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# Methodology for a Holistic Product Circularity Analysis (HPCA)

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## Abstract

This contribution introduces a methodology for assessing product circularity across its lifecycle to enhance sustainability within the circular economy. Addressing the current lack of holistic methods for systematic analysis, this bottom-up approach comprises three phases: data inventory, assessment and analysis, and interpretation of the results. Key data, including material specifics, energy usage, working time of humans and machines, transport routes, and processes involved, are compiled into a digital product datasheet. This facilitates the creation of a detailed product analysis in which the product system, with its inputs and outputs, is described in three stages of the product life cycle. Through the analysis and evaluation of products, the methodology identifies potentials to enhance circularity. Demonstrated through a spice grinder use case, a reference and a circular scenario are evaluated to describe the key differences. The methodology presents a significant step forward in understanding and enhancing circularity within product and material cycles.

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## 1. Introduction

A circular economy (CE) is an economic system that minimizes waste and pollution by ensuring that resources, products, and materials are continuously cycled through different retention options to preserve their maximum value. Influential contributions were made by William McDonough, and the German chemist Michael Braungart, who co-founded the Cradle to Cradle (C2C) design framework [1]. Transitioning from a linear to a CE enables more efficient utilization of rare resources and reduces resource dependency [2].

To advance the implementation and establishment of a CE, synthesis methods are required for the development of circular products, while analytical methods are essential for evaluating the circularity of both existing and emerging products. [1,3]

This paper presents the state of the art in circularity assessment, focusing on the most relevant methods and indicators for product evaluation. There is currently no generally accepted standard for evaluating product circularity

[4]. A methodology is proposed to address the existing gaps in circularity assessment.

## 2. Basics and state of the art

Analysis methods in sustainable product development primarily involve assessing product sustainability to ensure awareness of their environmental impacts. Life Cycle Assessment (LCA), the standardized method for evaluating environmental sustainability, has evolved into Life Cycle Sustainability Assessment (LCSA), which integrates all three dimensions of sustainability: environmental, social, and economic. [5,6]. Rooted in the concept of eco-efficiency, LCA analyzes product systems to optimize individual products along a linear life cycle. This is leading to reduced resource consumption and pollution but potentially optimizing inherently unsustainable systems, such as waste incineration, which undermines material circularity [7].

### 2.1. Retention options (RO) for product-level CE

After conducting an extensive literature review, Reike et al. [8] propose a 10R typology comprising two preventive options and eight ROs. These ROs are categorized into short loops, including "Refuse" (R0), "Reduce" (R1), "Resell/Re-Use" (R2), and "Repair" (R3), where the product maintains its original function. Medium loops involve "Refurbish" (R4), "Remanufacture" (R5), and "Repurpose" (R6), entailing product upgrades with involvement from producers or third parties. In contrast, long loops encompass "Recycle Materials" (R7), "Recover Energy" (R8), and "Re-Mine" (R9), where the original function of the product is no longer preserved. The selection between these loops depends on whether the function, the resources or the energy content of the product holds greater importance, with shorter loops being preferred when function outweighs resource or energy considerations. [8]

### 2.2. Circularity indicators and circular assessment methods

In the study by Oliveira et al. [9], circularity indicators at product and company level were investigated. The findings revealed that the majority primarily focus on resource and material recovery strategies in the environmental dimension of sustainability. The review concludes that while the examined indicators offer extensive information, they are often incomplete, leading to superficial assessments of the CE. [9]

The Material Circularity Indicator (MCI), developed by the Ellen MacArthur Foundation in collaboration with Granta Design, combines material recycling, lifespan, and usage intensity into a single metric to measure material flows across the entire lifecycle. It is applicable to materials, products, and companies. Designed primarily for product design, it also supports procurement, investment decisions, and internal reporting. Input parameters include material's origin and post-use destination percentages, with output values ranging from 0 to 1, where higher scores indicate greater circularity. [10]

The Product Circularity Indicator (PCI) was developed to address key limitations identified in the MCI, particularly in its ability to account for product-level circularity more comprehensively. While the MCI focuses on broader product system boundaries and primarily evaluates recycling efficiency, the PCI incorporates material-level factors such as losses during feedstock and component production, as well as the impact of reuse. This allows for a more nuanced understanding of circularity, emphasizing durability, component reuse, and material value retention across multiple lifecycles, making it a more detailed tool for evaluating product circularity. [11]

The Circularity Evaluation Tool (CCET) evaluates alternative product concepts circularity potential during the early stages of product design and development. It was developed through extensive literature review and collaboration with manufacturing companies. The CCET aims to help designers make informed decisions about material choices, assembly methods, and product lifespan. The tool was tested and verified across several manufacturing companies and has proven effective in supporting circularity-related decision-making at the design phase. [4]

The Circular Economy Indicator Prototype (CEIP) [12] is designed for manufacturers and retailers of tangible goods to assess the intrinsic circularity performance of the products they develop or sell. Using a 15-question Excel tool, the CEIP evaluates different product lifecycle stages: design, manufacturing, commercialization, usage, and end-of-life. It generates a circularity score and visualizes performance in a spider diagram [13]. The Circular Economy Toolkit (CET) [14] is an online tool for assessing the circular performance of products and services. It follows a checklist of circular economy principles, identifying strengths and areas for improvement across all product lifecycle stages. The CET also indicates opportunities and feasibility for enhancing circularity [14]. The Circularity Potential Indicator (CPI) [15] evaluates circularity potential through a questionnaire addressing 20 attributes, aligned with the Ellen MacArthur Foundation's circular economy framework, and is available in Excel and web-based formats [15]. The Longevity Indicator (LI) measures how long resources remain in use within circular systems, emphasizing material retention over time. It calculates contributions to material circularity by assessing initial product lifetimes, refurbishment cycles, and recycling processes, offering a tool for decision-making and CE performance evaluation [16].

Another promising approach, as proposed by Luthin et al. [17], entails the development of an integrated framework for assessing CE concepts. This framework, termed circular life cycle sustainability assessment (C-LCSA), combines CE indicators with LCSA methods, integrating LCA, Life Cycle Costing, and Social Life Cycle Assessment. Key indicators for C-LCSA include material circularity, product circularity, and longevity. These indicators were selected based on their suitability for evaluating circularity across the product life cycle. While traditional life cycle approaches require adaptation for CE application, C-LCSA offers a structured approach to identifying trade-offs between circularity improvements and environmental, economic, and social impacts, aiding decision-making in industrial ecology. Additionally, the C-LCSA framework addresses challenges in data availability and interdisciplinary collaboration, providing guidance for future studies in assessing CE concepts and ensuring comparability across assessments. [17]

In their critical review on testing product-level CE indicators, Jerome et al. [18] highlight a significant gap in existing methodologies, noting that "no indicator accounts for resource use in the use phase, and there is limited attention to lifetime extension strategies". [18]

The "ISO 59020" establishes a framework for measuring and assessing circularity across multiple levels. The procedure outlined comprises three essential steps. The first step involves setting the boundary of the system under evaluation, specifying system levels, functional units, goals, and scopes. The second step encompasses measuring resource inflows and outflows of the system, selecting appropriate circularity indicators, and describing the system in detail to facilitate tracking changes in resource flows. The third step involves reviewing measurement results, assessing value and impact, consulting stakeholders, and reporting circularity performance outcomes. [19]

### 3. Need for action and requirements for Holistic Product Circularity Analysis (HPCA)

The HPCA methodology aims to address key deficits identified in existing circularity evaluation methods. Current approaches often lack specificity in identifying areas for circularity improvement within the product life cycle (PLC), merely providing a numerical score without clear guidance on optimisation strategies. This deficit underscores the need for a methodology which addresses the identification of hotspots in the different phases of the PLC for enhancing circularity. These optimization potentials can be identified by a qualitative assessment and a quantitative analysis of the product system in the different stages of the PLC. There is a need for comprehensive indicators that capture resource utilization throughout the entire PLC and adequately consider strategies for extending product lifetimes.

While existing standards such as ISO 59020 allow flexibility in defining system boundaries, this reduces the comparability of different results. Thus, a standardized methodology for evaluation is necessary. Transport routes should be integrated into circularity analysis, to make the size of the cycles visible. Additionally, factors such as the resources needed for repair and disassembly (time, energy, material) should be considered, to identify cost drivers and cycle efficiency. An interface should be implemented to integrate existing data from databases into the analysis.

Companies and product developers need a methodology to design both the product and its associated material cycles. These material cycles start at the beginning of life (BoL) stage where the company has full control. To ensure full material circularity, the company needs to know what happens to the product in the middle of life (MoL) and end of life (EoL) stages regarding the planned material cycles.

The users of the products need a clear evaluation of the circularity of the product they are buying. They have a major influence on the circularity of the products, as they decide from the MoL stage onwards how the product is treated, i.e. whether the actual planned material cycles are adhered to. To do this, however, they need to know which material cycles are planned for the product.

### 4. Methodology for HPCA

The HPCA methodology is structured into three distinct phases, elaborated upon in the subsequent sub-sections. An overview of these phases is provided in Fig. 1. In the initial "data inventory" phase, the product developer compiles all necessary information into a Digital Product Datasheet (DPD), forming the basis for the assessment process. At this stage of the methodology development, the DPD is represented as an Excel spreadsheet. The DPD monitors and documents the product throughout its whole PLC. If data is not available, literature values are used for estimating based on various databases and the knowledge repository. The knowledge repository is a centralized database that consolidates information from various sources, including external databases, and internal knowledge from product developers, the company, and previous products. It serves as a resource for

product developers, assisting in the design and development process by providing estimated data when specific values are unknown. A concept of how this data aggregation might be done with graph-based databases is shown in the work of Schweitzer et al. [20].

An automated algorithm processes the data from the DPD and computes circularity scores across three stages of the PLC during the "analysis and assessment" phase. These stages encompass the BoL, production phase; the MoL, usage phase; and the EoL, ending of operation phase. Finally, in the "interpretation of the results" phase, assessment outcomes are presented through a dashboard, as depicted in the excerpt on the right of Fig. 1. This dashboard offers a qualitative assessment and quantitative analysis of materials and energy usage, along with transportation distances and transportation-energy implicated throughout the PLC phases.

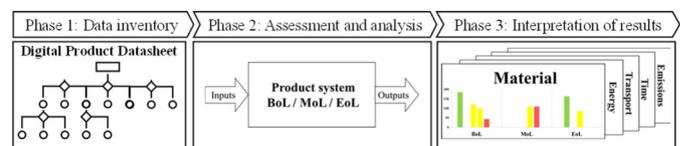


Fig 1. Overview of the HPCA methodology

Companies can estimate product circularity during the development phase and later validate these estimates against actual data once production begins. In this way, not just a product is developed, but also the material cycles to which the product goes in the different phases of its PLC. This highlights the importance for companies to understand and monitor what happens to their products after sale. The DPD allows them to track product outcomes and evaluate how closely these align with the intended circularity cycles.

Providing the DPD to the customer informs him about the circularity of the product he is purchasing. In advance he may have the possibility to see his influence on the product circularity starting at the MoL stage depending on how he uses the product and if he contributes to the planned circular strategy that is developed for the product. As a result, the customers are held accountable and made aware of their impact on circularity.

The assessment can be conducted either during the product development process of a new product to estimate, evaluate, develop, and optimize the material circularity, or retrospectively for an existing product to compare its circularity with similar products. The outcome of the assessment provides a holistic evaluation of the product across all stages of the PLC.

The method claims to represent a holistic product circularity analysis, but not a holistic sustainability analysis. As product circularity is primarily described by the material cycles and their efficiency, the environmental dimension of sustainability is mainly considered. Data for assessing the economic and social dimensions of sustainability are already partly available in the DPD and an assessment of these dimensions can be carried out using complementary methods such as LCSA.

#### 4.1. Phase 1: Data Inventory

The necessary data for the DPD are derived from diverse sources, including material- (i.e. Granta Edupack [21]), LCA-,

and process-databases, as well as computer aided design (CAD) and product data management (PDM) systems, and the knowledge repository, as shown in Fig. 2. These sources provide insights into the product's assemblies, parts, and manufacturing processes. Additionally, self-generated data, such as energy consumption measurements during manufacturing processes, further enrich the DPD with insights based on real data. The collected data encompasses various parameters crucial for product circularity assessment and analysis, including material composition and weights, process details, human and machine working time, energy consumption, transport distances, and associated monetary costs. Throughout the PLC, inputs and outputs of the product system are documented in the DPD, ensuring a comprehensive record of the product's journey from BoL to EoL.

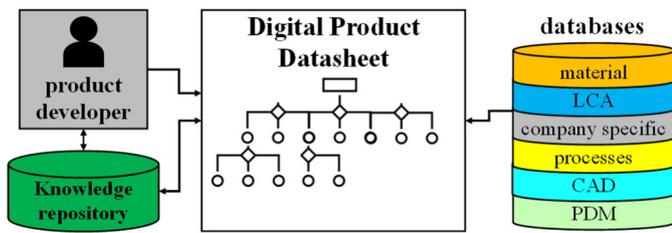


Fig. 2. Phase 1 – Data inventory

Furthermore, the DPD serves as a centralized repository for storing and organizing the inputs and outputs of the product system at each stage of the PLC. This structured approach facilitates effective data management and enables seamless integration of diverse data sources, ranging from material databases to real-time energy consumption measurements. By consolidating data related to material usage, manufacturing processes, energy consumption, and transport routes, the DPD contains all information for a holistic view of the product's circularity performance. Moreover, the ability to express parameters as costs allows for an evaluation of the economic impacts of circularity strategies at each stage of the PLC.

4.2. Phase 2: Assessment and Analysis

The assessment and analysis phase involves distinguishing between the qualitative assessment and quantitative analysis of parameters under consideration. Qualitative assessment is categorized in terms of CE as positive (green), neutral (yellow), or negative (red). Material, energy and emissions parameters undergo both qualitative assessment and quantitative analysis, while time, monetary, and transport parameters are subjected solely to quantitative analysis, providing insights into the efficiency and scale of cycles without determining circularity quality. The data itself is rated qualitatively depending on its source. Self-determined data are rated positively, while the absence of data results in a negative rating, and information sourced from literature or databases is rated neutral. This approach aids in identifying gaps in data collection.

Fig. 3 provides a detailed overview of the qualitative assessment of the parameters under consideration, categorized into input and output across the stages of the PLC: BoL, MoL, and EoL. Inputs at BoL comprise materials used in product production, while those at MoL include materials necessary for

spare parts and operation, and at EoL, materials essential for disassembly (for example solvents). Outputs include production waste at BoL, spare parts and operational materials at MoL, and disassembled products and their constituent materials at EoL.

rating	positive +	neutral 0	negative -
Material Input	<ul style="list-style-type: none"> <li>Material from R7 and R9</li> <li>Components from R2 R4, R5</li> </ul>	<ul style="list-style-type: none"> <li>Renewable primary material (biological)</li> </ul>	<ul style="list-style-type: none"> <li>Non-renewable primary material</li> </ul>
Material Output	<ul style="list-style-type: none"> <li>R7, R2, R4, R5, R6</li> <li>R8 - Ash is recirculated</li> </ul>	<ul style="list-style-type: none"> <li>R8 - Ash is backfilled</li> </ul>	<ul style="list-style-type: none"> <li>Landfill</li> <li>R8 - Ash is deposited</li> </ul>
Energy Input and Output	<ul style="list-style-type: none"> <li>Energy from renewable sources</li> </ul>	<ul style="list-style-type: none"> <li>Energy from non renewable sources with compensation</li> </ul>	<ul style="list-style-type: none"> <li>Energy from non renewable sources</li> </ul>
Emissions	<ul style="list-style-type: none"> <li>no operating materials or material abrasion</li> </ul>	<ul style="list-style-type: none"> <li>Operating materials or material abrasion from biological cycle</li> <li>GHG from fossil fuels with compensation</li> <li>GHG from renewable fuels</li> </ul>	<ul style="list-style-type: none"> <li>Operating materials or material abrasion from technical cycle</li> <li>Substances from the restricted substances list</li> <li>Green house gases</li> </ul>
Data	<ul style="list-style-type: none"> <li>Self-determined data</li> </ul>	<ul style="list-style-type: none"> <li>Literature data</li> </ul>	<ul style="list-style-type: none"> <li>Estimated or no data available</li> </ul>

Fig. 3. Qualitative rating of material, energy and emissions inputs and outputs

Fig. 3 illustrates the evaluation of energy inputs and outputs based on the renewable or non-renewable nature of their sources. Compensation means that the greenhouse gases (GHG) which are emitted due to the use of non-renewable resources is offset by supporting projects that reduce or capture an equivalent amount of GHG. The energy in BoL is required for production, in MoL the energy is needed for producing spare parts and the operation of the product and in EoL it's the energy necessary for disassembling and recycling processes. For products that produce energy in the MoL or are incinerated at the EoL, energy can also leave the product system.

Material cycles can be categorized into technical and biological: the technical cycle, which handles non-biodegradable materials, enabling continuous recycling without quality degradation, and the biological cycle, where biodegradable materials decompose and reintegrate as nutrients into ecosystems [1]. This concept originates from the C2C design framework. Since emissions are unwanted in terms of product circularity, they should be avoided.

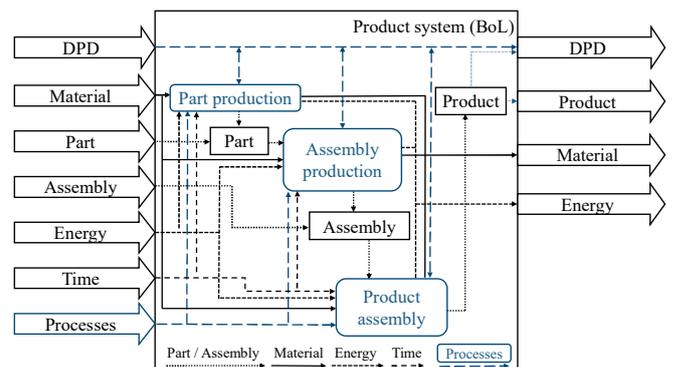


Fig. 4. Inputs and outputs of the product system at BoL stage (Production)

The product system in the BoL stage with its defined system boundaries is depicted in Fig. 4. Within this stage, various inputs such as materials, parts, assemblies, time of machines and humans, energy, processes and the DPD go into the product system. Production processes encompass part production, assembly production, and the final product assembly. Outputs generated during this stage comprise materials, including production waste, and energy, represented by waste energy. Furthermore, the final product and its associated DPD emerge as significant outcomes of the BoL assessment.

Furthermore, Fig. 4 reveals material, part, and assembly flows within the BoL stage. Moreover, arrows symbolizing

time and energy allocation provide insight into their distribution across various processes. Processes employed in part production, assembly production, or product assembly are illustrated, underscoring the role of specific characteristics in each process. For instance, welding as an assembly process needs welding solder for fastening parts, alongside human and machine working time and energy input. This detailed visualization offers a comprehensive understanding of the intricate interactions between resources and processes within the BoL assessment.

For the MoL and EoL product systems, similar diagrams as Fig. 4 are generated and the flows of in and outputs continue. In the MoL product system, the same DPD and product are inputs, as well as time, energy, processes, materials, spare-parts necessary for using and repairing the product. The outputs are the DPD, the obsolete product, material, parts, assemblies, energy and the Functional Output (FO) of the product use (i.e. runtime or processed volume). Processes in the MoL are repair, maintain und use of the product. At the EoL stage the inputs include the DPD, the product itself, and the necessary material, energy, and time for disassembly and RO processes. The outputs consist of parts, assemblies, and materials that can either be recirculated or disposed of, along with energy, which may include waste energy or usable energy if R8 is applied.

#### 4.3. Phase 3: Interpretation of Results

The final stage involves interpreting the collected and evaluated data, as shown in the excerpt of Table 1, which can be presented in a dashboard with diagrams for enhanced visualization. It reveals instances where parts or materials leaving the product system lack viable circularity strategies and may need to be incinerated or deposited. Additionally, quantitative data recorded in the DPD identifies assemblies with economically unfeasible disassembly due to excessive time requirements, enabling product developers to enhance circularity in existing or future product generations.

The evaluation delineates the PLC stages and material in and outputs with the highest circularity improvement potential, as well as identifying major cost drivers. To compare different RO, the evaluation can be carried out with different EoL scenarios. This can show which RO is the most efficient to close the circulation of materials in terms of time and energy.

### 5. Case Study: Application of HPCA to a Spice Grinder

To evaluate the developed concept, an application was conducted using a spice grinder as a case study. This product consists of 18 individual parts crafted from seven different materials and works using salt as its operating material. The product's Functional Output (FO) is quantified in kilograms salt grinded. Two scenarios were conducted: a "reference" scenario representing anticipated usage and a "circular" scenario where the material cycles were closed, the lifetime extended and only energy from renewable sources was used. The results, presented in Table 1, demonstrate the application of HPCA by illustrating how material cycle closures are assessed and highlighting the efforts required for their implementation in terms of emissions, time, energy, and cost.

Table 1. Overview of HPCA case study with different scenarios

scenario stage	reference scenario				circular scenario			
	BoL	MoL	EoL	PLC	BoL	MoL	EoL	PLC
Energy + in [kJ]	3116	931	1563	5610	6883	4881	2536	14300
Energy + out [kJ]	623	186	313	1122	1376	972	512	2860
Energy o in [kJ]	0	0	0	0	0	0	0	0
Energy o out [kJ]	0	0	0	0	0	0	0	0
Energy - in [kJ]	3767	1057	1723	6547	0	0	0	0
Energy - out [kJ]	753	211	1650	2615	0	0	0	0
Time Human [s]	300	1200	2000	3500	300	2500	2200	5000
Time Machine [s]	200	240	2500	2940	200	1300	3000	4500
FO [kg]	0	8.5	0	8.5	0	85	0	85
Material + in [g]	190	0	0	190	354	1173	37	1564
Material + out [g]	5	0	164	169	105	1173	286	1564
Material o in [g]	120	0	0	120	0	0	0	0
Material o out [g]	100	110	85	295	0	0	0	0
Material - in [g]	44	110	0	154	0	0	0	0
Material - out [g]	0	0	0	0	0	0	0	0
Transport [km]	12500	1000	300	13800	12500	2200	500	15200
Transport [kJ]	36	10	3	49	36	22	7	65
all Energy In [kJ]	6919	1998	3289	12206	6919	4903	2543	14365
Emissions [g]	0	0	0	0	0	0	0	0
Emissions [g]	500	530	300	1330	500	650	350	1500
Data + [%]	0	0	0	0	0	0	0	0
Data o [%]	50	50	50	50	40	40	40	40
Data - [%]	50	50	50	50	60	60	60	60
Costs [€]	9.5	5	3.5	18	9.5	42	8.5	60
Energy/FO [kJ/kg]	0	1049	1436	1436	0	139	169	169
Costs/FO [€/kg]	0	1.7	2.1	2.1	0	0.6	0.7	0.7
Legend	positive	neutral	negative	not rated	hotspot	FO = Functional Output		

Due to a lack of detailed information about the origins and manufacturing processes of the components and materials, estimations were necessary. This is reflected in Table 1 in the line of the data rating. The materials of the individual parts were identified, and their corresponding energies required for production and material recycling were determined with a material database. The processes used to manufacture, repair and recycle the parts were estimated while the related energy and time for the processes were determined with literature data. For transportation, a combination of ship and truck transport was assumed, with both scenarios being relatively local. The data of the material, energy, time and transportation for every individual part and the resulting assemblies are inserted into an excel sheet which is divided into the three different stages of the PLC. The result is the sum of all parameters, categorized by the stages of the PLC, with a total sum calculated for the entire PLC to compare the overall values, as displayed in Table 1.

In the reference scenario different material in and outputs were predicted for BoL and EoL. During the MoL phase, the grinding mechanism of the grinder is estimated to require replacement after ten fillings. The new spare parts are made from raw materials and the old ones are fed to R8. This has the highest impact on material circularity and is thus marked as a hotspot in Table 1. After five replacements of the grinding mechanism the grinder reaches obsolescence. At this point, reuse is no longer applicable, and the grinder is discarded via R8. In the circular scenario the materials stem from recirculated sources in BoL. Throughout the MoL, the grinding mechanism is repaired 50 times and broken parts are recycled with R4, R5, or R7. At the EoL stage all its components and parts are completely recycled with R4, R5, or R7. Also, just renewable energy was used. These scenarios enable a comparison of energy consumption and circularity impacts, while also highlighting trade-offs, synergies, and conflicts.

At the bottom of Table 1, two indicators are listed that reflect the efficiency of the cycles. The indicator Energy/FO represents the energy efficiency of the cycle, and the indicator Costs/FO represents the cost efficiency. In the case study the circular scenario is in both categories more efficient. However,

it was assumed that spare parts were available near the product's location, and that repair and recycling facilities were close to the area of use. As transport distance and energy intensity increase, there is a point where circular operation consumes more energy than linear usage. If the energy and costs for spare parts are higher, and the time required for repair increases, the outcomes may differ. This can be analyzed with HPCA, enabling the planning and observation of material circularity.

## 6. Conclusions and outlook

In this contribution, an overview of CE fundamentals, with a particular emphasis on circularity assessment, has been provided. Through an exploration of existing methodologies and indicators, deficiencies have been identified, leading to the proposal of steps to address them. Subsequently, the requirements for HPCA have been delineated. An important aspect is its structured evaluation, divided into three distinct stages of the PLC: BoL, MoL, and EoL. The methodology integrates qualitative assessments of material, energy, and emissions, providing a detailed understanding of circularity at each stage. It also accounts for transportation, revealing the size and efficiency of the cycles.

By integrating HPCA into the product development process, the size, efficiency, and effectiveness of the planned product cycles can be visualized, thereby identifying areas suitable for circularity enhancement. Thus, material cycles become an integral part of the product development process. Furthermore, it can highlight the effort required to improve product circularity. Leveraging the architecture and data of a DPD, HPCA enables automated assessment for generating fast results. Additionally, the DPD serves as a storage for necessary data, enabling the validation of theoretical values derived during the development process while tracking the product throughout its entire PLC, making it clear whether the developed cycles are maintained and if the assumptions for time, energy, and material were correct. It also shows which data is missing. The collected data are stored in a knowledge repository, creating a database for future developments to improve accuracy. This can help when data availability is insufficient. To enhance data collection efficiency, exploration of graph-based databases is proposed for future implementation.

Looking ahead, HPCA will be refined through evaluations of more complex sample products with enhanced data quality, as well as its application in the product development process during the creation of new products. Additionally, the selection of appropriate indicators tailored to each stage of the PLC will be prioritized. Finally, further refinement will better reveal trade-offs between economic and environmental factors, providing clearer insights into the economic viability of circularity initiatives.

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