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Review

Sustainable Product Innovation and Consumer Communication

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Abstract: Sustainable product innovation and its communication with consumers are essential for the realisation of sustainability through sustainable consumption. This research conducted a structured review addressing sustainable product innovation, including sustainable product development and service, environmental and socio-economic impacts, communication of the sustainable product innovation to consumers via ecolabelling and declarations, and sustainability benchmarking. The review revealed that current research in sustainable product development and service focuses more on environmental and economic aspects, but the social aspect has not been given enough attention, and the interconnection between product development and service needs to be further addressed. Systematic sustainable innovation, considering the whole life cycle of the product to control and improve overall sustainability in the early product development stages should be paid more attention. To overcome the gaps, a framework for sustainable product development and services (SPDS) was developed and presented. Furthermore, this review found that communicating understandable environmental and socio-economic performance of products and services with consumers is still challenging. Barriers are identified in deriving benchmarks through sustainability performance assessments. This paper also provides examples of overcoming the barriers in sustainable benchmarking and communication with the "eco-cost" method, which engages both B2B and B2C customers to promote sustainable consumption.

Keywords: sustainable product development; product service; sustainability; ecolabel; eco-cost; sustainable consumption; consumer communication

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1. Introduction

Sustainable product innovation and its communication with consumers are essential for the realisation of sustainability through sustainable consumption. Consumers are the receivers of the products developed and the services offered, and they make decisions on the consumption of the products and acceptance of the services. Therefore, it is important to communicate the sustainability information of the products and services to the consumers, to achieve the sustainability goal.

The concept of "sustainable development" emerged from the Brundtland Report [1], which defined the term as "development that meets the needs of present generations without compromising the ability of future generations to meet their own needs". In 2015, the United Nations published 17 Sustainable Development Goals (SDGs), including targets that address environmental and climate change impacts, socio-economic issues, sustainable innovation, and consumption, which provide support to governments to align their national development plans and policies with the SDGs [2]. Driven by sustainability, triple bottom line (TBL), a framework for sustainability that encompasses three dimensions of performance, namely social, environmental, and financial, was brought out as the expansion of the environmental agenda in a way that integrates the economic and social

lines [3]. In this definition of TBL, profit, people, and the planet are used as the three lines to measure sustainability performance.

Sustainability can be achieved by developing products that are more sustainable than the existing state [4,5]. On one hand, from the perspective of life-cycle management (LCM), the product development phase determines the materials, suppliers, manufacturing methods and costs, as well as the value chain actors during the service phase, which is the most controllable and effective phase to avoid potential sustainability risks and reduce costs [6]. For sustainable product and service innovation, the measurement of the environmental and socio-economic performance are significant indications for decision-making, ecolabelling scheme, marketing, etc. Life-cycle assessment (LCA) methodology, including environmental life-cycle assessment (E-LCA) and social life-cycle assessment (S-LCA), is constantly used to assess sustainability performance and determine how well the chosen sustainability requirements have been met [7].

On the other hand, in the context of TBL sustainability, the other objective of sustainable development is to create value to best meet consumer needs while balancing environmental, social and economic perspectives. However, there are difficulties to achieve sustainability of TBL by simply conducting sustainable product design [8–10]. Sustainable purchase is a bridge between sustainable production and the realisation of sustainability. Therefore, studies to enhance sustainable purchasing are surging, such as creating product–service systems (PSS) that combine a marketable product and service to meet specific consumer needs and create profit for stakeholders, and better communication with consumers with ecolabelling or declaration with sustainable information to support sustainable purchasing. However, further efforts are still required to effectively integrate those methods into sustainable innovation and communicate sustainability to consumers.

The importance to communicate product sustainability to consumers gained international consensus decades ago as part of global efforts to achieve sustainable development. Ten years after the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, the international community met at the World Summit on Sustainable Development and reaffirmed its commitment to the "Agenda 21" adopted in Rio. Stakeholders agreed on the Johannesburg Plan of Implementation (JPOI) to "accelerate the transition to sustainable consumption and production". Crucially, the JPOI stakeholders recognised the need to develop and, where appropriate, adopt voluntarily, effective, transparent, verifiable, non-misleading and nondiscriminatory tools to inform consumers about sustainable consumption and production [11].

The review presented in this paper focuses on sustainable product innovation and customer communication. In the remaining parts of this paper, Section 2 includes reviews on sustainable product design and manufacturing, product service with PSS, E-LCA and S-LCA, and social impact on product development and service. The gaps are identified and explained within the section. Building on the existing knowledge and gaps identified, an approach, namely the "Sustainable Product Development and Service" (SPDS) approach, was developed and presented, the approach aims to support sustainable products and services through the systemic innovation underpinned by interdisciplinary methods and tools. In Section 3, methods for communication of product sustainability with consumers are reviewed and discussed, including ecolabelling and declarations, and eco-cost-related communication means. In Section 4, the key findings of this literature review and related issues are presented. Section 5 concludes the review and highlights future research.

2. Sustainable Product Innovation through Product Development and Service

2.1. Sustainable Product Design and Manufacture

Product design and manufacture are the key stages of product development as defined in [12]. In this subsection, the literature on sustainable design is reviewed first, followed by the review of the literature on sustainable manufacturing.

Research studies addressing the environmental aspect of product design emerged in the 1990s. Studies in methods and approaches such as "green design" (Dowie, 1994) or

"eco-design" investigated the theoretical basis for sustainable design [13]. At the same time, life-cycle assessment (LCA), a method originally from the field of environmental engineering, was introduced into the product design discipline by the Society of Environmental Toxicology and Chemistry (SETAC) and the International Standards Organisation (ISO) to measure the environmental profile of products or services throughout their life cycle [14,15]. Environmental impact assessment software tools based on the LCA method have been developed, such as Simapro [16], Gabi [17], openLCA [18], and more reviewed by Su, Ren, and Wu [19], making the implementation of LCA increasingly accessible and feasible. Subsequently, LCA has been considered an evidence-based reference in decision-making during sustainable product development, such as the selection of materials and design concepts, as well as environmental labelling schemes and environmental declarations [15,20].

In recent years, numerous studies have been conducted on sustainable product development methods and tools for sustainable design. They focus on a wide range of topics including the selection and evaluation of environment-friendly materials [21–23], innovation studies on product development with integrated eco-design tools [24–26], and decision-making support tools and evaluation criteria for sustainable design [27–29]. These studies provide case-specific approaches that aim to reduce the negative environmental impacts of particular products. However, as the dimension of sustainability evolves, the interpretation of a sustainable product goes beyond a product with "recyclable material" or a "green exterior". Rather, it is an interdisciplinary approach to the creation of new products or services to produce products/services that best meet the needs of consumers while considering environmental, social, and economic perspectives with the best possible coverage. Therefore, a comprehensive sustainable solution within the product life-cycle and supply chain is necessary. Social and economic aspects are also essential aspects to be considered in sustainable design [30,31]. Nevertheless, few studies address the three pillars of sustainability during the product innovation process.

Sustainable manufacturing (SM) is of importance and inevitability amongst industries [32]. SM can be described as the implementation of sustainable design. The definition of SM varies amongst researchers. Most definitions emphasise environmental sustainability in the context of the manufacturing process and trade-offs between environmental and economic factors [33]. For example, according to the U.S. Department of Commerce, MS is "the production of products using processes that minimise negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers, and are economically sound" [34]. Malek and Desai described SM as the integration of environmental considerations into economic aspects of business that aims to reduce negative impacts during manufacturing processes [33].

Most of the studies deal with qualitative aspects and focus on a particular aspect or issue and industry. The literature from the automotive industry is the most extensive, followed by the electronics industry [33], which could be due to the high energy consumption of these industries and their products. There are a number of review studies on the topic of SM, such as [35–37]. Energy efficiency is the most studied topic by SM, followed by sustainable accounting and auditing. Topics on product design for remanufacturing and recycling and eco-design are also identified in SM studies [35–37].

Ahmad et al. reviewed various sustainability indicators for the manufacturing sector and the constant use of these indicators [38]. Gbededo et al. conducted a systematic review of the contribution of sustainable manufacturing approaches that sought to address social aspects of SM [39]. The study focused on life-cycle sustainability assessment and proposed a roadmap framework for the sustainability assessment of discrete-event simulation. The authors argued that the production process should be evaluated and optimised based on holistic sustainability goals. However, the choice of assessment indicators is not in line with UNEP guidelines for social life-cycle assessment. Furthermore, the framework requires an established product and site-based manufacturing process to obtain the data for the assessment. Therefore, the design and manufacturing process cannot be easily adapted or optimised to the assessment outcome, not to mention the cost of change.

2.2. Product–Service System

In the context of TBL sustainability [3], one of the main objectives of sustainable design is to create value and innovation to best meet consumer needs while balancing environmental, social and economic perspectives.

However, barriers have been found and it is difficult to achieve sustainability of TBL by implementing sustainable product design alone [8–10]. The traditional business model of selling products prevents consideration of the potential impacts of the other activities in the life cycle of the product after the sale, as the suppliers profit from selling the products and have no interest in extending the life of the product or reusing/repairing it, thus increasing consumption and disposal more than necessary. A more significant scope for action to promote radical change for sustainable consumption seems to lie in extending the opportunities for innovation beyond the product to a PSS [40].

A PSS is defined as a system that combines a marketable product and service to meet specific consumer needs [10]. A PSS integrates aspects of the physical product side (goods) with an intangible service offering, such as after-sales service including maintenance, repair, and end-of-life service or similar. There are various PSS classifications, see e.g., [41–43], but three main types of PSS have become established, namely product-oriented PSS, result-oriented PSS and use-oriented PSS [44]. Studies show that a PSS has great potential for environmental sustainability, sustainable production, sustainable consumption, and customer satisfaction [45]. Therefore, comprehensive sustainable solutions within the product life-cycle and supply chain should cover sustainable development and sustainable service to achieve the TBL of sustainability.

The most recognised benefit of PSS is the reduction of environmental impact, which was agreed on by 62% of articles on PSS [46]. This effect is also one of the main reasons for developing and implementing a PSS. The PSS concept has been proposed as a way to address and contribute to system-level improvements [10]. PSS is designed to extend the life and usefulness of products to enable better utilisation of resources and reduced waste production. From the customer's perspective, the extended life of products promotes energy efficiency during the consumption phase and also reduces the costs associated with consumption.

From a sustainable development perspective, designers/engineers should consider the environmental impact of a product and service primarily at the design stage, while particular attention needs to be paid to the potential opportunities for reducing environmental impact at the use stage by providing alternative system solutions rather than owning products [47].

There are policy-driven reasons for business providers and industries to undertake sustainable consumption innovations [48], such as the profit in a sustainable business model for shared value creation. A PSS reduces mass production, which leads to a reduction in manufacturing costs. With the added value to the product, PSS providers can be more competent than traditional product providers in many ways, such as increasing sales, consumer retention and loyalty, and entering new markets. These benefits are based on consumer satisfaction, which promotes socio-economic sustainability.

2.3. Social Impact

Social sustainability is less developed in TBL and has not received the attention it deserves [49,50]. According to the Western Australia Council of Social Services, "*Social sustainability occurs when the formal and informal processes; systems; structures and relationships actively support the capacity of current and future generations to create healthy and liveable communities. Socially sustainable communities are equitable, diverse, connected and democratic, and provide a good quality of life*" [51].

In recent years, the dimensions of social sustainability are addressed in the decision-making processes [52]. However, the development of social sustainability has been less considered in the literature [53,54]. A recent study shows that only 16% (46 out of 279) of sustainability-related indicators consider social performance, while 61% (170 out of 279)

measure environmental performance [7]. Moreover, few studies capture social performance for product development intentions that can inform the development of new sustainable products or product–service systems [7]. A number of studies, such as those in [33,36,39], revealed that the same problem exists in SM, the social dimension of sustainability is underrepresented compared to the environmental and economic dimensions of sustainability. The economic dimension is still the topic with the highest percentage in the SM literature. As part of the sustainable product development framework, this is further evidence of the need for a holistic approach to sustainable product development (design and manufacture) that considers the triple bottom line of sustainability.

On the one hand, this may be due to the "intangible" and "complex" nature of social aspects and their interrelationships [55,56]. On the other hand, product developers are still in the dark in terms of the triple bottom line of sustainability [57], especially in how to integrate social aspects and how to incorporate the results of social assessment into product/service design remains a challenge. Consequently, there is a need to explore issues and opportunities from both social and environmental perspectives to design products and services so that potential risks can be mitigated from a more holistic perspective for different stakeholders.

2.4. Environmental and Social Life-Cycle Assessment in Sustainable Product Development

E-LCA addresses the environmental aspects and potential environmental impacts (e.g., use of resources and environmental consequences of releases) throughout the life cycle of a product, from raw material extraction through production, use, end-of-life treatment, recycling, and final disposal [15]. The procedure for conducting an E-LCA consists of four steps: goals and scope definition, in which system boundaries and unit of analysis are set; life-cycle inventory—the collection of all elementary input and output flow from and into the system in terms of resource use and emissions; life-cycle impact assessment (LCIA)—the assessment of impacts associated with the flows in the inventory, covering a wide range of environmental impact categories (such as climate change, acidification, ecotoxicity, etc.); interpretation.

S-LCA is a method for assessing the social impacts of products and services throughout their life cycle, coving supply chain, including use phase and waste treatment. S-LCA has the same assessment procedure as E-LCA, the stakeholder categories, i.e., workers, local communities, society, consumers, and value chain actors, form the basis of an S-LCA assessment as they are the items for which a justification for inclusion or exclusion in the scope must be provided. Associated with the stakeholder categories are the subcategories of impacts that encompass socially significant themes or attributes [58].

There are a large number of E-LCA studies on sustainable product development and a growing number of S-LCA studies [59]. However, E-LCA and S-LCA should be conducted together to understand the rationale for promoting sustainability and to identify opportunities for improvement.

Franze and Ciroth have identified both environmental and social hotspots in the life cycle of a notebook and raised production [60,61]. These are pioneering studies that show early efforts in combining E-LCA and S-LCA. Foolmaun and Ramjeeawon conducted a comparative E-LCA and S-LCA of used polyethene terephthalate (PET) bottles in Mauritius to identify a suitable method of disposal of used PET bottles [62]. A software tool was used for E-LCA while three categories of stakeholders and eight subcategories of indicators were examined in the S-LCA study. Agyekum et al. created a simplified S-LCA approach combining a comparative LCA of bicycle frames with a simplified S-LCA due to data limitations [63]. Chongyang et al. conducted a comparative environmental and social LCA of manual and mechanical harvesting of sugarcane in Brazil, reporting that mechanical harvesting has better environmental and social performance [64]. In a more recent case study, Khorassani et al. developed an S-LCA operational model based on the UNEP/SETAC guideline and a standard E-LCA to identify the environmental and social hotspots in cultural heritage restoration [65]. These studies show that the results of E-LCA and S-LCA

can be interrelated or completely different, so both dimensions need to be assessed to understand sustainability holistically.

Moreover, E-LCA and/or S-LCA are usually conducted in the last stages of the design process where detailed information to calculate the performance of a product/service can be obtained. However, it is not as flexible and effective as the early design phase (conceptual design phase) in capturing the holistic sustainability of a product. Therefore, it is important to identify risks as early as possible in the design process to address and mitigate them at a lower cost [6]. However, when it comes to sustainable design, it is difficult to convert the "uncertain" variables into design requirements [66]. The conceptual design phase starts with "product design specifications" (PDS). Nevertheless, there are obstacles for designers/engineers in companies in designing sustainable PDS, especially:

- In identifying and designing bespoke PDS towards sustainability;
- The lack of a clear evidence-based design guide for the specific product [57,67];
- The lack of a comprehensive strategy [68].

2.5. Sustainable Product Development and Service Approach

2.5.1. Overview

From the above review, a systematic approach that covers the whole life-cycle stages and addresses TBL during sustainable product innovation is needed. To overcome the gaps and challenges identified in the previous sections, the authors proposed the sustainable product development and service (SPDS) approach, to support sustainable products and services with systemic innovation underpinned by interdisciplinary methods and tools [12].

Figure 1 illustrates the overview of the SPDS approach. This approach is within the framework of life-cycle thinking and life-cycle management (LCM) and is supported by sustainable product development and the PSS methodology [10,69]. Life-cycle thinking considers the product or service's life cycle as a whole so that any action could have an effect on the entire system of the product or service itself [70]. LCM can be described as the application of life-cycle thinking in practice under the life-cycle approach [71]. It has been mainly considered as a business management concept aiming to enhance the overall sustainability performance of the business and its value chains in general.

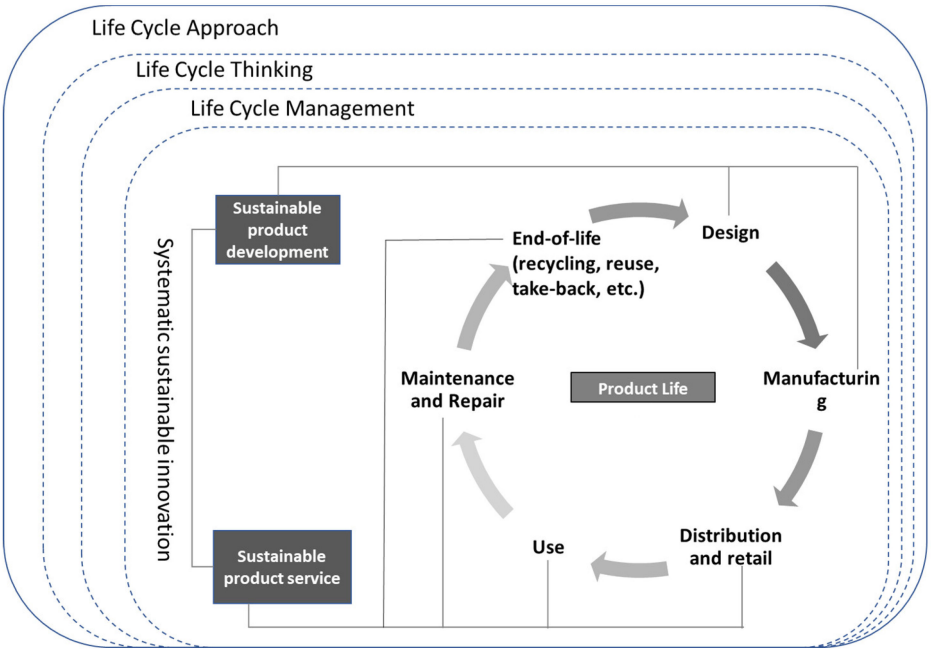

Figure 1. Overview of the SPDS approach.

However, the existing frameworks and concepts exhibit certain shortcomings during the implementation of sustainable innovation. For instance, as a business management concept, LCM focuses on implementing supply chain information and activities. However, it lacks specific methods in terms of sustainable product development. The SPDS approach is supported by various techniques and tools, such as LCA, to provide feedback on sustainability issues. This aids in identifying the opportunities for a specific enterprise to improve the sustainability performance of the new product and service, and to reveal the sustainable performance of the proposed product and service, which is advanced compared to LCM and PSS. Furthermore, the PSS adds a service component to a physical product in business models [72], such as an after-sale service of the existing product, which merely ensures incremental innovation in products and not a complete transformation in the procedure of system development [73]. Therefore, to achieve systematic sustainable innovation, both product development and service must be considered simultaneously. For these reasons, the SPDS approach aims to improve sustainability by enabling the development of a sustainable product and service as a bundle to create a systematic sustainable innovation.

The key features of the proposed SPDS approach can be summarised as follows:

- As a life-cycle approach developed based on the existing frameworks and approaches, the SPDS is more advanced than the existing LCM and PSS applications.
- It considers all stages of the product life-cycle, from product design, manufacture, distribution, retail, use, maintenance, and repair, to EoL.
- The TBL of sustainability is addressed in both products and services.
- The interaction between product development and service phases enhances sustainability performance.

The SPDS approach covers the entire life cycle of the product, addresses three aspects of the TBL (environmental, social, and economic) and can be adapted according to the individual needs of the business/practitioner. It covers all stages of the product life cycle: design, manufacture, distribution, retail, use, maintenance and repair, and end of life. The first two stages, design and manufacturing, are covered by the sustainable product development phase, while the remaining stages are covered by the sustainable product–service phase.

2.5.2. Implementing the Approach

Figure 2 illustrates the SPDS implementation process. The approach starts with the definition of sustainable goals. Then, a sustainable product and service conceptual construction is conducted, consisting of data collection, sustainability assessment of in-service products (existing products), and implication of product and service design.

LCA methods, including E-LCA and S-LCA, are both applied. The results obtained from the assessments are analysed and the interlink between the results of E-LCA and S-LCA is identified to determine the evidence-based objectives and opportunities for the assessed case [74]. The overlapping results of E-LCA and S-LCA identify the main opportunities for improving overall sustainability. They can therefore be directly applied to the design of sustainable products and services.

The LCA results of the existing product, together with recommendations received from other sources to improve the products, are integrated into the product design specification (PDS). Following the PDS, product design is carried out with an iteration process supported by the design for service (DfS) and service for design (SfD) methods. The DfS considers the service factors (such as facilitating the products repair, recycling and reuse) in the design phase to ensure sustainable features in the service phase of the product. The SfD addresses the issues related to product performance that arise during the product–service phase and provides useful feedback to improve the product. The sustainable characteristics of the product are then determined, followed by the manufacturing process where the appropriate sustainable manufacturing methods are applied.

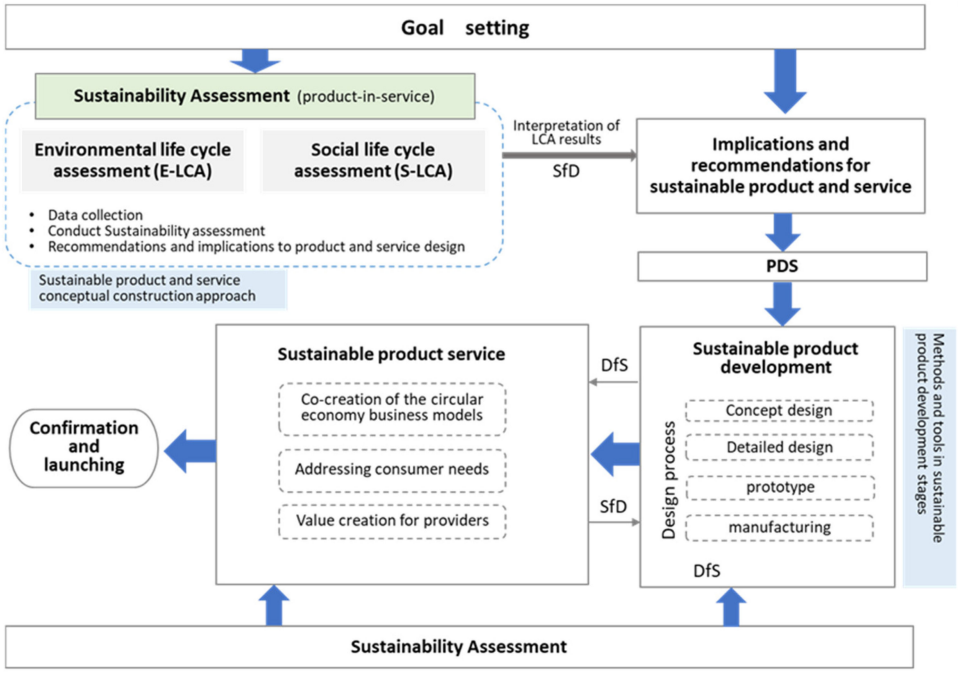

Figure 2. Flowchart implementing the SPDS procedure.

Since the development of sustainable products and services requires interdisciplinary knowledge, co-creation is carried out based on the knowledge of life-cycle thinking and LCM. Designers and value chain actors will be involved in the co-creation to develop circular economy business models. The aim is to develop a product and service that meets consumer needs and creates value for providers with reduced environmental and social impacts. An application example of a sustainable lighting product and service can be found in the authors' other study [12].

3. Communication of Product Sustainability with Consumers

Ecolabels and eco-declarations provide information on the relevant environmental characteristics of a product or service. The eco-cost method, which is further detailed in Section 3.2, also provides information on products' impact on the environment. Consumers can use the information to select products or services, which is expected to influence purchasing decisions in favour of their products or services. In this section, the existing ecolabels and declarations evaluating environmental impact are reviewed, and the eco-cost method is presented together with its implementation using ecolabels and product descriptions. The gaps are identified, the "Eco-cost" method is briefly introduced and then, eco-cost-based consumer communication methods are demonstrated and reviewed with business-to-consumer (B2C) and business-to-business (B2B) examples.

3.1. Ecolabelling and Declaration

The International Standards Organisation (ISO) has developed standards series for different ecolabelling applications, including guiding principles such as ISO 14020-Environmental labels and declarations [75], and classification standards that are referred to as ISO Types I, II, and III. Type I (ISO 14024) is a multi-attribute label developed by a third party which identifies the overall environmental preference of a product (i.e., good or service) within a product category based on life-cycle considerations [76]. Examples include the Nordic Swan and the German Blue Angel. Type II (ISO 14021) is a single attribute label developed by the manufacturer [77]. Type II claims are based on self-declarations by manufacturers or retailers, e.g., "made from x% recycled material" [78]. Type III (ISO 14025) is an ecolabel whose award is based on a full life-cycle assessment [79]. Type III claims consist of quan-

tified product information based on life-cycle impacts. These impacts are presented in a form that facilitates comparison between products such as a set of parameters. However, the information does not include a comparison or weighting with other products [78].

The EU Ecolabel includes more than 30 product groups ranging from washing machines, cleaning products, computers, paints and varnishes, footwear, light bulbs, televisions, writing paper, and mattresses, some cleaning products, etc. [80].

Ecolabel criteria vary by product or service category and are regularly revised and updated. They apply to each stage of the product life cycle from manufacture to disposal and cover all impacts relevant to a given product group, such as natural resources used in manufacture, energy, water and chemicals, through to recycling. Certified products must be independently certified to meet the strict published criteria.

Global Green Tag is a registered certification in Australia and the United States. It is an independent rating and certification scheme for environmentally friendly products based on life-cycle analysis [81]. The ecolabel distinguishes a product at the high end of the green product market by scoring, weighting, and developing an EcoPOINT score (−1 to +1). The system provides metrics for sustainability that include positive impacts such as carbon sequestration, positive biodiversity, or health impacts of products.

Climatop aims to label the products and services with better environmental performance. Products within the same category are compared with regard to their environmental emissions [82]. Only products whose CO_2 emissions are 20% lower than average receive the label. Independent organisations calculate the life-cycle assessment (LCA) of the products in accordance with the standard ISO 14040. The label is valid for two years.

GreenCircle Certified provides third-party certification of sustainable aspects of products and manufacturing processes [83] including manufacturers, suppliers, and regulators. GreenCircle Certified provides validation of recycled content, rapidly renewable raw material, carbon footprint reduction, and renewable energy use. Certifications are also available for closed-loop products, LCA optimised products, and sustainable manufacturing practices.

In addition, environmental declarations are becoming increasingly important to communicate data on the environmental impacts of products in the supply chain. The International EPD System (EPD) summarises details of the environmental impacts of the product such as global warming potential, for each aspect of the product's life-cycle [84]. More specifically, environmental declarations are a standardised type of LCA study that allows comparisons between products that perform the same function. There are a variety of environmental declaration programmes in different industries, such as The Eco-Profile, Environmental Profiles, Product Environmental Profiles (PEP), etc. The legal requirement in the European market is Regulation (EC) No. 66/2010 (Ecolabel Regulation), which has been adopted by the major companies. Most carbon footprint certification tools, whether by a third party or a company working on its products, rely on a range of LCA approaches and data: The Carbon Reduction Institute offers carbon-neutral certification schemes [85].

Amongst the products that carry the ecolabels, food and electronic products are preferred by verifiers and organisations, mainly because they are industries with high energy consumption. Amongst commercial ecolabels, the EU Energy Label is the most widely used. All European manufacturers and retailers must comply with the energy efficiency of household electric refrigerators, freezers, washing machines, tumble dryers, dishwashers, air conditioners, ovens, and light bulbs. Products are generally rated from "A" to "G", with "A" representing the highest efficiency, e.g., "A+" and "A++" for the most efficient fridges and freezers. For organic food and farming, the word "organic" can only be used on food if it is produced following regulations, and farmers and processors must be certified by an approved organisation. LEAF certifies farms managed according to the principles of integrated farming, which demonstrate site-specific and continuous improvement in overall agricultural activities [86]. Similarly, The Soil Association certifies licensees that strictly adhere to European organic food production laws [87]. Additional

private standards used by approved bodies increasingly cover other products, including textiles, cosmetics, wood products and compost.

The results of the review show that existing ecolabels only cover selected categories of environmental impacts and certain aspects of a life-cycle perspective. For example, the European energy label only considers the category of energy and energy consumption in the use phase, but not the other phases of the life cycle, such as production and end-of-life treatment, and it is limited to electronic products. Most ecolabels are limited to certain product categories to meet specific criteria. The EU Ecolabel, for example, covers several product categories but needs to be extended to cover more product types. As a result, there is still a lack of clear information on the environmental impact of products that consumers can compare, such as the assessment of the environmental impact of a product over its life cycle.

EPDs are a compatible approach to self-declare the environmental information of products. However, although EPD can be communicated either between businesses or to consumers, the documents and assessment results are published on a dedicated platform that is not directly available to consumers at the time of purchase. Furthermore, the assessment results are academic/technical and not easily understood by the ordinary consumer. Additionally, as a voluntary self-declaration, publishing an EPD does not mean that the declared product is environmentally better than its alternatives.

To overcome those, eco-cost-based ecolabels and product description methods have been developed which are reviewed in Section 3.2 below.

3.2. Eco-Cost Based Consumer Communication Methods

Eco-cost indicates the environmental impact of products and services. Developed by the myEcoCost project supported by the European Commission's 7th Framework Programme, the eco-cost values are represented by material footprints and carbon footprints [88]. Eco-cost is also called eco-debit, derived based on the eco-point method [89], which is an aggregated value from three indicators (human health, ecosystems, and resources) calculated using the ReCiPe LCA method [90]. The eco-cost method has been further applied in the CIRC4Life project supported by the European Commission's Horizon 2020 programme [91], and the eco-cost was illustrated in eco-accounting and eco-shopping [92,93]. An ICT infrastructure for implementing the eco-cost was reported in [94].

3.2.1. Eco-Cost Based Ecolabelling

To overcome the gap in the existing ecolabels mentioned above, a new ecolabelling method was developed by the CIRC4Life project [91]. The eco-cost values are shown in the ecolabels which are calculated using the LCA method, which covers the entire life cycle of products and focuses on environmental impacts on resources and human health. The eco-cost results are communicated to consumers in an easily understandable way. The results are presented as a single value that allows easy comparison between different products. This approach facilitates sustainable decision-making based on the sustainability of products, i.e., comparing the environmental impact of a product with an alternative product before purchase.

Figure 3 shows an example of the ecolabel placed on the packaging of sausages demonstrated by ALIA, an industrial partner of the CIRC4Life project. Figure 3 is the details of this example's CIRC4Life ecolabel where the number 0.64 is the benchmarking eco-cost (average eco-cost value of this product category), and the number 0.47 in the centre is the eco-cost of the sausage which is 30% better than the benchmarking value (0.64–0.47)/0.64 ≈ 30% [95]. The labelling method has also been applied in the ecolabels of vegetable food products of Scilly Organics [96].

Figure 3. Ecolabel shown on ALIA sausage packaging.

3.2.2. Communication of Product Sustainability with Product Descriptions

The CIRC4Life project developed a means to communicate the eco-cost and LCA results with product descriptions via product catalogues and product Websites, which were demonstrated using domestic and industrial lighting products. Although the existing European energy label includes light bulbs and lamps, the criterion focuses on energy efficiency rather than the whole life cycle of the product, and although its new version from March 2021 takes eco-design into account, lighting products are not yet applicable [97]. The CIRC4Life project explored the way of overcoming the gaps and demonstrated the communication of the sustainable impact in the lighting sector. For the domestic lighting product, this was demonstrated in the Ona online shop [98]. To encourage sustainable consumption, eco-costs were made available (see Figure 4) to consumers on the company's online shop providing consumers with the environmental impact of each lamp by indicating the eco-cost, eco-information such as how the eco-cost was calculated and how to compare it, and the individual eco-account system at the time of purchase, allowing consumers to compare whether the environmental impact of a product is higher, lower or similar to alternative products. The social life-cycle performance of Spanish companies in the manufacturing of household appliances has been published on their website to promote socially responsible consumption (https://onaemotion.com/en/recyclable-lamps/ (accessed on 13 June 2022)). In addition, the company promotes sustainable consumption by providing incentives for consumers to return lamps for recycling or upcycling at the end of their life. In this way, consumers can receive eco-credits that they can offset against their eco-cost or spend on their next purchase.

For industrial lighting products, the communication of eco-cost and LCA is demonstrated by the industrial lighting company, Kosnic, whose customers are usually business clients rather than individual consumers [99]. The eco-costs are indicated on the product packaging and in the product documentation and can be found in the product catalogue and on the website.

The social life-cycle performance compared to the benchmarking companies in the electronics industry has been published on the website (https://www.circ4life.eu/slca (accessed on 13 June 2022)) to promote socially responsible consumption, see Figure 5. Product sustainability documentation is provided for the leasing service, such as information on eco-costs, environmental impact, and cost comparison with the business owner's existing service, Figure 6 is an example of the eco-cost communication between different fittings.

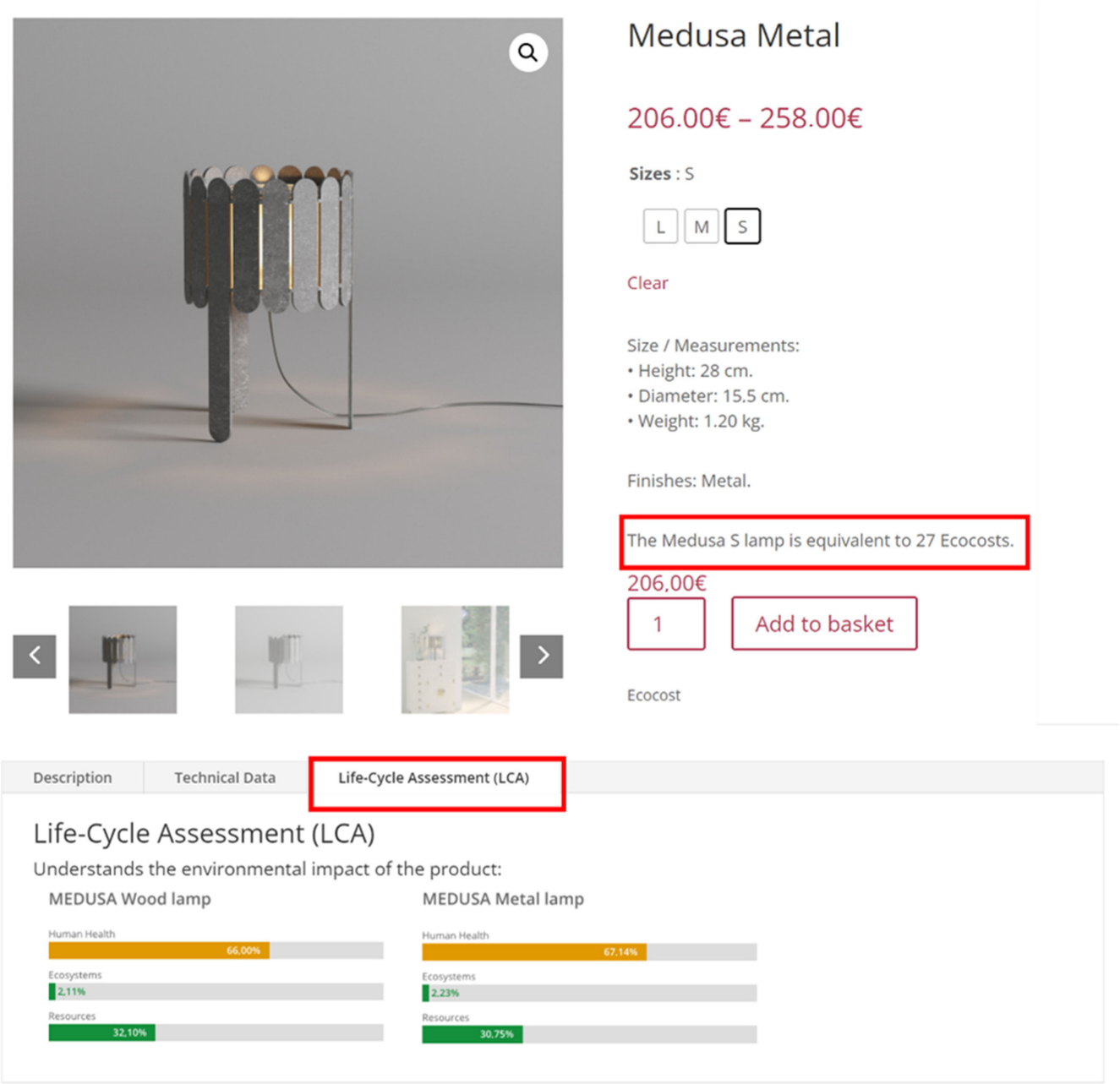

Figure 4. Eco-cost and LCA information on ONA's online shop.

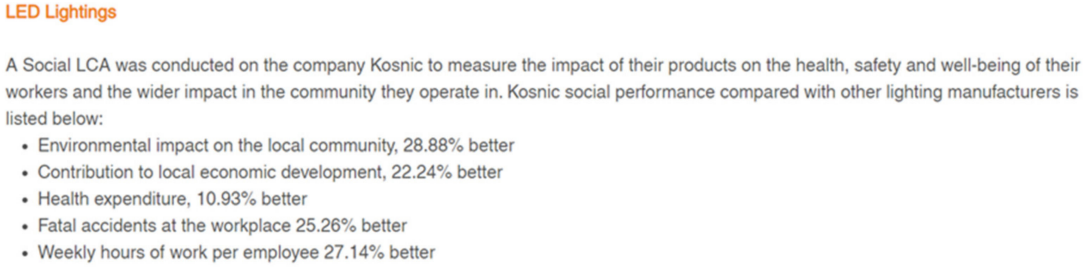

Figure 5. Social performance communication for industrial lighting product and supply chain.

Existing eco-cost of per lamp	Area	Quantity	Existing Lamp Type	Existing Lamp Wattage	Existing Lamp uselife	eco-cost on resources	eco-cost on eco-system	eco-cost on Human Health	Total Eco-cost of Existing fitting	Total eco-cost on resources	Total eco-cost on eco-system	Total eco-cost on Human Health
169	Warehouse 1	100	100W Arcus-compact	100	40,000	97.93	2.89	68.32	16900	9793	289	6832
Replacement Eco-cost of per lamp	**Area**	**Quantity**	**Replacement LED Fitting Type**	**Replacement LED Fitting Wattage**	**Replacement LED uselife**	**eco-cost on resources**	**eco-cost on eco-system**	**eco-cost on Human Health**	**Total Eco-cost of Replacement fitting**	**Total eco-cost on resources**	**Total eco-cost on eco-system**	**Total eco-cost on Human Health**
92	Warehouse 1	100	100w Arcus II - KLBA150L1	100	40,000	55.68	1.88	34.17	9200	5568	188	3417
Eco-cost Savings									**7700**	**4225**	**101**	**3415**

Overall, the Eco-cost of the replacement lamp (Arcus-II) has improved by 46 % in comparison with that of the existing product (Arcus-Compact) over the life of the LED. The Eco-cost of the three categories in the case of Arcus-II are 55.68, 34, and 1.88 for resources, human health, and ecosystems categories, which are improved by approximately 43, 50, and 35 %, respectively in comparison with those of Arcus-Compact.

- 'Resources' refers to potential risk on resource extraction, including oil, gas and coal related energy cost increasing.
- 'Human health' refers to potential harm to human body, potential risk on increasing diseases, such as respiratory diseases, cancer and malnutrition.
- 'Ecosystem' refers to potential damage to living species in freshwater, marine and terrestrial.

The eco-costs were calculated according to ISO14040 standard, using world recognised software and databases, as well as the most recent life cycle impact assessment approach (for more information about the assessment, please see CIRC4Life website).

Figure 6. Eco-cost communication for industrial lighting products and services.

4. Discussion

4.1. Sustainable Product Development and Service

There is an abundance amount of research regarding sustainable product development, whether on sustainable design or sustainable manufacturing; however, the existing research has clustered more with environmental or economic aspects of sustainability, and the social aspect is less considered. PSS has the potential to integrate the TBL of sustainability and has been identified as a solution to break the traditional product sales pattern and improve overall sustainability by facilitating sustainable consumption. Nevertheless, the existing

studies lack an efficient connection between product development and service, such as service elements added after the established product rather than a systematic innovation.

The authors present a framework for sustainable product development and service to overcome the gaps by considering the TBL of sustainability and improving the links between product development and service. Future research on sustainable product development and service should focus on the following: (1) more efforts should be made on TBL of sustainability, especially the social aspect; (2) systematic sustainable innovation, considering the whole life cycle of the product, including the potential service, to improve overall sustainability; (3) controlling impacts, i.e., environmental and social risks, in the early stages of development.

4.2. Ecolabelling and Declaration

The results of the review show that existing ecolabels cover selected impact categories and specific stages of a product's life cycle, such as energy consumption or food safety. In contrast, the CIRC4Life ecolabelling method is based on the LCA method ReCiPe, which assesses the whole product life cycle and covers human health, ecosystems, and resources, and, hence, the CIRC4Life ecolabelling is more comprehensive in terms of sustainability.

In the case of environmental declarations (Type III environmental declarations), the information provided is usually too technical for consumers to understand. This literature review discovered that communicating with consumers regarding the understandable socio-economic performance of products and services is challenging. The CIRC4Life project has explored ways of overcoming the gaps, such as communicating the eco-cost results with the public through ecolabels and product descriptions (detailed in Section 3.2), which provide examples of communicating with consumers in understandable ways that engage both B2B and B2C customers. Examples of communicating social impacts from the CIRC4Life project also are presented to promote socially responsible consumption.

In addition, benchmarking a particular product in the market requires large amounts of assessment results, barriers are identified in the existing literature on sustainability performance assessment in deriving benchmarks, for example, for lighting products, mainly due to the variety of functional units, assessment criteria and impact indicators. Therefore, an agreed functional unit for a particular product range is useful for future research in detecting performance for benchmarking. Furthermore, as the social impact is increasingly valued for consumers in purchasing, the mechanisms by which environmental and socio-economic performance can be integrated as a whole to reveal sustainability in ecolabelling and declaration schemes require further work.

From the managerial perspective, sustainable products and service development requires interdisciplinary knowledge, and the measurement of the environmental and socio-economic performance are significant indications for decision-making, ecolabelling scheme, marketing, etc. Therefore, incorporating the sustainability know-how with the knowledge of life-cycle thinking and LCM, to facilitate co-creation with engineers and value chain actors to develop circular economy business models is necessary. Furthermore, utilising a sustainable product and service innovation framework, such as SPDS, can be the groundwork for integrating businesses' sustainability efforts based on the product life cycle. With the integration of Omni-channel marketing methods, the communication of sustainability information of products and services can also improve the consumer experience and empower customers to become loyal brand advocators, creating a positive circularity toward sustainable business.

5. Concluding Remarks

This paper presented the literature review regarding sustainable product innovation and communication of sustainability to customers. Current research in sustainable product development and service addresses more environmental and economic aspects than the social aspect. Product–service systems have great potential for environmental sustainability, sustainable production, sustainable consumption, and customer satisfaction,

yet the interconnection between product development and service needs to be further addressed. Furthermore, this review found that communicating with consumers regarding the understandable environmental and social performance of products and services is still a challenging task. Barriers are identified in sustainability performance assessment in deriving benchmarks. To fill the above gaps, the SPDS approach, as well as the sustainable benchmarking and communication with the "eco-cost" method, were developed and presented in this paper as an attempt to address this issue.

For sustainable product innovation, future studies should pay more attention to building systematic sustainable innovation, considering the whole life cycle of the product, including the potential service, to improve overall sustainability, and control sustainability impacts in the early stages of product development. For communication of sustainability with consumers, an agreed functional unit for a particular product range is useful for future research in detecting performance for benchmarking. The mechanisms by which environmental and socio-economic performance can be integrated into ecolabelling and declaration schemes require further work.

The contribution to the knowledge of this paper is evident in four aspects. First, the paper provides a structured review on the topic of sustainable products and services based on over one hundred pieces of literature. Second, we present a systematic approach, the SPDS, to address the gaps identified in current research. Third, we identify the problems and research limitations in sustainable product development and benchmarking research and discuss opportunities for future work to locate problems in the field. Finally, we provide examples of overcoming the barriers to sustainable benchmarking and communication that can benefit future research in this area and for consumers to facilitate their sustainable consumption.

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