



# Context-Based Methodology for a Holistic Development of Circular Products and Business Models

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**Abstract.** Developing circular products and business models requires a holistic perspective on the product life cycle and its context. This contribution introduces a methodology consisting of five phases, categorized into three perspectives, linked by analysis and synthesis activities. This new approach embraces the adaptability of the dynamic product context through the creation of new material and information cycles. Contextual elements, which influence product development yet are not inherent parts of the product, are systematically considered. Moreover, it identifies starting points for the development of new circular product and business model scenarios, which can be also used to systematically discover problem shifts in the impact areas of sustainability. Circularity and sustainability assessments of the product portfolio, the business model, and the context serve as the methodological foundation for deriving requirements in product development. For this purpose, the scenario technique is further developed and integrated into evaluation methods. By assessing technical feasibility in the preliminary concept, requirements and technical constraints are integrated into cycle planning processes. This ensures that holistic circularity considerations are initially addressed. Thereby, the gained context sensitivity provides manufacturing companies with decision-relevant information, allowing them to leverage their potential from an integrated view of products and material/information cycles.

**Keywords:** Circular design · Context Engineering · methodology · product planning and design · scenario and evaluation methods

## 1 Introduction

The circular economy (CE) intends to transform material, emission, and energy industries into circular and sustainable systems [1]. As a result, CE markets are increasingly featured alongside consumers in the development of new products and business models (BM) [2]. The inclusion of material and information cycles in product development (PD) means that the context of a product to be developed is expanded to include the variability of existing and planned cycles. Consequently, the context can no longer be assumed to

be static [3]. The System Context is defined as a “part of the system environment that is relevant for the definition as well as the understanding of the requirements of a system to be developed” [3]. Accordingly, the context for the example of a battery electric vehicle (BEV) encompasses, among other elements, material cycles of rare earths and charging infrastructures. The requirements and effects of the context must be continuously evaluated during the development of product ideas and BMs, particularly concerning the technical feasibility of cycles. At the same time, CE strategies, enable the product to be used over several life cycles [1]. In this way, savings can be achieved in terms of raw material consumption, energy consumption, pollutant emissions and costs. To leverage this potential in the sense of a CE, issues affecting several product generations must be addressed, leading to challenges in capturing requirements. To develop more circular products a better understanding of the interrelationships between context, product and BM development is needed. For this purpose, the aim of this research is to review the state of the art, subdivided into context considerations, design strategies, and circularity analysis approaches. Based on the need for actions, a conceptual support methodology for holistically aligning the dynamic context of BM and PD with its product life cycle (PLC) is introduced.

## 2 State of the Art

### 2.1 Context Consideration in Product and Business Development

The context analysis of PD processes constitutes a pivotal source of situational awareness about requirements for the product, which are not obvious and only arise through chained dependencies, often remaining unknown to stakeholders. A holistic, goal-oriented, and iterative analysis of the context is often not standard practice, but the following approaches do exist. To provide targeted support to product developers, the “SASTPD” approach [4] pursues the goal of holistically considering the system and context boundaries of raw materials up to the end of life and uses iterative assessments with Life Cycle Assessments (LCA) for this purpose. Fernandes et al. [5] consider the context analysis with reference to the product type. Relevant context variables of different product categories are collected and categorized on an empirical basis by Gericke et al. [6]. The model-based MESSIAH approach [7] analyzes functions and processes in the early phase of PD regarding their environmental and social value as well as circularity. GIGA-MAPS [8], offer a way to capture contextual information on a visual map to gain knowledge through visual enrichment. An approach was introduced by Langer and Lindemann [9] to evaluate the effects of dynamic changes in PD on the context, considering numerous criteria including reaction delay, sensitivity, response characteristics, and criticality.

### 2.2 Circular Design Strategies

Transitioning from a linear to a CE necessitates simultaneous evolution of BM and PD strategies [10–12]. Therefore, the successful adoption of a CE mandates close collaboration among businesses, governments, academia, and society [13]. Additionally, it

requires innovation and advancements in supply chains, product and service designs, and emerging technologies for circular business models (CBMs) [14]. Due to a lack of standardized classification for circular PD, the approach of Bocken et al. [10] “Closing, Slowing, and Narrowing the Loop” subdivides methods to direct their focus on specific areas of the PLC. Based on the ISO 59004 framework [15], approaches can operate at various levels, including the system, product, component, or material level and contribute to one or more of the “Ten Retention Options”, depicted by Reike et al. [16]. CBMs constitute a pivotal element in bolstering the CE [13], however, prevalent CBMs also often lack standardization [17]. Consequently, companies implementing circularity principles must innovate their BM [18]. The implementation of the CE affects numerous components of a company’s BM [19], necessitating substantial change. To facilitate this transition, Geissdoerfer [17] outlines four CBM strategies: Cycling, Extending, Intensifying, and Dematerializing. Although the ISO 59010 [20] defines the CE as an economic system that inherently contributes to sustainable development, sustainability is often not initially considered in CBMs [21] or considerations are merely restricted to recycling practices and use-oriented product service systems [22].

### 2.3 Circularity Analysis and Evaluation

CE is conceptualized across Macro, Meso, Micro, and Nano levels, which provide a framework for implementing CE strategies at different scales [23, 24]. According to de Oliveira et al. [23], each level necessitates different methods to assess circularity adequately. For instance, to evaluate circularity at the product level, various indicators and methodological approaches exist, but none has yet prevailed as the standard. Building upon the Material Circularity Indicator (MCI) [25], the EMA initiated the Circulytics project, wherein the MCI has been further refined and tested in real-life environments with companies [26]. The ISO 59020 [27] establishes circularity assessment guidelines to analyze circularity at all levels in three steps: system boundaries, measuring circularity, and reporting the results. Luthin et al. [28] propose Circular Life Cycle Sustainability Assessment (C-LCSA), merging CE indicators with LCSA methods to evaluate circularity across PLC and addressing trade-offs between circularity and environmental, economic, and social impacts. So far, only a few methods exist for evaluating CBMs. An approach for developing a set of indicators that link CE principles, CBM, and the pillars of sustainability is proposed by Rossi et al. [29].

### 2.4 Need for Action

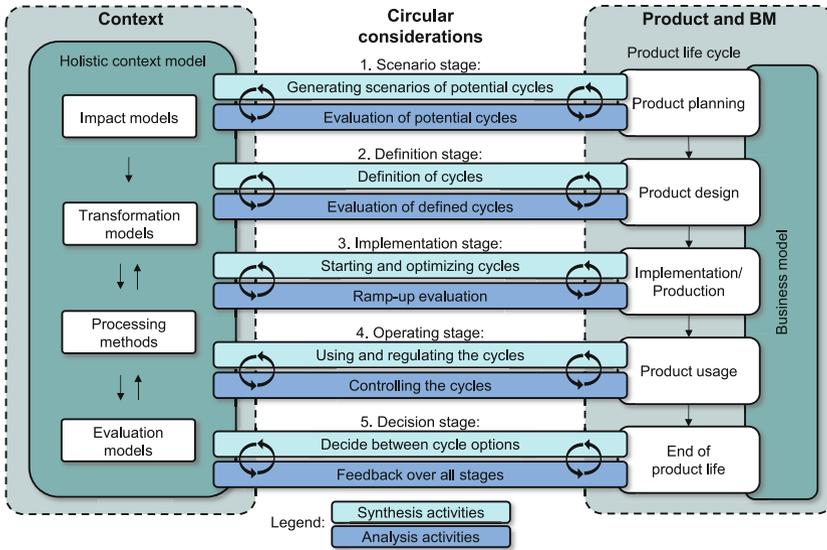
Building on the main findings in the state of the art, this chapter will derive the requirements for a new methodology. Context analysis approaches [9] enable the classification of external context factors. The inclusion of material and information cycles necessitates the formalization and continuous assessment of the context throughout the PLC. However, semantic models for capturing context [8] don’t consider differentiation of known/unknown and relevant/irrelevant information, which is crucial for future cycle scenarios. Approaches observing BM innovation focus on individual stages, neglecting the ongoing activities needed to align a company’s capabilities with the dynamic changes mandated by a CE [30]. Most publications on CBMs assume a single economic

context, which biases the proposed BM [31]. Considering a variety of context scenarios would promote the implementation and evaluation of CBMs. The majority of existing methods and tools are not suitable for some CE-specific challenges [19], and none covers all phases of CBM innovation. Sassenelli et al. [32] also emphasizes the need for a methodology for conducting a CE performance evaluation of CBMs to provide practitioners with an assessment tool that quantifies the benefits of CE. Additionally, there is a lack of decision-making procedures for influencing product concepts at an early stage of PD [33]. The necessary feedback from technology to circular markets via BM does not take place sufficiently, meaning that products are not assessed to context compliance and circularity. Given the mentioned deficits, there is a need for methodological support to systematize the continuous consideration of a dynamic context, provide improved understanding, and better align context with the development of circular products and BMs. This contribution proposes a methodology designed to support the development of more circular products from the early stages of development throughout their entire PLC. Additionally, the approach should bidirectionally consider the interrelationships between context, PD, and BM development to assess and optimize each other's influence for greater circularity. To ensure this comprehensive consideration, various analysis and synthesis methods need to be included (Sect. 2), supporting circularity across all levels, from material to global scale.

### 3 Context-Based Methodology

The context-based methodology, displayed in Fig. 1, comprises the context and the common PLC with its corresponding BM, systematically interconnected through various synthesis and analysis activities, forming circular considerations across five stages, which are continuously exemplified with an example of a BEV development.

The **context** consists of four internal viewpoints, collectively forming the holistic context model. Firstly, the impact models simulate the reality and formulate objectives concerning sustainability parameters. Transformation models, such as the approach proposed by Rusch et al. [34, 35], are necessary to translate the target values of the impact models into addressable values for PD. These models should also enable product developers to identify problem shifts in an early phase. Processing methods such as GIGA-Maps [8] or Model-based Systems Engineering [3] are employed to capture and process the context, facilitating traceability and the accumulation of relational knowledge. These methods may be also supported by an engineering graph, as proposed by Schweizer et al. [36]. Lastly, the evaluation models, e.g. Langer & Lindemann [9], evaluate the context and validity of information under the influence of factors such as frequency of change, criticality of effect, precision, quantity, actuality, and permissible deviations. The subdivision into these four viewpoints effectively supports the partial integration of various model approaches. Through the interaction of these models, it consistently enhances the situational awareness of product developers. Changes in both product and context can be systematically analyzed and synthesized with reference to circular considerations. This process enables the derivation of requirements for the product and the BM from the continuously gained knowledge to enhance circularity. The **product life cycle** consists of five life cycle phases: planning, design, production, usage and end of life, known from



**Fig. 1.** Context-based methodology for a holistic development of circular products and business models

various development processes [37]. Circular strategies can also lead to an extension of the product usage and place greater emphasis on the end-of-life phases in the early phases of BM and PD. The understanding of a dynamic context as a result of the implementation of circular considerations leads to the need for phase-specific valuation methods. It should be noted that, at this point, the sequence of the steps described may vary and be iterative depending on the task. **Circular considerations:** To develop products that have a higher level of circularity, continuous alignment with the context, and vice versa, must occur throughout the entire PLC. This alignment is maintained for each phase of the PLC across the five stages, as depicted in the center of Fig. 1. Each stage is subdivided into synthesis and analysis activities that iteratively interact with each other. With the help of analysis methods, the interrelationships can be understood better, while synthesis methods help to generate more circular solutions. The analysis throughout the PLC is carried out with the ISO 59020 [27] or C-LCSA [28], as they can assess a product beginning at the early stages of development. Starting from the realization stage, the MCI [25] can also be used for the assessment on material level. In the first stage, the *scenario stage*, various scenarios for potential cycles based on the product planning by using scenario techniques [38] are generated and projected into the context model. Through appropriate assessment methods (Sect. 2.3), the potential cycles are evaluated within the future context, and conclusions for further product planning are drawn. For example, political scenarios or future BEV drive technologies could be developed, in which the circularity of the used energy storage systems and the availability of resources are considered. This stage is iterated until the most relevant and promising material and information cycles for the considered products have been identified. These cycles result in requirements for the product and BM. In the second stage, the *definition stage*, subsequent cycles are

progressively clarified and defined, leveraging CBM design and circular product design strategies as outlined in Sect. 2.2. As granularity increases, these cycles can be more precisely harmonized and synchronized with the dynamic context through the more intensive application of circularity analysis and evaluation techniques to avoid problem shifts. For example, cycles could be defined that consider the reuse of individual BEV components. The third stage, the *implementation stage*, follows the product design and focuses on implementing and optimizing the planned and developed cycles. During the Ramp-up, physical interactions between the PLC and the context occur through the utilization of existing and the establishment of new material and information cycles. These interactions should be monitored from the outset for analysis purposes using appropriate tools. For instance, make or buy decisions, contracts and procurement processes must be designed to establish the cycles. The fourth stage, the *operating stage*, continues these activities to effectively control all relevant cycles throughout the use-phase and continuously assess them within the dynamic context and, if necessary, cycles can be adjusted through appropriate CBM design or circular PD strategies. In this manner, materials that have become critical due to dynamic changes in the context can be substituted with suitable alternatives. Namely, changing prices and demand of recyclates can influence the further production and recycling of BEV components. In the fifth and final stage, the *decision stage*, decisions are made about the cycles that do not behave as planned at the end of the PLC. In addition, to dissolve or transfer cycles into other cycles whereby closing cycles should be prioritized. The closing of material and information cycles is realized using a feedback loop with the help of the control mechanisms established in the previous stages, such as tools for material identification or maintenance in databases. This enables materials to be integrated into new product generations or existing material cycles within the context, while information about circularity practices can be documented and lessons learned can be reflected. As an example, it can happen that less parts as planned can be reused due to a deviating BEV utilization.

## 4 Discussion

Given the stated requirements, the methodology provides an overview of the interrelationships between context and PLC phases by visualizing the possible methodological connections. The user is provided with several appropriate synthesis and analysis methods to guide the development of more circular products within the circular considerations. The combination of these can cover the different levels of circularity and bidirectionally consider the interrelations. The continuously updated holistic context model allows the developer to observe the dynamic context. Through these measures, the alignment of the context to the BM and PD, resulting in the potential to develop more circular products, is being elevated. Nevertheless, it should be noted that the introduced methodology, and its non-linear application can be very complex, even for relatively simple products. These shortcomings are mainly due to the size of the context and the number of interactions with it. Furthermore, quality, architecture, actuality, documentation, and comprehensiveness of necessary data utilized in this iteration of the methodology need to be further elaborated. The methodology provides the framework for further research into digital assistance systems at the interface between circular markets and companies,

so that, for example, the ability to forecast the availability of materials can be supported. Similarly, the intersections between the different models and stages need to be further defined. In this sense, the choice of methods and the application of each method can be adapted depending on the specific use case to ensure compatibility. Beyond that, the PLC and the BM must further be integrated to contribute to a holistic development model. Lastly, methodological limitations arise from a further consideration of a longer PLC or multiple product generations.

## 5 Conclusion and Outlook

This contribution highlighted in the state of the art that existing methods lack sufficient holistic and temporal formalization for context processing, preventing the evaluation of context validity. Additionally, existing tools do not adequately address the phases of the CE, and BMs are not sufficiently adapted to dynamics and scenarios. Furthermore, it has been derived from the state of the art that the interrelationships between context, BM and PD are unclear. Therefore, this paper presents a novel methodology that systematically connects the dynamic context and the development of circular products and BMs through circular considerations. The foundations for circular assessment methods are derived from product, business, and context scenarios, while various assessment methods are also proposed for the specific phases of the PLC. Due to the high level of abstraction and the scope of the methodology, the focus was placed on the basic idea and priorities for further research were identified. Based on an application example, the methodology will be detailed and applied in further contributions within real-life environments. The realization of closed-loop strategies leads to an extension of the lifetime of a product and its components. Thus, the interoperability between individual product generations and the development of a single product becomes crucial, so that further research based on the proposed methodology will follow.

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