users: the manufacturer, for whom the packaging is designed, and the consumer. The consumer's role is limited to opening and emptying the packaging, which has minimal environmental impact. The manufacturer, on the other hand, uses the packaging throughout the product's lifecycle by filling, sealing, and distributing the packaged goods. For this analysis, the environmental impact of the packaging was primarily evaluated based on the manufacturer's use, specifically focusing on the distribution phase, in accordance with the guidelines of PN-CR 13910: 2002, which recommends including the transportation stage in the life cycle assessment of packaging.

It is important to note that the products selected for cluster analysis not only vary in terms of their functionality but also in terms of their unit mass, longevity, usage intensity, and energy demands during the use phase. When examining energy requirements, products were divided into two broad categories: "active" products, which require energy to perform their function (e.g., furniture, laptops, vacuum cleaners, biomass boilers, cars, and buildings), and "passive" products, which do not need energy to fulfill their function (e.g., milk, packaging, tiles). However, among passive products, there are some that, while not directly requiring energy to function, rely on additional materials or activities that do. These are referred to as "accompanying environmental interventions." For example, washing detergent and textiles both require water and energy for their intended use—washing. These accompanying interventions are inseparable from the product's life cycle and play a critical role in determining the product's environmental impact. In such cases, the product's weight, service life, and usage intensity are key factors that determine the significance of these interventions in the overall life cycle.

Technological differences between products were also taken into account in the formulation of the product set for cluster analysis. The LCA analyses—limited to GWP and CED—were conducted for a variety of material solutions (e.g., cotton versus polyester t-shirts, timber versus aluminum versus PVC window frames, masonry versus wooden buildings). In addition, different recycling rates and waste management scenarios (e.g., recycling, incineration, or landfilling of window frames) and varying production technologies (e.g., organic versus conventional milk production) were considered. Usage scenarios were also analyzed, such as comparing vacuum cleaners used in domestic versus commercial environments. This wide range of products and conditions was intended to assess whether these differences should influence product classification. The cluster analysis thus serves as a kind of sensitivity analysis, exploring how variations in material solutions, usage conditions, production processes, and final disposal options affect the classification of products. By measuring the extent to which these differences impact environmental outcomes, this analysis provides insights into the broader effects of material and technological choices on product sustainability. The findings from this study can inform the development of ecodesign strategies and offer valuable guidance for improving product classification methodologies based on environmental criteria.

4. DISCUSSION

It can be concluded that considering each life cycle stage in terms of its environmental impact—measured by GWP100a and CED—resulted in some degree of variation in the classification outcomes from the cluster analysis. One of the most notable changes occurred with functionally identical products, specifically vacuum cleaners. In the initial cluster analysis, all vacuum cleaners were grouped together in the same subclass, A2, based on their overall characteristics. However, when classification was performed using GWP100a and CED as the primary environmental impact indicators, the different usage intensities of vacuum cleaners in domestic versus commercial settings led to a reallocation. The lower intensity of use in household environments, compared to commercial settings, shifted the balance of environmental impacts. Specifically, the relative contribution of the production stage to the overall environmental footprint increased for home-use vacuum cleaners. This shift caused the reallocation of these vacuum cleaners from their original classification to a different group, one that combined active products with varying environmental impacts across their life cycles. This outcome illustrates how variations in the intensity of product use can influence the environmental significance of different life cycle stages and, consequently, alter product classifications based on environmental criteria.

The reclassification of vacuum cleaners highlights the importance of accounting for product usage patterns when assessing environmental impacts. While functionally identical products may share similar design and operational features, their environmental impacts can vary significantly depending on how, and where, they are used. This example underscores the need for a nuanced approach to environmental classification, one that considers not only the product's inherent characteristics but also its usage context, as different scenarios can substantially affect the overall environmental performance. Another compelling example includes products such as the "Office Lighting Unit," "Lighting System with fluorescent lamps," and "Lighting System with LEDs." Although these products are very similar in terms of functionality, they differ from vacuum cleaners in both durability and design. In the cluster analysis, both lighting systems were

classified in the same subclass (A2), whereas the "Office Lighting Unit" was placed in a different subclass (A1). This classification aligns somewhat with the GWP-based categorization, where the lighting systems were grouped as active products, contrasting with the "Office Lighting Unit," which was classified as active combined. In the CED-based classification, however, all three products fell into the same class of active products.
Another noteworthy case involves window frames: "Window Frames, timber, 100% incinerated" and "Window Frames, PVC, 100% landfilled." As seen on the far right side of Figure 1, these were the only products for which the final disposal stage played a significant role in GWP. In the cluster analysis, both types of window frames were categorized as B1, alongside other window frames, due to their similarities in unit mass, longevity, intensity of use, and the absence of power requirements during the usage phase. However, in Figure 1, these two types of window frames were classified as passive combined, while products such as "Window Frames, Al., 100% landfilled" and "Window Frames, PVC, 100% recycled" were classified as purely passive. In Figure 2, all window frames were placed in the same product group (passive), regardless of the disposal method, which aligns to some extent with the cluster analysis classification. Crucially, in both the cluster analysis and the GWP and CED comparisons, no breakdown occurred for other functionally equivalent products with different material compositions, such as milks, T-shirts, packaging materials, and buildings. This suggests that differences in material construction and technology (e.g., usage intensity and disposal method) have the most impact on a product's classification when the environmental impact across different life stages is analyzed through the lens of GWP. As a result, designers should also consider, at least qualitatively, the material and technological choices, rather than focusing solely on the product's weight. A shift in the final disposal scenario or changes in usage conditions (such as intensity of use or durability) may shift a product from one class to another, thereby altering the eco-design recommendations.
Given these insights, it is important to explore how the environmental classification of products can assist SMEs in implementing ecodesign processes. SMEs often face challenges in applying advanced ecodesign tools like LCA due to limited financial and human resources. The proposed classification system offers a solution by combining two key criteria for product categorization: the "energy" functional dependency and the importance of various life cycle stages. Using this system, eco-design classes were defined, their characteristics established, environmental hotspots identified, and guidelines for improvement suggested. This framework provides essential information for designers engaged in ecodesign efforts, helping them navigate the complexities of sustainability in product development. The classification of products based on GWP, CED, and life cycle stages not only enhances the accuracy of product categorization but also aids in refining eco-design strategies. For SMEs in particular, this classification can serve as a practical alternative to more resource-intensive tools like LCA, helping them to prioritize environmental considerations within their capacity. By focusing on key life cycle stages and the specific environmental impacts of materials and technologies, this approach empowers designers to make more informed decisions that contribute to sustainable product development.

5. CONCLUSIONS

This article emphasizes the increasing importance of eco-design for SMEs and explores the use of environmental product classification as a foundational tool for initiating eco-design processes. The main goal of the article is to propose a classification system that meets the needs of designers, particularly in identifying environmental "hotspots" that may emerge during the various stages of a product's life cycle. In the study, 50 products were analyzed and classified according to specific criteria, including mass, longevity, intensity of use, and energy requirements. The cluster analysis used these criteria to classify the products, making a primary distinction between passive and active products. However, because cumulative values for Global Warming Potential (GWP) and Cumulative Energy Demand (CED) were employed as diagnostic variables in the cluster analysis, further distinctions between product types (e.g., active, active combined, passive, and passive combined) were not possible. This limitation also prevented the identification of more granular subgroups, such as passive combined products that were production-intensive, transport-intensive, use-intensive, or final disposal-intensive.
From a design perspective, the ideal approach for interpreting these classifications would involve using diagnostic variables that reflect the percentage contribution of each life cycle stage to the product's overall environmental impact. This method would allow products to be classified based on how environmental burdens are distributed across their life cycles. However, such a solution is not feasible due to the statistical complexities involved. Specifically, environmental indicator values can take either positive or negative values, and dividing two interval values is not a valid statistical operation, making this approach impractical. To overcome these limitations, the selected products were classified based on comparisons of specific environmental impact indicators—namely GWP 100a and CED—and a division into three distinct life cycle stages: production, use, and final disposal. This classification method facilitates the integration of eco-design activities, providing designers with a clear framework for addressing the environmental impacts of specific product groups. Moreover, this classification system has broader applications beyond simply identifying eco-design opportunities. For instance, designers can use this framework not only to implement ready-made eco-design solutions but also to assess the extent to which proposed interventions may reduce the environmental impacts of the products under review. By understanding the environmental hotspots within each product group, designers are better equipped to develop solutions that target the most significant environmental issues. The environmental classification of products, combined with knowledge of the sources of environmental impacts, can also serve as a foundation for developing simplified Life Cycle Assessment (LCA) inventory models. These models would focus on addressing the most pressing environmental concerns, enabling SMEs to conduct streamlined LCAs that capture the most relevant data without requiring the time and

resources needed for a full-scale LCA. For SMEs, which often face constraints in human and financial resources, this simplified approach offers a practical means of incorporating sustainability into product development processes. In conclusion, the proposed environmental product classification system not only facilitates eco-design activities but also provides a flexible framework for assessing the potential environmental benefits of various design interventions. By categorizing products according to their life cycle stages and environmental impacts, this system offers designers and SMEs an accessible tool for improving product sustainability. Additionally, it serves as a stepping stone toward developing more comprehensive but simplified LCA models that focus on key environmental factors, enabling SMEs to implement eco-design practices in a more efficient and resource-conscious manner.

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