Achieving Global Sustainability Through Sustainable Product Life Cycle

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Abstract. Sustainable product life cycle management aims at minimizing the negative impacts on the environment, society, and economy by managing different stages of a product's existence. Proper management of the product life cycle thus leads to a reduction in several types of waste such as materials, energy, and time. While there is significant progress on the key enabling technologies and resources for sustainability within the last decade, the traditional models used for product life cycle sustainability are outdated thus hindering a successful shift toward a circular economy and hence these outdated models should be updated properly to cover the needs of the modern manufacturing landscape. In this paper, we challenge the traditional way of managing a product's life cycle and propose a new sustainable product life cycle approach with the emphasis on multiple life cycles of products as well as their components and materials through iterative repurposing and reuse, and by integrating the disposal concept from the early phases of conception and design for achieving global sustainability. We highlight that by adopting the proposed approach, it is possible to achieve a longer period of actual use of products and save a significant amount of resources.

Keywords: Sustainability · Re-use · Re-purpose · Product life cycle · Global · Sustainable product life cycle

1 Introduction and Literature Review

From an engineering perspective, product life cycle (PLCs), which are associated primarily with the creation of new products, cover the phases of a product's entire life from inception through design and manufacturing, service and distribution, and the manufactured product's end of life [1, 2] This traditional and limited view was originally developed for manufacturers. It aims to achieve maximum profits and value at each phase of a product's life cycle and hence focuses on economic indicators rather than environmental and societal impacts [3].

Sustainable development is a principle that seeks to satisfy the needs of the present while conserving and enhancing resources for future generations [4]. To accomplish

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this goal, it is important to gradually change approaches to development and use proper methods and key enabling technologies to create more sustainable products [5, 6]. Sustainable product life cycle (SPLC) management is a method for managing the different phases of a product's existence to minimise negative impacts on the three pillars of sustainability: environment, society, and economy [7]. In this context, SPLC enhances the reuse, remanufacturing, and recycling of all materials involved in the creation of products [8] Moreover, repurposing directs products or materials for use in different functions than they were originally designed and produced for [9]. Determining alternative uses for outdated assets leads to cost savings in terms of both disposal and materials. While sustainability-oriented key enabling technologies and resources have made significant progress within the last decade [10], the traditional models used for PLC sustainability are outdated and thus hinder a successful shift toward a circular economy. Accordingly, these outdated models should be updated to address the needs of the modern manufacturing landscape [11].

The concept of PLCs has formed a fundamental component of marketing theory for more than seven decades. Following its initial proposition in 1950 [12] and significant growth in the 1960s thanks to the influence of a prominent article by Levitt, [13] it has remained a central element in different disciplines from marketing to new product development despite its flawed nature criticised by leading academics for decades 11, 12. The PLC we refer to and challenge in this study, however, is associated with the creation of a product that begins with the extraction of raw materials and ends with the materials from this product being reused, recovered, recycled, or disposed of [16] Properly managing the PLC thus reduces several types of waste, such as materials (e.g., mineral resources), energy, and time [17].

According to Hood, [18] to decrease overall waste society should be more open to repurposing previously owned products. Geissdoerfer et al. (2017) [11] define the Circular Economy as "a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops". Circularity can only be achieved by integrating an SPLC approach from the initial product design to the repurposing of waste and by fostering the reuse and recycling of materials to minimise negative impacts on the environment as much as possible [17, 18]. Single-use products and materials, such as plastic packaging in the food industry, are one of the major contributors to global waste and should be eliminated to improve sustainability [16, 21]. Hence, it is of paramount importance to improve the design of new products by revising the outdated models of the PLC theory with the addition of a sustainability dimension [22].

Although widely accepted, the PLC theory has many flaws. A major critique is that the traditional PLC theory considers products to have only one life cycle before recycling and therefore does not give enough consideration to product reuse and repurposing. However, not all products must advance to end of life and disposal; instead, they can return to the growth phase via repurposing and reusage, hence achieving multiple iterative life cycles. Finally, the traditional PLC models used today are outdated and unable to fully cope with the current social, environmental, and economical challenges of the modern world [23] In this paper, therefore, we address this gap and propose a new SPLC approach that emphasises multiple life cycles of products and their components and materials through

iterative repurposing and reuse and that integrates the disposal concept from the early phases of conception and design to achieve true global sustainability.

Guided by these aforementioned obstacles, this paper challenges traditional PLC management and seeks to achieve global sustainability by adding new inner cycles for repurposing and reusability that consider multiple product lives simultaneously and by removing the notion of disposure from the main cycle and incorporating it into the design phase.

2 Sustainable Product Life Cycle

The PLC perception affects the sustainability of a product's design as well as its production, distribution, use, and recycling. The traditional PLC was developed without considering the needs of contemporary and future societies and markets and is therefore obsolete and unable to describe modern concepts arising from modern needs. Furthermore, a fault of the traditional PLC is the disposal and waste of products within their life cycle; Sect. 2.1 provides further information on this aspect. The PLC is an outlook and is foundational to the sustainable creation of products. If this fundament is incorrect or outdated, then the product will not be sustainable.

2.1 Proposed Sustainable Product Life Cycle Framework

The proposed SPLC was developed in consideration of the latest concepts that contribute to sustainability—such as zero defect manufacturing [22, 23], product reusability, and repurposing—and how to better exploit products and knowledge [26]. The radical change our proposed SPLC brings is that it considers multiple lives for a product rather than only one. Traditionally, the PLC has consisted of a single life cycle, starting with the conceptualisation of the product until its disposal or recycling. Usually when a product reaches the disposal stage, the recycling phase still has significant remaining useful life (RUL); therefore, the product is terminated not based on the product's operability but on the personal responsibility of the user. Often the product can operate normally, and even when a product cannot operate as designed, its included components can be used elsewhere. Therefore, two key concepts our upgraded SPLC model introduces are reusability and repurposing.

Figure 1 illustrates the proposed SPLC model, which is intended to function as a roadmap for sustainable designing, manufacturing, living, and thinking. The figure is colour coded to demonstrate the different PLC stages. The main cycle (blue) is the traditional PLC model, which has existed for many years and significantly affected the adoption of circularity. We modified the traditional PLC slightly by removing the notion of disposure from the main cycle and incorporating the concept of zero waste and sustainability into the design and develop phase. This enrichment to the design phase is mandatory since it is crucial for circularity and because if the product is not designed in a specific way, then reusage and repurposing will not be possible, as occurs at present. From our SPLC, it is evident that the disposal step (marked in red) has been removed from the cycle. Disposing a product is an undesirable step that disrupts the cycle and must be avoided as it is not sustainable to create waste of any form. The second

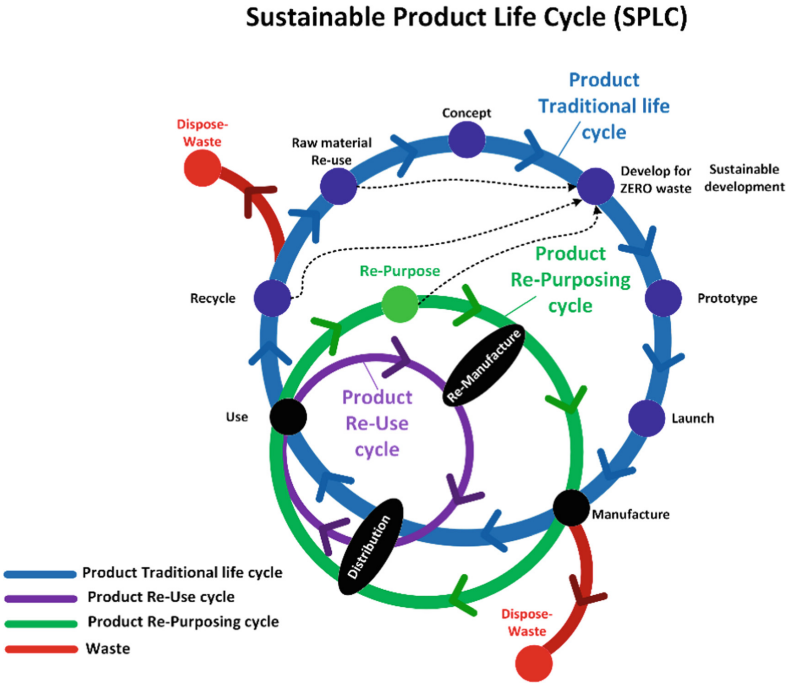

Fig. 1. SPLC

innovation of our SPLC model occurs at the use phase of the product. Traditionally, products are used and then recycled or disposed of. To increase the sustainability and exploit 100% of a product's RUL, we added the repurpose and reuse cycles (signified by purple and green, respectively). Products are currently treated as if they have a single life and are then recycled or disposed of; however, a product or part of a product can have multiple lives until it reaches the global end of life. Once the first life of a product has concluded, our model proposes two pathways. If the product can be used for its original purpose, then remanufacturing is performed if necessary and the product is reused. If the product cannot operate as originally intended or its use is no longer required, then the product or components of the product are repurposed. Reusing or repurposing 100% of the consumed resources for manufactured products will significantly increase the global sustainability of modern life. The reuse and repurpose loop continues until the global end of life of each product or component is reached. Because recycling focuses only on materials, other types of resources, such as manufacturing time, cannot be recycled; therefore, these extra cycles will help exploit better not only the natural resources but also the human effort and manufacturing time. Additionally, a knowledge cycle arising from the use, repurpose, reuse, recycle, and product design phases provides valuable information and feedback for the development of new sustainable products compatible with SPLCs. The proposed SPLC aims to improve all three pillars of sustainability, economy, environment, and society. Utilizing all the remaining useful life of a product

not only the material waste is reduced but also the resources spent (money, human time etc.) are utilized more efficiently and they are not wasted.

2.2 Product Remaining Useful Life

Utilising the entire RUL of a product is crucial for improving global sustainability [27]. Figure 2 illustrates the difference between a single PLC and multiple PLCs. It also demonstrates the existing single-PLC situation that our proposed model addresses. The waste that using a single PLC creates is tremendous and includes not only material-based wastes but also human effort, manufacturing time, and other types of time wastes that cannot be recycled, thus leading to a dramatic reduction of sustainability. From Fig. 2, it is evident that adopting the proposed approach would achieve a longer period of product use and save a significant quantity of resources.

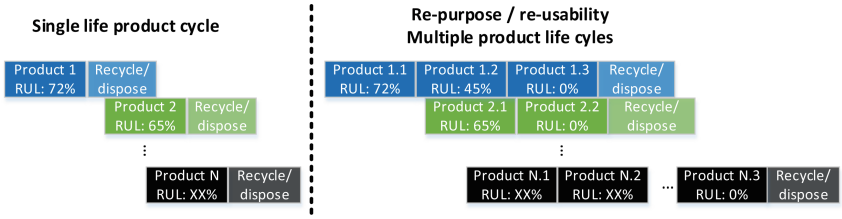

Fig. 2. Single versus multiple PLCs

2.3 Sustainability Levels

Sustainability is a term that is difficult to measure [28], but it is possible to estimate how the sustainability level is affected by different actions. Figure 3 depicts the basic concepts of both traditional PLCs and the proposed SPLCs. The sustainability level is a measure that considers the performance of all three pillars of sustainability (economy, environment, and society) at the same time. It is evident from the figure that the concepts and mentality of traditional PLCs correspond to extremely low levels of sustainability. The bottom of the chart contains any form of waste, which is unwanted and should be avoided as much as possible. The next row contains products that are used only once and then recycled. Recycling prevents the scale from swinging immediately towards the negative side but is not a sustainable solution. The goal is to not create waste, and therefore new methods and outlooks are required.

The proposed SPLC introduces the concepts of repurpose and reuse, which offer significantly higher sustainability levels. Repurpose corresponds to a lower level of sustainability than reuse because more effort is required to change the purpose of the initial product or components. To reuse a product, in many cases almost no significant effort is needed. In general, sustainability will only be achieved by changing mindsets and inventing ways to avoid creating waste, whether material or any other type.

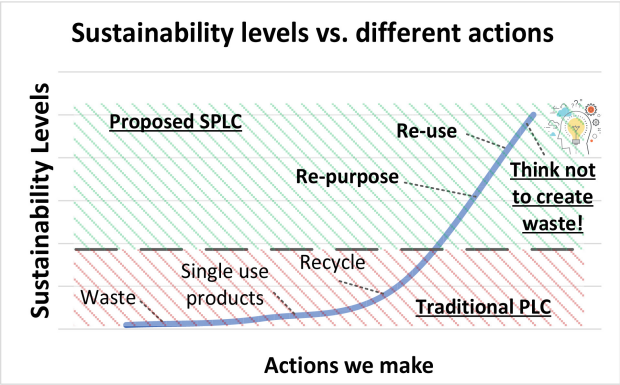

Fig. 3. Sustainability levels versus actions

3 Sustainable Product Life Cycle Implications and Future Steps

Adopting the proposed SPLC will increase global sustainability, but this increase comes with many implications. The main implication that will occur and potentially disrupt or change the industrial market is that the number of new products being produced will be significantly reduced because manufactured products will be reused or repurposed. Manufacturers should shift from focusing on producing new products to developing and establishing systems and procedures for remanufacturing and reusing products. To this end, new methods and manufacturing systems should focus on remanufacturing products, maintaining high-level quality, and utilising zero defect manufacturing [22, 23]. At the same time consumers should be familiarized with re-using and re-purposing concepts to embrace re-using products and in general buying products with re-used or repurposed components. Data-driven technologies and Industry 4.0 technologies in general are key for the successful implementation of our proposed model as these technologies help achieve the required knowledge for building the SPLC model.

Furthermore, the product design is critical for implementing the proposed SPLC model. Manufacturers must design collaboratively with other manufacturers or at minimum have a plan for incorporating existing products into their new products. Collaborating could provide opportunities to repurpose the products of other manufacturers when they have reached their first end of life (not the global life cycle). Therefore, new collaborative design methodologies are needed and would capture the reuse and repurpose concepts. To achieve the collaboration design and simultaneously maintain the intellectual property rights of each manufacturer, new communication and collaboration platforms are needed to facilitate this procedure. Enhanced methods, protocols, and standardisation procedures should be created to successfully implement the repurposing and reuse of products.

Numerous products that are intentionally designed to be single use, such as packaging in the food and other industries, currently exist. These types of products disrupt the sustainability cycle and require radical changes in terms of the product design.

4 Conclusion

In this paper, we focused on the shortcomings of the traditional PLC concept and proposed a new approach for an SPLC as an enabling factor toward achieving true global sustainability. The novelty of the new SPLC model is manifold. First, it considers multiple lives for a product rather than only one. Second, it removes disposal from the main cycle and incorporates it into the design phase. Finally, it adds new repurpose and reuse cycles. This new SPLC model will help advance further developments in fields that cope with the social, environmental, and economical challenges of the modern world. Manufacturing companies' top management must embrace the concepts of reuse and repurpose, think globally, and not create waste.

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