

Article

Triple-C: A Tridimensional Sustainability-Oriented Indicator for Assessing Product Circularity in Public Procurement

Simone Wurster ^{1,*} and Luana Ladu ^{1,2}¹ Department of Innovation Economics, Technische Universität Berlin (TU Berlin), 10623 Berlin, Germany² Bundesanstalt für Materialforschung und -prüfung (BAM), S.2 Akkreditierung und Konformitätsbewertung, 12489 Berlin, Germany

* Correspondence: simone.wurster@tu-berlin.de

Abstract: Various microlevel circular economy indicators for assessing sustainability and, partly, additional sustainability characteristics have been developed, but an integrated solution considering the environmental, social, and economic pillars remains a research gap. **Method:** Based on a multimethod approach, including surveys and the analysis of existing sustainability assessment methodologies and standards, this paper proposes a concept for a multidimensional circular economy indicator tailored to public procurers. It relies on attractive existing building blocks including: (1) the ecological scarcity method, (2) European and international sustainability standards and indicators, and (3) the STAR-ProBio-IAT concept. **Results:** This article presents the concept of the composite indicator Triple-C, consisting of 20 elements and aimed at facilitating sustainable circular public procurement. It is intended to be incorporated into software that facilitates sustainable product decisions among public procurers in Germany. **Conclusions:** We propose a generic indicator concept covering all three (environmental, social, and economic) sustainability pillars. More research and additional standards are needed to develop the Triple-C concept further into product-specific applications.

Keywords: circular economy; sustainability assessment; circularity; ecological scarcity method; life-cycle assessment; LCA; life-cycle costing; LCC; social sustainability; indicators



Citation: Wurster, S.; Ladu, L. Triple-C: A Tridimensional Sustainability-Oriented Indicator for Assessing Product Circularity in Public Procurement. *Sustainability* **2022**, *14*, 13936. <https://doi.org/10.3390/su142113936>

Academic Editor: Mirco Peron

Received: 30 July 2022

Accepted: 10 October 2022

Published: 26 October 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

1.1. The Need for a New Composite Indicator for the Circular Economy

According to the OECD and World Bank figures presented by the European Commission, global consumption of materials is forecast to double until 2060, accompanied by a significant waste problem: an increase in annual waste generation by 70% is expected by 2050 [1]. In addition, our economy is only 8.6% circular [2], and the rest is largely based on the linear model of take–make–dispose, generating demand for 100 billion tons of materials annually. In response to this problem, the European Union launched the Green Deal, a concerted strategy for a carbon-neutral, resource-efficient, and competitive economy. Expanding the circular economy (CE) shall make a decisive contribution in this context [3].

The CE represents a production and consumption model in which materials and products are shared, leased, reused, repaired, refurbished, and recycled for as long as possible, and their life cycle is extended [4]. Specifically, it relies on nine (initially four) “R strategies” [5,6], mainly covering the aspects to which the definition of [4] refers: reduce, reuse, recycle, and recover. In line with [7], the “reduce” strategy also includes the reduction of energy consumption, i.e., energy efficiency. In terms of the United Nations Sustainable Development Goals, the CE addresses SDG 11 (sustainable cities and communities) and SDG 12 (responsible consumption and production), closely linked with SDG 6 (clean water), 8 (decent work), and 15 (life on land) [8].

Various initiatives to promote the CE exist, e.g., by the World Economic Forum, the European Commission with its first [9] and new Circular Economy Action Plan [3], the

Ellen MacArthur Foundation, and the World Business Council for Sustainable Development (WBCSD) and national initiatives such as Germany's Koalitionsvertrag (Coalition Agreement) 2021–25 [10], the Circular Economy Roadmap for Germany [11], and Germany's Standardisation Roadmap Circular Economy [12]. Other activities include the implementation of the monitoring framework on the circular economy of Eurostat, prepared as an answer to the first Circular Economy Action Plan and the Global Reporting Initiative Standard. See Section 1.2.2 for details.

Facilitating circular public procurement plays an important role in this context [13,14] because the public sector is a major player in stimulating market demand. On a global scale, public procurement accounts for around 13% of GDP [15]. The public sector is also crucial in stimulating and promoting demand-side innovations [16]. By using their purchasing power to procure environmentally friendly goods and services, they can also contribute fundamentally to sustainability in production and consumption [17]. From a national point of view, realizing sustainable and circular procurement is, for example, crucial for public procurement in Germany. The implementation of green public procurement and the rising importance of life-cycle analyses, e.g., regarding mobility investments, are substantial elements in this context. Social aspects are essential as well. See Section 1.4 for details.

Suitable assessment methods and indicators are crucial for product selection, but fundamental gaps exist regarding circular aspects. According to Saidani et al. [18], “the wide range of existing [CE-related] sustainability indicators [. . .] [is] not specifically tailored to assess the economic, environmental or social performance of CE-related strategies [. . .]. In most cases, the focus is on one of the three aspects (only).”

The gap regarding the link to the three sustainability pillars is also discussed pillar-wise. Gaps regarding the link between environmental life-cycle assessment (LCA) studies and circularity indicators are, e.g., described by [19,20]. Likewise, social indicators are underrepresented in the 87 contributions on product indicators, with [21] as the only important example. Kristensen et al. [22] describe various gaps in circular economy indicators' state of the art, but does not even mention social aspects. Saidani et al. [18] specified the gap regarding the integration of social aspects as follows:

The view provided by the [present] [circularity] indicators [shows] some lacks [. . .]. (M)ost of the [circularity] indicators depict economic and environmental impacts, social consequences remaining barely addressed. This missing dimension is an issue often highlighted (in research on Sustainable Development Indexes).

Specifically, the need for an integrated indicator includes the challenge that “the best end-of-life pathway may also vary when looking at the [. . .] social component”, but also “the cost” [18]. In summary, there is a need for sustainability-oriented composite indicators to assess the circularity of products, providing aggregated information on environmental, social, and economic aspects. This paper tries to overcome this present gap and provide a sustainability index that addresses all three sustainability pillars, covering environmental, social, and economic aspects. On this basis, this article provides a concept for an easy-to-use multidimensional circularity indicator, tackling the needs of public procurement professionals.

1.2. Literature Review

1.2.1. Sustainability, Its Assessment, and Indicators

The state of the art of sustainability and sustainability indicators was recently presented by [23]. They adopted [7]'s sustainability definition as the “goal of sustainable development which encompasses environmental, social and economic aspects, in which the needs of the present are met without compromising the ability of future generations to meet their needs.”

Ecological sustainability is, for example, measured by environmental life-cycle assessments (LCA) based on the ISO standards ISO 14040 and ISO 14044 (see, e.g., [24,25]), and the ecological scarcity method (ESM) [26–29].

According to the LCA description of ISO standard 14044, ESM belongs to the life-cycle impact-assessment phase (LCIA), which is the third phase of the LCA. The purpose of LCIA is to provide additional information to help assess a product system's life-cycle impact results so as to better understand their environmental significance.

The value of the ESM method was, for example, acknowledged by the Science Magazine [30]. In Germany, ESM is also known as "Methode der ökologischen Knappheit" (MÖK) [24,25]. ESM is an ecological impact-assessment method that uses "(w)eighting as an optional step in life-cycle impact assessment [. . .], which is based on the ratio of desired policy targets to the current environmental situation" [29]. Specifically, it relies on "eco-factors, which measure the environmental damage in eco-points (UBP) per unit of quantity" [27]. Various versions with different elements and weightings exist depending on relevant political goals. According to [26], the first ESM version was developed in 1990, followed by its application in numerous companies and institutions, particularly in Switzerland and Germany, showing the method's feasibility impressively. Besides the work of [26,27,29] regarding Germany, Switzerland, and the EU, Ref. [28] provides data for all EU member states. Figure 1 shows an example of its structure.

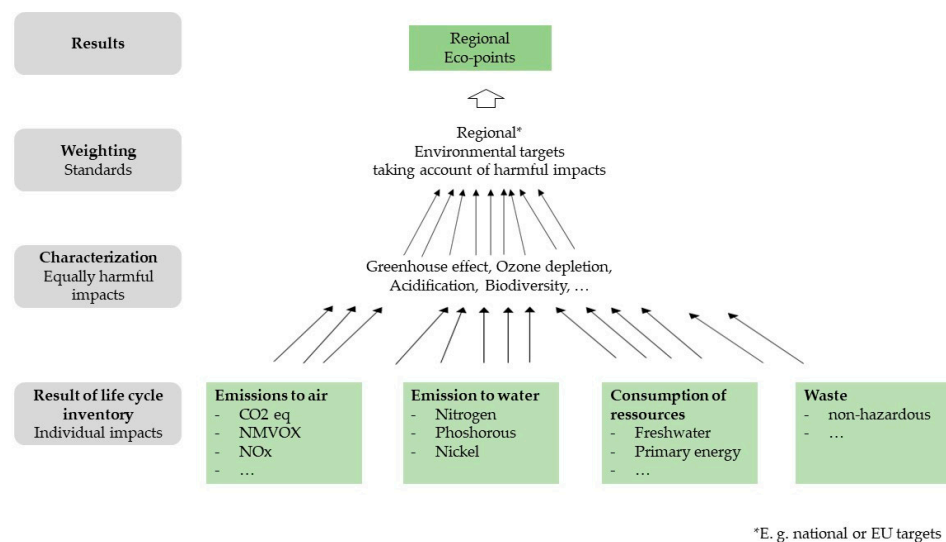


Figure 1. ESM structure according to Ahbe et al. [26] and Ahbe et al. [28]. Source: based on [26,28], "e.g. national or EU targets" replaces "Deutsche Umweltziele" and "UBP-D" of [26] and "EU28" of [28].

The current version of the formula to calculate the ESM score is, for example, provided by [28], while the first version was provided by [31]. Source [27] provides examples on how to calculate the Swiss ESM score for an electric vehicle per passenger kilometer (pkm) with average vehicle utilization of 1.6 persons and for methane (CH₄). Another example provided by [32] is a comparison of production-related ESM scores for three types of fuels: 786 ESM scores/1 gasoline, 711 ESM scores/1 diesel and 541 ESM scores/1 natural gas in Switzerland. A particular advantage of ESM is its specific suitability for providing environmental information of component-based products.

Additional methods are discussed by [27], e.g., Environmental Footprint v. 3.0. Usually, these methods do not integrate social aspects. However, first approaches, particularly the UN Environment Programme (UNEP)'s social life-cycle approach [31,32], address this problem.

Other work includes green Six Sigma approaches (see [33] for an overview and also [34,35]). In this context, the different focus of the contributions is noteworthy. Six Sigma is a management system for quality improvement, and the three contributions mentioned above focus on manufacturing. Therefore, procurement professionals, buyers in general, and their purchasing decisions are less focused. In contrast, our development has the specific aim of supporting people entrusted with buying decisions. Since manufacturers

also want to make attractive offers compared with competing solutions, their interests are addressed simultaneously.

LCA and the ESM are discussed further in the following sections, particularly in Section 3's Sections 3.4 and 3.7.

Relevant concepts in this context are "principles", "criteria", "indicators", and "composite indicators". While composite indicators are discussed in Section 2, EN 16751 [36] provides the following definitions for the first three concepts:

- Principle: "aspirational goal that governs decisions or behaviour"
- Criterion: "requirement that describes what is to be assessed"
- Indicator: "quantitative, qualitative or binary variable that can be measured or described to assess an aspect of a defined criterion"

1.2.2. Current State of Circular Economy Indicators

This section presents the state of the art of circular economy indicators with a particular emphasis on composite indicators.

Based on [18]'s classification of indicators at the microlevel, including "products, companies, consumers," meso-level indicators, particularly referring to ecoindustrial parks, and macrolevel indicators for "city(ies), region(s), nation(s) and beyond", our focus is on microlevel indicators for products, while selected additional research is presented to explain the relevant research gaps.

Composite indicators can be defined from a technical and a conceptual point of view. Technically, they are "mathematical combinations (or aggregations) of a set of indicators". From a conceptual point of view, they are "based on sub-indicators that have no common meaningful unit of measurement, and there is no obvious way of weighting these sub-indicators" [37]. PACE [38] distinguishes between process performance and headline indicators. At the same time, [39] provides a valuable overview of relevant topics regarding environmental, resource-related, and socioeconomic aspects in their Figure 4, highlighting the importance that circularity aspects must not be considered separately. Describing the relations between the indicators on different levels, [40] refer to system-wide (cascade factor) and sector- (cascade factor, recycled input rate, recovery rate) or product-based (material circularity indicator) views.

A detailed study of circular economy indicators' state of the art is provided by [18].

Their taxonomy consists of 55 indicators, including 20 microlevel indicators, which are presented later in this section in more detail. Another contribution belonging to the most detailed studies on product indicators is [22]. They provide an overview of 30 indicators, identify relevant clusters, and evaluate their importance by summarizing that:

(T)he majority of indicators is focused on recycling, end-of-life management or remanufacturing, while fewer indicators consider disassembly, lifetime extension, waste management, resource-efficiency or reuse.

That gap regarding the link to at least one sustainability pillar is addressed by [41], who present "a complementary environmental-impact based indicator that measures the environmental value retained through reuse, remanufacturing, repairing or recycling." Links to the other two sustainability pillars are not created. Another example is ref. [40], who work with "material flow analysis indicators (e.g., domestic material consumption) and circularity/resource efficiency indicators" (in particular with a cascade factor and the MCI (see below), and indicators on recycled input and the recovery rate). Social aspects are, however, not considered.

In the following, we present prominent product-specific indicators and indicators with a broader scope. In this context, Ref. [42] highlight the importance of indicators for labeling.

Product-Level Indicators

The simplest versions of product-related CE indicators are the scores on recycled and recyclable content and energy efficiency. In this context, Ref. [40] highlights that the cascade factor permits “both material and energy use”. Regarding recycled content, the international Ecolabel Index [43] can be filtered to show labels that refer to this indicator. For energy efficiency, it refers to 22 labels with a broader scope, though not specifically focused on the CE. More complex indicators are presented in the following.

As part of their 55 circular economy indicators, Ref. [18] identified 20 indicators as microindicators, which are shown in Box 1. These indicators were classified according to the criteria loops, performance, perspective, usages, transversality, dimension, units, format and sources.

Box 1. State-of-the-art microlevel circularity indicators and related instruments according to [18]. Source: own box based on text by [18].

• Cradle-to-Cradle Material Reutilization Part (C2C)	• Measuring Regional CE–Eco-Innovation (MRCEEI)
• Circularity Calculator (CC)	• National Circular Economy Indicator System (NCEIS)
• Circular Economy Index (CEI)	• Product-Level Circularity Metric (PCM)
• Circular Economy Toolkit (CET)	• Resource Duration Indicator (RDI)
• Circularity Index (CI)	• Recycling Indices (RIs) for the CE
• Closed Loop Calculator (CLC)	• Resource Productivity (RP)
• Circular Pathfinder (CP)	• Reuse Potential Indicator (RPI)
• Circularity Potential Indicator (CPI)	• Recycling Rates (RRs)
• End-of-Life Recycling Rates (EoL-RRs)	
• Eco-efficient Value Ratio (EVR)	
• Input–Output Balance Sheet (IOBS)	
• Material Circularity Indicator (MCI)	

Saidani et al.’s [18] statement on the research gap regarding circular economy indicators addressing the three sustainability pillars presented in Section 1.1 was formulated after they had analyzed all these indicators. Nevertheless, two items of Box 1 (C2C and MCI) are presented below:

Cradle to Cradle (C2C) is an advanced, internationally recognized, and widely used product-assessment approach to the circular economy with criteria in five dimensions: (1) material health, (2) recyclability, (3) renewable energy (use), (4) water stewardship, and (5) social justice. Based on the C2C approach, the recognized C2C certificate was created. Products are evaluated by a five-step scale from “basic” to “platinum” [44]. Together with various other labels with different foci, C2C is also a recognized label in public procurement in Germany. An example is provided by [45].

Another example, the **Material Circularity Indicator (MCI)** of the Ellen MacArthur Foundation, measures the circularity of material flows for selected products and is used as an assessment tool for companies to improve product design and material procurement [46]. A helpful description is provided by [47]. The MCI is shown on a scale of 0 to 1, with 1 representing complete circular material flows: 100% of materials from reused components or recycled material and zero waste. The indicator can be used to assess products and also companies in an aggregated manner. The MCI is also, for example, used by [19,48], and [40]. In addition, it was used in various external case studies cited by [18] and frequently suggested by [18]’s indicator advisory tool.

Regarding the combination of circularity analyses with other sustainability assessment, our literature review also unveiled several examples of a combination with life-cycle assessments, including life-cycle costing [19,20]. Notable aspects of [20] include the contribution to climate change (GWP), human toxicity, and the Service Life Ratio (SLR). An additional interesting element in ref. [19] is the Circular Economy Indicator Prototype, while ref. [49] shows the complexity of describing products by indicators by presenting 25 performance indicators for the production of eggs alone.

Additional indicators identified by our analyses are the UMI, Madaster, and the French repairability index.

The Urban Mining Index (UMI) [50] was developed as part of a doctoral thesis at the University of Wuppertal [51]. The urban mining approach supports the goal of managing building materials in cycles that are as closed as possible and compatible with the environment. A central element in this is the anthropogenic raw material store, which is understood as an “urban mine”.

Madaster’s [52,53] name stands for a new type of cadastre for (building) materials. In the online platform of the same name, <https://madaster.de/plattform/> (accessed on 9 July 2022), buildings are registered, including the materials and products they contain. The platform offers real estate owners and other stakeholders the possibility to store, manage, enrich and share data of their properties. This facilitates reuse, promotes smart design, and eliminates waste.

The French repairability index (RPI) is dedicated to the particular circularity aspect repairability. More information can be found at [54]. Like the Reuse-potential indicator, it refers to a specific “R” element. The consideration of other sustainability aspects is low.

An additional contribution, although not primarily marketed as a “circularity” or “circular economy” “index” or “indicator” is the **Integrated Assessment Tool** for bio-based products, presented in Section 1.3.

Company- and Country-Level Indicators

Besides the product-level indicators, we also analyzed company- and country-level indicators for a deeper understanding of the topic area and as a source for potential building blocks for our work.

Our presentation of company-level indicators starts with “Circulytics” and Circular Transition Indicators (CTI).

Circulytics is presented by the Ellen MacArthur Foundation [55] as “the most comprehensive tool available in the world for measuring the circular economy performance of companies”. Likewise, the CTI tool of the World Business Council on Sustainable Development (WBCSD) [56] helps companies to analyze the circularity of their material flows and energy consumption.

Various other circular metrics for businesses are presented by [18,39], including, e.g., Circle Assessment, Circelligence, Circularity Gap Metric, and, also in this context: Cradle to Cradle Certified. In addition, various circular indicators for governments exist, which are summarized by PACE [38]. An important initiative in a specific product area is also the New Plastics Economy Global Commitment [56,57]. Additional important work on circular economy indicators takes place in the ISO committee ISO/TC 323 Circular Economy, while Global Reporting Initiative/GRI 306: Waste 2020 [56] and Ecovadis [58] provide supplementing reporting and rating opportunities.

The overviews indicate an important difference between product-specific indicators and those with a broader scope. While Circulytics and CTI provide indicators, which address environmental, social, and economic aspects, the scope of product-specific indicators is very limited:

- Although examples of a combination of circularity and life-cycle assessments, including life-cycle costing, could be identified (see, e.g., [19,20]), our analysis confirmed that an appropriate combined product-level indicator, which provides a single score for all sustainability pillars, is missing.
- The limitations of the indicators in [18]’s overview, described by these authors themselves, were presented above. Regarding the two examples, C2C and MCI, additional limitations exist in the context of our study.
 - C2C does not include LCA or ESM, which is also specifically focusses on the needs of component-based products. The absence of this aspect is a remarkable gap, which refers, for example, to international LCA standards or ESM’s focus

on political policies. The economic dimension and life-cycle cost, which are very important for procurement decisions, are barely considered by C2C.

- The MCI is presented as a tool for designers. However, the linkage to other sustainability indicators is a gap. Even if designers use more indicators, the question of how to relate these indicators and come to overall conclusions remains. An attempt to combine indicators is made by [59]’s MCI-based cost-normalized material circular economy indicator MCIE. However, other environmental and social aspects are not considered.
- Even the two advanced product-related indicators UMI and Madaster, with the narrow scope on buildings, consider selected sustainability areas only. In particular, they are not combined with information on social sustainability, although the need for integrated analyses with additional environmental, social, and economic indicators is understood, e.g., [19,20].
- In general, social indicators are underrepresented in the 87 contributions on product indicators, with [21] as the only important example.

In this context, it is remarkable that [31]’s literature review does not even mention social and economic indicators. Links to environmental indicators are more established. For this reason, Harris et al. [60] summarize:

(F)ew studies compare circularity indicators with environmental performance or link the circularity indicators between society levels ([. . .]. However, adequate tools exist at each level (e.g., life cycle assessment (LCA) [. . .]).

In summary, no suitable LCA/LCIA-considering circularity index or indicator covering all sustainability pillars of a product exists. This article addresses this research gap.

1.3. The Integrated Assessment Tool

Addressing the gaps described in Section 1.2, an interesting building block analyzed and partially adopted in this paper is the integrated assessment tool (IAT) that resulted from the former EU project STAR-ProBio (see [61] for details). The IAT consists of 48 sustainability indicators. Specific questionnaires to provide information regarding the quantitative indicators of the tool are proposed at the end of [62]. For the quantitative indicators, metrics and assessment methodologies are provided. The IAT is associated with 10 SDGs—2, 3, 6, 7, 8, 9, 10, 12, 13, and 15—and is coherent with the current European standard EN 16751. Details of the indicator-based IAT are shown in Table 1.

Table 1. Key characteristics of the IAT.

Application Area	Bio-Based Products
Content	The IAT represents a cumulative scoring system, in particular on policies, environmental LCA results, indirect land use change (ILUC) aspects, circularity, social and economic aspects.
Indicators and thresholds	The 48 IAT indicators rely on 33 sustainability protection areas and 24 principles. Six indicators are critical and must be met to achieve a sustainability score. The concept provides thresholds for each indicator compared to an ideal situation, a specific target, a reference scenario, or a minimum requirement.
Scoring	The IAT provides numerical scores according to the characteristic of each indicator. For quantitative indicators, the assigned score is 2 when the indicator performs as expected; for qualitative indicators, the comparable score is 1. If an indicator cannot refer to appropriate results, the assigned score is 0. The maximum score is 105.
Representation	Visualization of the score is possible

Source: based on [62].

The IAT proposed an integration of existing methodologies to provide a holistic sustainability assessment of bio-based products, covering the three sustainability pillars, ILUC and circularity. The tool combines LCA and non-LCA metrics to guide companies in reporting on the sustainability of their bio-based products, considering both quantitative and qualitative aspects. Following the EN 16751 standard, it proposes principles, criteria, and indicators. EN 16751 itself derived its principles from ILO working standards [63] as described in its Section 6. For this reason, different principles and indicators included in EN 16751 and in the IAT, although primarily designed for addressing bio-based products, can be extended to a broader scope.

IAT's scoring system is based on a simple assignment of values (0, 1, or 2) to established facts based on a threshold to be reached. These aspects make the IAT very interesting tool as a guidance for the bio-based industry in conducting sustainability assessments of their products. Its grounding in an EN standard also facilitates its use for certification.

1.4. Sustainability Criteria Included in Public Procurement Regulations

The Directive on Public Procurement from 2014 (Directive 2014/24 EU) is decisive for procurement in the public sector, while the Circular Economy Action Plan of the EU Commission of March 2020 [3] seeks mandatory minimum criteria for sustainable procurement. The procurement directive of 2014 and related documents were transposed into German law in 2016. Procurement regulations with an environmental focus in Germany are presented in [14]. An important example is the amended Kreislaufwirtschaftsgesetz (KrWG) as amended on August 10, 2021, which includes a preference obligation for resource-conserving products in §45 [64]. According to this paragraph, public authorities have to give preference to products that:

- “have been manufactured using production processes that conserve raw materials, save energy, conserve water, are low in pollutants or low in waste,
- have been produced by preparing them for reuse or by recycling waste, in particular by using recycled materials, or from renewable raw materials
- are characterized by durability, ease of repair, reusability, and recyclability, or
- lead to less waste or less pollutant waste compared to other products or are more suitable for environmentally sound waste management.” (own translation)

Nevertheless, Section 7 of the Federal Budget Code (BHO), requiring that cost and performance accounting shall be introduced in appropriate areas, remains unaffected [65,66]. The federal states have additional requirements for public procurement. Varying requirements are binding regarding social sustainability. For example, public procurement professionals have to consider ILO labor standards [63] in different ways in their procurement processes, e.g., public procurement laws of the federal states of Berlin, Bavaria, and Hamburg, to mention a few.

A survey of the ConCirMy project was conducted to explore the need for sustainability and circular economy information by public procurement professionals. As the results show, the procurement professionals are most interested in life-cycle costing (LCC) information, followed by information on labels, end-of-life options, and LCA information (see Section 3 for details).

Based on the needs specified above, this article has four objectives:

1. to develop a sustainability-centered indicator for assessing product circularity that also considers the needs of component-based products explicitly
2. to address all sustainability pillars by the solution
3. to facilitate the representation of the results by one single figure
4. to provide a solution that addresses the needs of public procurement specifically.

This article is structured as follows: Section 2 describes the methodology; Section 3 presents the concept of the “Triple-C indicator” for the circular economy and its elements; Section 4 discusses Triple-C's strengths and weaknesses. Section 5 provides a conclusion.

2. Materials and Methods

This research is part of the German ConCirMy (Configurator for the Circular Economy) project (2019–2022), which aims at supporting the establishment of a circular economy. The main output of the project (planned for December 2022) is a sustainability recommendation software system that provides interested parties in supply chains, in particular fleet managers and public procurers, with sustainability information that can subsequently be used in business decisions and (purchasing) processes. ConCirMy's first use case refers to car tires.

The following three-step research method was applied to identify elements to be included in the concept of a comprehensive sustainability indicator to support public procurers in buying sustainable circular products (see Figure 2):

1. Identification of relevant information needs by desk research and surveys
2. Identification of building blocks for the indicator framework
3. Specification of a concept for a sustainability-oriented circularity indicator for products—the Triple-C.

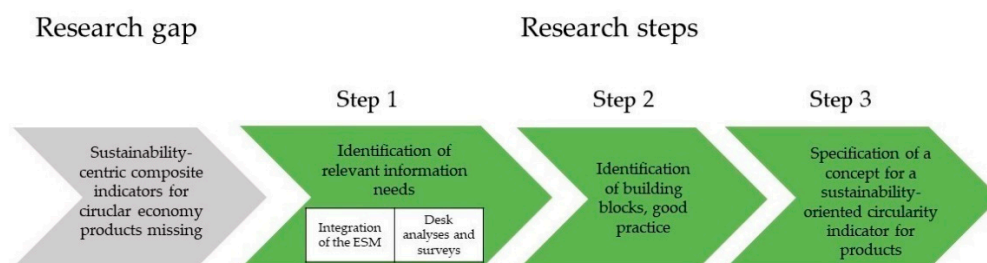


Figure 2. Steps to address the research gap. Source: own figure.

1. Step 1-Identification of relevant information needs by desk research and surveys:

Step 1 (July 2019–Mid-July 2022) aimed to analyze sustainability information needs that should be provided by sustainability information systems with a particular focus on public procurers' information requirements. The step resulted in identifying specific interests to be used for developing a concept for a sustainability-oriented composite indicator. Its key activities included analyses on the application of the ESM method by the ConCirMy project partner CAS and two-stage socioeconomic analyses of stakeholder needs: The first wave (July 2019–September 2021) had a narrow product scope on the first use case. The second one (September 2021–mid-July 2022) had a broader focus on needs for sustainability information and priority products.

Our research in both stages relied on surveys of various stakeholder groups. The first wave was dedicated to the first application of a sustainability information system, car tires, and the second one aimed to identify additional products apart from tires for which sustainability information is most needed.

An important element of this first wave was a two round survey among the members of the German Federal Association for Fleet Management.

The second wave included three different surveys to analyze the sustainability and circularity information needs of three specific categories of stakeholders: leasing companies, scientists, and procurement professionals. The procurement professionals were reached with the help of the German Competence Center for Sustainable Procurement. In total, 134 sustainability experts from 5 circular and bioeconomy networks, 49 public procurement professionals, and 15 leasing companies participated.

2. Step 2-Identification of building blocks for the indicator framework:

Work in step 2 (January–July 2022) was driven by stakeholders' interest in an overall indicator. A Web of Science analysis for the search terms circular economy + indicator + products led to 87 hits (data of an updating check of 4 August 2022). Relevant articles were presented in Section 1. Another key element included expert discussions in the working group on

assessment and indicator systems for the circular economy of the work on the Standardisation Roadmap Circular Economy organized by DIN, DKE, and VDI. In addition, a consultation was conducted with eight circularity indicator experts and high-level public professionals on 24 June 2022.

3. Step 3-Specification of a concept for a sustainability-oriented circularity indicator for products:

Based on the results of the previous steps, step 3 specified the kind of integration of the different building blocks in the concept of the indicator. To address the interests of procurement professionals, emphasis was put on purchasable products. Regarding the indicator structure, the indicator elements and the emphasis of selected elements, stakeholders' needs were considered specifically. For example, the indicator development considered the specific interest of public procurement professionals in LCC information. Particular work was dedicated to the analysis of the IAT. In detail, the development of the Triple-C concept relied on two versions. The first interim version used environmental indicators of the IAT that are also relevant beyond the bioeconomy, while the final version integrated the ESM. Three criteria guided the adoption of IAT protection areas and indicators for Triple-C's final version: (1). relevance beyond the bioeconomy, (2). compatibility with an ESM component, and (3). suitability for public procurement. The results are presented in the next section. Finally, Triple-C consists of an environmental composite indicator, an LCC indicator, and nine social and nine circular indicators.

3. Results

3.1. Basic Requirements

3.1.1. Identified Information Needs

This section describes the fundamental information requirements to be addressed by the sustainability-oriented indicator concept to assess product circularity. Figure 3 provides an overview of the relevant information needs resulting from step 1. This overview is generic and shall be used for all stakeholder groups, also including public procurers.

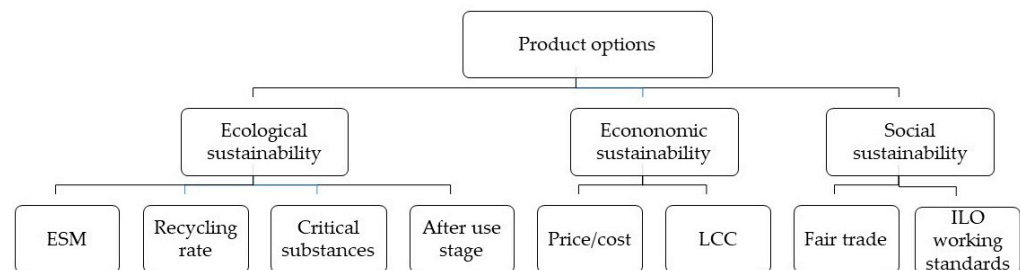


Figure 3. Consideration of sustainability aspects in the ConCirMy project. Source: own figure, inspired by a ConCirMy figure (in German).

The figure reflects the following aspects in particular:

- Relevant sustainability information according to state of the art in literature (see Section 1)
- The requirement for an overall assessment of the product's sustainability through production, use and disposal, taking into account ecological, social and economic aspects indicated by 57% of the professionals involved in the second round of the survey among fleet managers.
- The wish that "there must (. . .) be an index (that) evaluates certain aspects of sustainability. For example, recyclability (. . .)." in the survey among researchers.
- Fundamental information needs by public procurement professionals based on federal law and federal states regulation, e.g., regarding social sustainability.
- The stakeholder consultation on 24 June 2022 that stressed the importance of LCC information for procurement professionals.

- Additional survey results described in Figure 4 and at the end of this section.

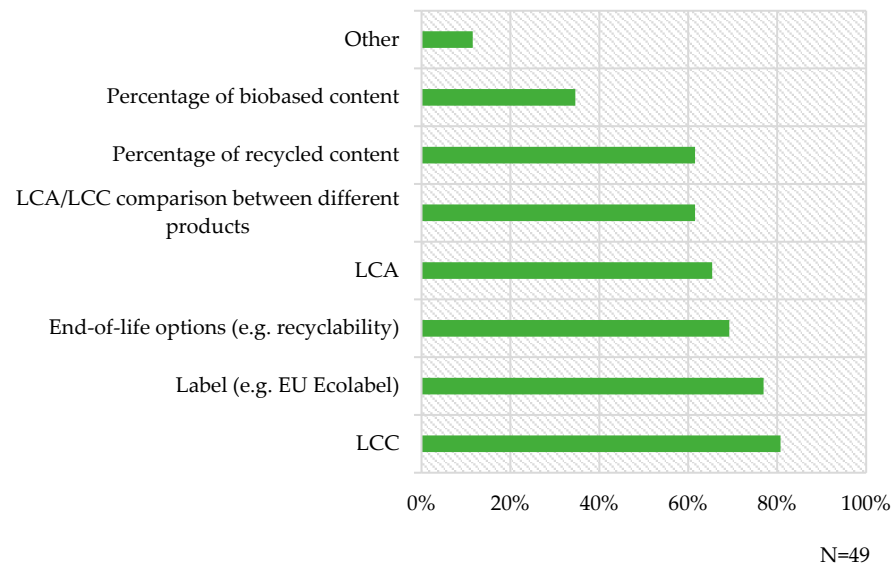


Figure 4. Required information by public procurement professionals. Source: own figure. Note: The need for social information is particularly specified by the different regulations of the federal states.

According to Figure 3, at least eight key information requirements were specified: ESM information, recycled content, critical substances, LCC and other financial information, fair trade on the side of the suppliers, compliance with ILO [63] working standards, and, if relevant/possible, information on the after-use stage.

Section 3.2.1 provides details on ESM and Section 3.2.2 on LCC. Regarding procurement professionals, Figure 4, as a result of our public procurement survey shows, e.g., their particular interest in Life Cycle Costing (LCC) information, labels, end-of-life options, and LCA information.

The relevance of recycled and recyclable content was not only stressed by the survey shown in Figure 4 but also by additional interviews and surveys, e.g., [13], Figure 3 and [23]. According to [27], integrating specific circular economy indicators, such as the share of recycled or recyclable content in the ESM is currently impossible.

Discussions in the national working group on circular economy indicators stressed the research gap regarding a sustainability-oriented indicator for assessing product circularity and its broader relevance.

3.2. Key Building Blocks Identified and Selected to Be Included in the Proposed Indicator Structure

Step 2 of the methodology led to the identification of three relevant building blocks to be included in the indicator concept. These are the ESM (Section 3.2.1), a detailed life-cycle costing analysis (Section 3.2.2), and parts of the IAT (Section 3.2.3).

3.2.1. The Ecological Scarcity Method

As described in Section 3.1, the ESM was chosen as an important element to be included in the concept of a comprehensive indicator structure. The reasons for choosing the ESM were sevenfold:

1. The method has a wide range of relevant environmental impacts that are included to give an overall picture close to the actual conditions.
2. As a one-dimensional method, it enables direct environmental comparison of companies, products, or services based on a single indicator. Despite this broad approach, a clear result is obtained when the method is applied.
3. ESM has a versatile application possibility, and thus the method is transferable in all conceivable and necessary industries.

4. ESM is comprehensive in terms of environmental impacts. It can be applied extensively and provides a single value for the total environmental impact.
5. The method is based on the policy objectives in a country or region. ESM, therefore, provides a transparent presentation for each country.
6. For laypersons, the result is easy to understand.
7. As an innovative solution, the ESM was not yet established as software in Germany. Therefore, ConCirMy aimed to offer a first attempt to make this method accessible as software for enterprises and usable for the public. The development of the software should be carried out based on life-cycle assessment data.

As described in Section 1, the product-specific ESM result is the individual ESM score. Triple-C considers ESM results by analyzing whether relevant maximum scores, set by regulation or individually by the users, are not exceeded.

3.2.2. Life-Cycle Costing

Life-cycle costing (LCC) is an essential public procurement aspect in the EU [67]. In principle, the 2014 EU procurement rules require that contracts rely on the most economically advantageous tender (see [67,68]). Sustainability aspects allow modifications (see [69]), but do not touch the importance of LCC information. In contrast to the price, LCC also considers the costs of resource use, maintenance, and disposal, which are not reflected in the purchase price [67]. Various approaches for LCC calculations exist. Table 2 provides an example with 10 elements of the LCC method developed in the German project “National implementation of the new EU procurement directives”.

Table 2. Key elements of life-cycle costing analyses. Source: based on the LCC tool of the Öko-Institut developed as part of the project “National implementation of the new EU procurement directives”.

No. of Cost Element	Cost Element	Cost Group
1	Purchase price	Acquisition costs
2	Installation costs	
3	If applicable, further acquisition costs	
4	Insurance	Follow-up costs
5	Maintenance (material costs, procured service), spare parts, if applicable, further follow-up costs	
6	Electricity	Operating supplies
7	Drinking water (supply, disposal), rainwater/service water	
8	Other operating supplies, if applicable	
9	Personnel (according to relevant pay groups)	Personnel
10	Disposal fees, other disposal costs, if applicable	Disposal

3.2.3. Building Blocks of the Integrated Assessment Tool for Bio-Based Products

Another building block analyzed and partially adopted for Triple-C is [62]’s IAT, described in Section 1.3.

From the 33 areas of protection proposed by the IAT (see Table 1 of [62]), we finally selected 16 for our composite indicator due to their relevance beyond the bioeconomy and their compatibility with ESM: 6 circular areas, 9 social areas, and the economic area life-cycle costs. Regarding the indicator structure, 9 circular and 9 social indicators relevant beyond the bioeconomy and a modified version of its LCC indicator were finally adopted for Triple-C. See the next sections for details. The scoring system was also kept for the selected social and circular indicators. The following sections provide details for this as well.

3.3. First Draft of the Triple-C Indicator Concept

This section presents the first draft of the concept of Triple-C composite indicator. “Triple” refers to its coverage of the three sustainability pillars, and “C” to circularity.

At the beginning, the relevant life-cycle stages of its scope were defined. They include (1) material production and manufacturing, (2) product manufacturing, (3) product use (different loops possible), and (4) end-of-life. For the first Triple-C draft, we adopted 21 overall protection topics proposed by the IAT. Twelve protection areas were excluded due to their varying importance beyond the bioeconomy: indirect land use change, terrestrial eutrophication; potentially affected biodiversity; acidification; soil erosion; freshwater eutrophication; land use soil quality, food security; land use rights; economic development; health and safety of local communities and local employment. (As we will show later, our final concept includes the ESM, which considers acidification differently according to Figure 1.)

The IAT criteria and indicators were analyzed in the next step. According to Table 3, we found 28 out of 48 indicators relevant for a broader product scope beyond the bioeconomy: 18 related to the environmental pillar, nine indicators to the social pillar, and one related to the economic pillar.

Table 3. Overview of indicators used for the interim Triple-C concept.

Pillar		No.	Basic IAT Indicator No.
Environ-mental	Life-cycle aspects	1–9	1–6, 12, 19, 20
	Circular aspects	10–18	22, 24–26, 28–32
Economic		19	33 (modified)
Social		20–28	35–42, 48
Total			

Source: Own table with elements of IAT [36,62] (particularly their Annex A).

On this basis, the environmental pillar is represented by 9 LCA and 9 circularity indicators. For the social pillar, Section 1 describes the importance of the ILO's international labor standards for public procurement professionals, which were considered specifically, and concerning the economic pillar, Section 3.2 and Table 2 provide details on LCC elements. As guidance for LCC calculations, several specifications exist in Germany already, particularly the specifications [70,71].

3.4. Development of the ESM-Based Triple-C Indicator Concept

The analysis in our research step 1 unveiled that various stakeholder groups are interested in ESM information, particularly regarding automotive solutions. Therefore, it represents a relevant building block. ESM's main protection areas are air, water, resources and waste influencing the greenhouse gas effect, ozone depletion, acidification and biodiversity. Besides protection areas on resource and waste management, the IAT's protection areas include water scarcity, particular matter, global warming potential, human toxicity and fossil resources depletion in this context. Triple-C adopts the ESM protection areas. As the IAT, it has additional protection areas on social and economic aspects and detailed circularity-related protection areas. Specifically, we adopted from the IAT six circular areas (waste management, process material circularity, product renewability, hazardous chemical use, resource efficiency, and energy efficiency), nine social areas (fair salary, fair competition, forced labor, feedback mechanisms, transparency, health and safety of workers, child labor, equal opportunities, health and safety of users) and the economic area life-cycle costs.

Regarding the presentation of environmental impacts, ESM works with environmental impact points for the following impact areas: emissions (particularly air and water emissions with various subtopics), resource consumption (including use of energy, land, primary mineral resources (minerals and metals), gravel mining, and freshwater consumption) and waste [27]. The number of ESM indicators varies between different versions (see [27], p. 48 for ESM indicators in Germany and Switzerland compared with comparable environmental impact assessment methods).

According to Table 4, the Triple-C concept refers to ten ESM elements. Depending on the regional variant, the ESM result may include other/additional elements.

Table 4. Overview of indicators used for Triple-C.





Pillar	No.	Basic IAT Indicator	Indicator On	Expected Performance	Threshold To Be Met	
Environmental	Life cycle	1 ¹	-	ESM with 10 elements (a) CO ₂ eq, (b) NMVOX, (c) Nox, (d) Nitrogen, (e) Phosphorus, (f) Nickel, (g) Freshwater, (h) primary energy, (i) non-hazardous waste, (j) additional aspects) Note: a–c = emissions to air, d–f = emission to water, g,h = consumption of resources	According to regulation or to be set by the user	Expected performance
	Circular aspects	2–10	22, 24–26, 28–32	(2). greener alternatives to the use of substances of very high concern, (3). % of biogenic carbon/total carbon (product) renewability, (4). use of recycled or renewable raw materials and the recyclability of the end product, (5). the product's MCI, (6). measures to manage and reduce waste, (7). guidance and clear instructions to consumers on how the product should be disposed after use, (8). energy efficiency, (9). measures taken to promote the use of renewable energy, (10). share of renewable energy compared to a relevant process	IAT [62] minimum requirements	Expected performance
	Economic	11	33	The analysis of the LCC elements * meets thresholds set by the user * (a) purchase price, (b) installation costs, (c) if applicable, further acquisition costs, (d) insurance, (e) maintenance (material costs, procured service), spare parts, if applicable, further follow-up costs, (f) electricity cost, (g) water cost, (h) other operating supplies if applicable, (i) personnel cost, (j) disposal fees, other disposal costs if applicable	To be set by the user	Expected performance
	Social	12–20	35–42, 48	(12). forced labor, (13). child labor, (14). salary of workers, (15). equal opportunities, (16). health and safety of workers, (17). health and safety of end users, (18). mechanisms for users to provide feedback, (19). measures taken to address transparency, (20). fair market competition	IAT [62] minimum requirements	Expected performance

¹ Excluding life-cycle costs, which are shown separately. Source: Own table with elements of IAT [36,62] (particularly their Annex A)

The LCC indicator consists of ten elements: (1) the purchase price, (2) installation costs, (3), if applicable, further acquisition costs, (4) insurance, (5) maintenance (material costs, procured service), spare parts, if applicable, further follow-up costs, (6) electricity, (7) drinking water (supply and disposal), rainwater/service water, (8) other operating supplies if applicable, (9) personnel cost, and (10) disposal fees and other disposal costs, if applicable) according to Table 2 in Section 3.2.2.

Table 5 summarizes Triple-C elements.

Table 5. Triple-C elements.

Environmental Dimension ESM Indicator with 10 Elements	Circular Dimension 9 IAT Indicators	Social Dimension 9 IAT Indicators	Economic Dimension LCC Indicator with 10 Elements
			

Icons: Ecalyp, Freepik, Teamwork, and Kiranshastry from www.flaticon.com (accessed on 5 August 2022). Source: own table.

Based on the results, the minimum requirements according to Figure 3 are considered by our approach as follows:

- ESM: indicator 1
- Recycled content: indicators 4 and 5
- Critical substances: indicators 1 and 2
- After-use: indicator 7 (see also comment below)
- Price: considered as part of the ConCirMy approach, see Section 3.7
- LCC: indicator 4
- Fair trade: indicator 20
- ILO core working standards: indicators 12-16

Social sustainability in the after-use stage will be discussed in Section 4.2.

3.5. Triple-C Score and Presentation

The representation of the Triple-C results follows the guidance of [72], initially referring to environmental impacts only: The “impacts shall be communicated with the absolute value to ensure transparency and consumer education [while] a synthesis of the criteria can be proposed by means of a unique mark, color, or logo” [72].

The Triple-C score consists of the single scores of its four (life cycle [ESM], circular, economic [LCC], and social) dimensions with a maximum score of 2, respectively. The maximum total score is 8. If the threshold of a dimension is met, the individual score is 1. If not, that score is 0. If a result is significantly better than the threshold, the score is 2.

According to Table 4, the four dimensions have individual thresholds. Regarding the ESM and LCC dimensions, they are set individually. Concerning the circular and the social dimensions, receiving a dimension score of 1 requires fulfilling all mandatory IAT requirements of the relevant dimension and $\geq 50\%$ of the dimension’s maximum sum of single scores. Likewise, $\geq 75\%$ of the dimension’s maximum sum of single scores is required to get a dimension score of 2 (Figures 5–7). Details on each of the circular dimension’s 9 IAT-based indicators and the 9 IAT-based indicators of the social dimension can be found in [62]). Information on the different maximum scores of these single qualitative and quantitative indicators was also given in Table 1.

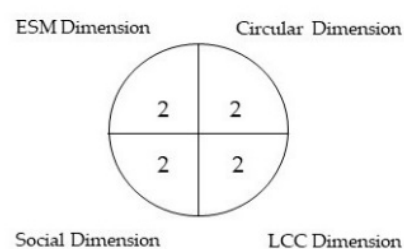


Figure 5. Representation of Triple-C dimension’s results in the total score based on the example of a maximum score of 2 per dimension.

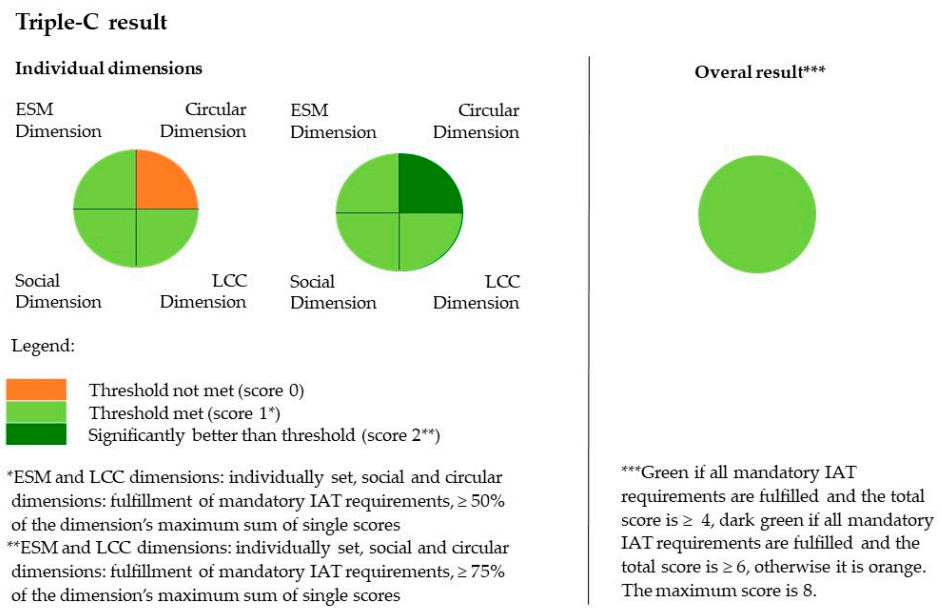


Figure 6. Representation of Triple-C results. Source: own figure.

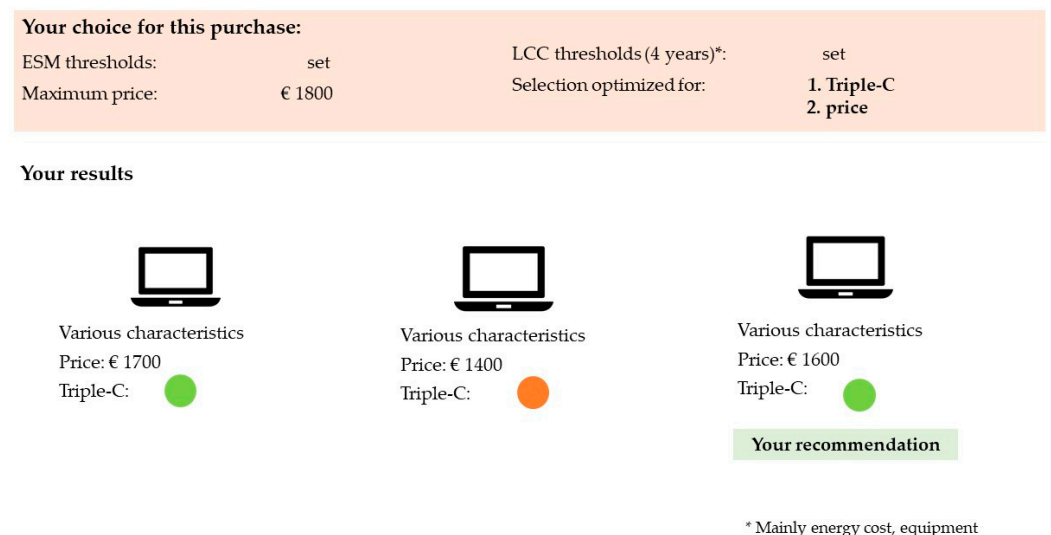


Figure 7. Example integration of Triple-C in sustainability recommendation software. Source: own figure.

Consequently, the threshold for a positive Triple-C result is met, if all IAT requirements are fulfilled and the total score is ≥ 4 . Likewise, a product performs significantly *better* than the total threshold if all mandatory IAT requirements are fulfilled and the total score is ≥ 6 . Otherwise, the score is shown in orange. As mentioned above, Triple-C's maximum score is 8. In addition, Triple-C provides colored information for all sustainability pillars and shows the indicator result in green if a threshold is met, in orange if it is not met, and in dark green if the result is significantly better than the threshold (Figure 6).

We expect that the Triple-C score will be most important for sustainability recommendation systems that compare and propose products.

Figure 7 shows a potential application of Triple-C by sustainability recommendation software based on a fictive product example. Its use requires two types of information:

- producer's data regarding all Triple-C indicators, including ESM and LCC results, and
- users' specification of ESM and LCC thresholds.

Additional thresholds are already defined by the IAT [62].

The development of a standardized format to provide the relevant data is recommended. For example, it shall ensure that “no child labor” can be ticked and that the relevant information is converted in Triple-C scores according to IAT principles.

As described by [67], requiring LCC information is common practice in public procurement. On this basis, the indicator considers the interest of public procurers and other buyers with specific cost-related requirements. An example of its direct consideration is provided by Figure 7.

Figure 7 also shows hits for a device based on the user’s search for suitable products. The user can select based on the best Triple-C score, the price, or additional product characteristics, which are not shown in the figure for simplicity. Two of the three products meet all Triple-C requirements by the user. This person is very price-oriented. Therefore, the system recommends the cheapest of the two remaining options to this user (highlighted in green in the figure).

3.6. Product-Specific Applications of the Triple-C

In addition to the input by procurement professionals in Section 3.1, we asked the 49 procurement professionals for which specific products they considered software with sustainability-oriented purchase recommendations to be interesting. They could list up to three products. According to Figure 8, the three product groups most frequently named in the first partial response include IT (hardware and software) and, with equal ranking, “vehicles, parts and accessories”, “construction products”, and other products (e.g., tools), followed by office supplies.

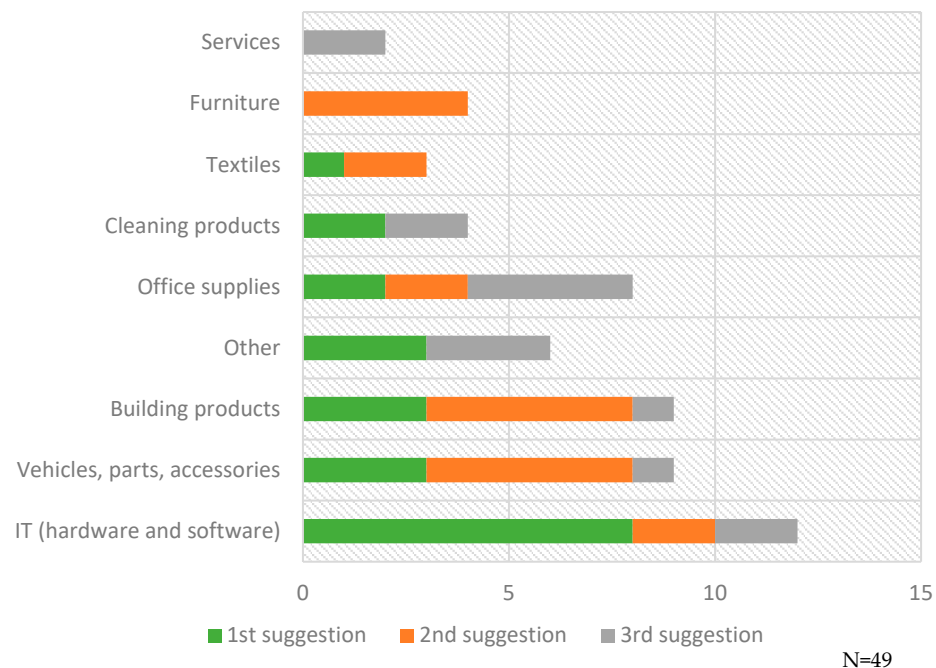


Figure 8. Products relevant to sustainability recommendation software from public procurement professionals’ point of view. Source: own figure.

Looking at the bars for each of these three categories as a whole, IT was again named by far the most frequently, followed equally by “vehicles, parts and accessories” and construction products. A brief description was then requested as to why sustainability-oriented purchasing recommendations are particularly relevant for these products. Overarching and product-specific reasons were identified. The overarching reasons included required legal compliance, high environmental contributions, a complex offering, high procurement volumes, and a need for specific sustainability information, such as life-cycle costs and social sustainability information.

3.7. Consideration of Other Life-Cycle Assessment Methods by Triple-C

A remaining aspect is the consideration of life-cycle assessment results and the selection of ESM from various assessment options. BAFU [27] provides an overview on eight life-cycle assessment methods and their elements on p. 48, showing that ESM's Swiss version is the most detailed. Nevertheless, a question remains on how other methods could be considered in Triple-C. Developing specified Triple-C-versions, such as Triple-C-ESM_{CH}, Triple C-ESM_{DE}, and Triple-C_{Environmental Footprint v. 3.0}, might be possible.

4. Discussion

4.1. Contributions of This Research

The starting point of our research was the research gap of CE-related sustainability indicators specifically tailored to simultaneously assess economic, environmental, and social performance. Consequently, this paper presented our contribution to overcoming these gaps by identifying potential solutions and developing the Triple-C indicator concept that relies on existing building blocks from various domains as central elements. In particular, this article provides:

1. A structure for an ideal easy-to-use multidimensional circular economy indicator, covering all three sustainability pillars. Specifically, it provides a composite indicator with 20 indicators, including the two combined ESM and LCC elements and 18 single indicators (see Table 4).
2. An indicator structure that relies on existing formal international and European standards, ESM, the MCI, and the IAT. On this basis, we also provide the first ESM-based integrated sustainability indicator for the circular economy.
3. A practice-oriented indicator structure that considers the needs of public procurement explicitly. Specifically, it shall help buyers to conduct sustainable purchasing decisions and therefore promote sustainable products, their future creation, and, finally, sustainable development.
4. An example of sustainability recommendation software that uses a multidimensional circular economy indicator. It is the first of its kind that works with ESM values.
5. Suggestions for specific product applications for the indicator's application in public procurement, particularly regarding information technology, mobility, and building products.

The Triple-C contributes to the sustainability and CE literature on indicators by trying to apply the work of [62] to new contexts beyond the bioeconomy and the application of various circular economy indicators such as the MCI. Likewise, it extends the work of [27] and tries to overcome the problems of integrating circular economy aspects in ESM by presenting both elements separately in a new indicator structure.

This article also supplements various other contributions on circular economy indicators (e.g., [50–58]) and provides some findings to be used to close the gap of sustainability indicators for circular products in public procurement. As a contribution to practice, the concept of such a Triple-C indicator shall be integrated into sustainability recommendation software and a German working group on circular economy indicators, stimulating further work in this context.

4.2. Limitations

We identified two limitations of Triple-C in particular.

1. One limitation is its geographic scope. Specifically, Section 1 described the role of sustainable and circular products for Germany's public procurement, relevant German and European regulation, and resulting needs for sustainability indicators. However, even in Germany, sustainability-related public procurement requirements vary, for example, regarding social sustainability, particularly ILO working standards. Triple-C considers the three sustainability dimensions profoundly. In addition, variants referring to individual federal states' specific public procurement needs with fewer

indicators might be interesting. Regarding the circular economy indicators, regional versions with fewer indicators might also be considered.

2. As in the IAT, several parts only cover the life cycle until the end of the production phase. The current concept addresses new products with circular content, but without giving specific information on use stages with different loops. Such information can be relevant for sustainability-conscious buyers and secondhand markets. Additional indicators considering the other “R” elements, such as “reuse”, “repair”, and “refurbish” would be useful if applicable.

Internationally, the regulatory framework conditions are diverse. Although we are not aware of a detailed international study in this context, Ref. [38] shows that the diffusion of circular practices varies globally, based on data from 20 of the more than 190 countries, but also with this narrowed scope with varying results. Therefore, our demonstration of circular economy practices shall also encourage the establishment of circular economy-related policy frameworks in additional countries. Section 5 discusses the implications for further research in more detail.

5. Conclusions

This article was motivated by the gap in sustainability-oriented composite indicators for circular products in research and practice. While authors such as [19,20,59] started by combining circularity indicators with other sustainability information, we present the first integrated approach in this context. Specifically, we introduced a concept for Triple-C composite indicator as one of the first multidimensional sustainability indicators for circular products. The Triple-C relies on four elements: ESM or LCA data, circularity indicators, LCC, and social sustainability elements.

Confronted with a research gap regarding sustainability indicators providing circularity information, IAT’s composite indicator was a beneficial discovery and became a fundamental building block for Triple-C’s creation.

The final goal of our work is to facilitate comparisons between products by software tools such as the future variants of the ConCirMy software. A critical success factor for providing Triple-C results is data availability in this context. This requires the motivation of the product companies but also appropriate technical infrastructures. In addition, we suggested the creation of a standardized data-exchange format for the relevant Triple-C information in Section 3. An advantage is that Triple-C uses already available data wherever possible. An example is MCI index data provided by the sustainability database Sphera (see [47]).

Besides our findings, our work also led to four implications for further research.

1. As mentioned at the beginning, our Triple-C element ESM is closely related to public policies, and its eco-points represent the ratio of desired policy targets to the current environmental situation. Regarding sustainable development, various policies referring to minimum quotas for certain sustainability characteristics also exist or are discussed, e.g., regarding recycled content. Likewise, an analysis seems helpful for which products minimum Triple-C requirements should be defined, e.g., regarding public procurement.
2. In addition to the survey results presented in Section 3, public procurement professionals expressed the specific need for product labels to support their procurement decisions. This will be an appropriate next step, for which Triple-C provides building blocks already. In Europe’s quality infrastructure, various sustainability issues are considered by the EU Ecolabel. Therefore, further work is encouraged to analyze Triple-C’s potential contribution in this context.
3. Triple-C was developed as a generic, product-independent composite indicator. Beyond this application, experts involved in our studies also highlighted the importance of considering product group-specific aspects in sustainability assessment. Likewise, Ref. [62] have shown by the example of bio-based products that individual product groups may require additional indicators. This will be subject to further work. Indeed,

more research is needed to adjust Triple-C in this context. As this paper primarily addresses the needs of German stakeholders, further research will also allow the integration of additional international perspectives.

4. Sections 1 and 3.1.1 described the research gap and options to address it. Our approach relies on good practice in other research areas specifically. Depending on the research focus, additional research options can serve further interests of research and practice. Such research should rely on four steps: (1) the identification of environmental, social and economic impact assessment methods, (2) the analysis and specification of options to integrate circular economy aspects, (3) the specification of indicator elements, and (4) the specification of the indicator, its structure and the weights of the different elements.

Authors of sustainability indicators and related instruments (e.g., LCA, Six Sigma, etc.) are encouraged to deepen this research stream by additional work that considers the topic from different angles.

Author Contributions: Conceptualization: S.W., investigation: S.W., methodology: S.W., writing—original draft: S.W., writing—review and editing: S.W. and L.L. All authors have read and agreed to the published version of the manuscript.

Funding: We acknowledge the support from the German Federal Ministry of Education and Research (BMBF) (ConCirMy project, measure ReziProK, funding 033R236E).

Institutional Review Board Statement: This study relied on proven data management techniques at Technische Universität Berlin. A cross-check by the team confirmed that the article does not contain information which would make the participants identifiable. Ethical review and approval were waived.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Raw data is stored at TU Berlin according to our privacy declaration describing that aggregated survey results are used for scientific research and lectures.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A New Circular Economy Action Plan: For a Cleaner and More Competitive Europe. COM (2020) 98 Final. 2020. Available online: <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020DC0098&from=EN> (accessed on 27 September 2021).
2. Circle Economy. Circularity Gap Report 2021. 2021. Available online: <https://www.circularity-gap.world/2021#downloads> (accessed on 24 September 2022).
3. European Commission. Circular Economy Action Plan. For a Cleaner and More Competitive Europe. 2020. Available online: https://ec.europa.eu/environment/pdf/circular-economy/new_circular_economy_action_plan.pdf (accessed on 27 June 2022).
4. European Parliament. Circular Economy: Definition, Importance and Benefits. 2015. Available online: <https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits> (accessed on 28 February 2022).
5. Potting, J.; Hekkert, M.; Worrell, E.; Hanemaaijer, A. Circular Economy: Measuring Innovation in the Product Chain. 2017. Available online: <https://www.pbl.nl/sites/default/files/downloads/pbl-2016-circular-economy-measuring-innovation-in-product-chains-2544.pdf> (accessed on 10 March 2022).
6. Kirchherr, J.; Reike, D.; Hekkert, M. Conceptualizing the circular economy: An analysis of 114 definitions. *Resour. Conserv. Recycl.* **2017**, *127*, 221–232. [CrossRef]
7. Wurster, S. Stichwort Circular Economy: Normen, Standards und Potential für Neuartige Taxonomische Positionierung. 2022. Available online: <https://din.one/pages/viewpage.action?pageId=98369740&preview=%2F98369740%2F98369744%2FDIN+Mitteilungen+2022-05+-+Circular+Economy+-+Stand+der+Normung%2C+Standardisierung+und+Potential+f%C3%BCr+neuartige+Klassifizierung+%28von+Dr.+Simone+Wurster%2C+TU+Berlin%29.pdf> (accessed on 30 July 2022).
8. Valverde, J.-M.; Avilés-Palacios, C. Circular Economy as a Catalyst for Progress towards the Sustainable Development Goals: A Positive Relationship between Two Self-Sufficient Variables. *Sustainability* **2021**, *13*, 12652. [CrossRef]

9. European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Closing the Loop—An EU Action Plan for the Circular Economy: COM/2015/0614 Final. 2015. Available online: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015DC0614> (accessed on 26 September 2022).
10. SPD, Bündnis 90/Die Grünen, FDP. Koalitionsvertrag 2021–2025 Zwischen SPD, Bündnis 90/Die Grünen und FDP: Mehr Fortschritt Wagen. Bündnis für Freiheit, Gerechtigkeit und Nachhaltigkeit. 2021. Available online: https://www.spd.de/fileadmin/Dokumente/Koalitionsvertrag/Koalitionsvertrag_2021-2025.pdf (accessed on 20 April 2022).
11. Acatech, Circular Economy Initiative Deutschland, SYSTEMIQ. Circular Economy Roadmap für Deutschland. 2021. Available online: <https://www.acatech.de/publikation/circular-economy-roadmap-fuer-deutschland/> (accessed on 25 May 2022).
12. DIN. Standardization Roadmap Circular Economy. 2022. Available online: <https://www.din.de/en/innovation-and-research/circular-economy/standardization-roadmap-circular-economy> (accessed on 15 July 2022).
13. Wurster, S.; Schulze, R.; Simon, R.G.; Hoyer, S. A Grounded Theory on Sustainable Circular Public Procurement in Germany: Specific Product Case and Strategies. *Sustainability* **2021**, *13*, 13525. [\[CrossRef\]](#)
14. Wurster, S.; Schulze, R.; Simon, R.G. On the Road to Circular Public Procurement: Case, Variations, and Potential Actions in Germany. *Sustainability* **2021**, *13*, 13784. [\[CrossRef\]](#)
15. Bosio, E.; Djankov, S.; Glaeser, E.; Shleifer, A. Public Procurement in Law and Practice. 2020. Available online: https://scholar.harvard.edu/files/shleifer/files/public_procurement_law_practice_11_may_2020.pdf (accessed on 30 September 2021).
16. Edler, J.; Georghiou, L. Public procurement and innovation—Resurrecting the demand side. *Res. Policy* **2007**, *36*, 949–963. [\[CrossRef\]](#)
17. European Commission. Green Public Procurement. 2020. Available online: https://ec.europa.eu/environment/gpp/index_en.htm (accessed on 30 July 2022).
18. Saidani, M.; Yannou, B.; Leroy, Y.; Cluzel, F.; Kendall, A. A taxonomy of circular economy indicators. *J. Clean. Prod.* **2019**, *207*, 542–559. [\[CrossRef\]](#)
19. Maceno, M.M.C.; Pilz, T.L.; Oliveira, D.R. Life Cycle Assessment and Circular Economy: A Case Study of a Photovoltaic Solar Panel in Brazil. *JEAM* **2020**, *10*, 99–111. [\[CrossRef\]](#)
20. Senán-Salinas, J.; Blanco, A.; García-Pacheco, R.; Landaburu-Aguirre, J.; García-Calvo, E. Prospective Life Cycle Assessment and economic analysis of direct recycling of end-of-life reverse osmosis membranes based on Geographic Information Systems. *J. Clean. Prod.* **2021**, *282*, 124400. [\[CrossRef\]](#)
21. D’Adamo, I.; Falcone, P.M.; Imbert, E.; Morone, P. A Socio-economic Indicator for EoL Strategies for Bio-based Products. *Ecol. Econ.* **2020**, *178*, 106794. [\[CrossRef\]](#)
22. Kristensen, H.S.; Mosgaard, M.A. A review of micro level indicators for a circular economy—moving away from the three dimensions of sustainability? *J. Clean. Prod.* **2020**, *243*, 118531. [\[CrossRef\]](#)
23. Wurster, S.; Reis, C.F.D.B. Priority Products for Sustainability Information and Recommendation Software: Insights in the Context of the EU’s Action Plan Circular Economy. *Sustainability* **2022**, *14*, 11951. [\[CrossRef\]](#)
24. Finkbeiner, M.; Inaba, A.; Tan, R.; Christiansen, K.; Klüppel, H.J. The New International Standards for Life Cycle Assessment: ISO 14040 and ISO 14044. *Int. J. Life Cycle Assess* **2006**, *11*, 80–85. [\[CrossRef\]](#)
25. Tarne, P.; Traverso, M.; Finkbeiner, M. Review of Life Cycle Sustainability Assessment and Potential for Its Adoption at an Automotive Company. *Sustainability* **2017**, *9*, 670. [\[CrossRef\]](#)
26. Ahbe, S. *Methode der ökologischen Knappheit für Deutschland: Umweltbewertungen in Unternehmen; eine Initiative der Volkswagen AG, 2., überarbeitete Auflage*. AutoUni-Schriftenreihe; Logos-Verlag: Berlin, Germany, 2014; Volume 68.
27. Bundesamt für Umwelt BAFU. Ökofaktoren Schweiz 2021 Gemäss der Methode der Ökologischen Knappheit: Methodische Grundlagen und Anwendung auf die Schweiz. 2021. Available online: <https://www.bafu.admin.ch/bafu/de/home/themen/wirtschaft-konsum/publikationen-studien/publikationen/oekofaktoren-schweiz.html> (accessed on 1 August 2022).
28. Ahbe, S.; Weihofen, S.; Wellge, S. *The Ecological Scarcity Method for the European Union: A Volkswagen Research Initiative: Environmental Assessments*; SpringerLink Bücher vol 105; Springer: Wiesbaden, Germany, 2018.
29. Muhl, M.; Berger, M.; Finkbeiner, M. Development of Eco-factors for the European Union based on the Ecological Scarcity Method. *Int. J. Life Cycle Assess* **2019**, *24*, 1701–1714. [\[CrossRef\]](#)
30. Scharlemann, J.P.W.; Laurance, W.F. Environmental science. How green are biofuels? *Science* **2008**, *319*, 43–44. [\[CrossRef\]](#)
31. Ahbe, S.; Braunschweig, A.; Müller-Wenk, R. *Methodik für Ökobilanzen auf der Basis ökologischer Optimierung: 133*; Bundesamt für Umwelt, Wald und Landschaft (BUWAL): Bern, Germany, 1990.
32. BAFU. Umweltbelastungspunkte für Personenwagen. Zusammensetzung und Rechenbeispiele. 2009. Available online: <https://www.news.admin.ch/news/message/attachments/16214.pdf> (accessed on 29 September 2022).
33. Rathi, R.; Kaswan, M.S. An inclusive review of Green Lean Six Sigma for sustainable development: Readiness measures and challenges. *IJAOM* **2021**, *13*, 129. [\[CrossRef\]](#)
34. Kaswan, M.S.; Rathi, R.; Garza-Reyes, J.A.; Antony, J. Green lean six sigma sustainability-oriented project selection and implementation framework for manufacturing industry. *IJLSS* **2022**, 2040–4166. [\[CrossRef\]](#)
35. Rathi, R.; Kaswan, M.S.; Garza-Reyes, J.A.; Antony, J.; Cross, J. Green Lean Six Sigma for improving manufacturing sustainability: Framework development and validation. *J. Clean. Prod.* **2022**, *345*, 131130. [\[CrossRef\]](#)

36. CEN. EN 16751, 2016 Bio-Based Products—Sustainability Criteria (BSI Version). 2016. Available online: <https://www.en-standard.eu/bs-en-16751-2016-bio-based-products-sustainability-criteria/> (accessed on 29 July 2022).
37. JRC. Composite Indicators—A Review: Second Workshop on Composite Indicators of Country Performance, Feb. 26–27th 2004. OECD, Paris. 2006. Available online: <https://www.oecd.org/sti/ind/29398640.pdf> (accessed on 29 July 2022).
38. PACE Circular Indicators For Governments: 2021. Available online: https://pacecircular.org/sites/default/files/2021-04/CircularIndicatorsForGovernments_FINAL.pdf (accessed on 29 July 2022).
39. Circle Economy & PACE. Circular Metrics for Businesses: Finding Opportunities in the Circular Economy. 2020. Available online: <https://www.circle-economy.com/resources/metrics> (accessed on 29 July 2022).
40. Gonçalves, M.; Freire, F.; Garcia, R. Material flow analysis of forest biomass in Portugal to support a circular bioeconomy. *Resour. Conserv. Recycl.* **2021**, *169*, 105507. [CrossRef]
41. Haupt, M.; Hellweg, S. Measuring the environmental sustainability of a circular economy. *Environ. Sustain. Indic.* **2019**, *1–2*, 100005. [CrossRef]
42. Medeiros, D.L.; Braghirolli, F.L.; Ramlow, H.; Ferri, G.N.; Kiperstok, A. Environmental improvement in the printing industry: The case study of self-adhesive labels. *Environ. Sci. Pollut. Res. Int.* **2019**, *26*, 13195–13209. [CrossRef]
43. Ecolabel Index. Ecolabel Index. 2022. Available online: <https://www.ecolabelindex.com/> (accessed on 30 July 2022).
44. C2C. Get Cradle to Cradle Certified™. 2022. Available online: <https://www.c2ccertified.org/get-certified/levels/> (accessed on 22 September 2022).
45. Kompass Nachhaltigkeit. T-Shirts: 23 Labels. 2022. Available online: <https://www.kompass-nachhaltigkeit.de/en/product-search/apparel-textiles/t-shirts#/filters/query> (accessed on 22 September 2022).
46. Ellen MacArthur Foundation. Material Circularity Indicator (MCI). 2022. Available online: <https://ellenmacarthurfoundation.org/material-circularity-indicator> (accessed on 30 July 2022).
47. Sphera. Circular Economy. Material Circularity Indicator (MCI). 2022. Available online: <https://gabi.sphera.com/solutions/circular-economy/> (accessed on 21 July 2022).
48. Gil Muñoz, V.; Muneta, L.M.; Carrasco-Gallego, R.; de Juanes Marquez, J.; Hidalgo-Carvajal, D. Evaluation of the Circularity of Recycled PLA Filaments for 3D Printers. *Appl. Sci.* **2020**, *10*, 8967. [CrossRef]
49. Rukundo, R.; Bergeron, S.; Bocoum, I.; Pelletier, N.; Doyon, M. A Methodological Approach to Designing Circular Economy Indicators for Agriculture: An Application to the Egg Sector. *Sustainability* **2021**, *13*, 8656. [CrossRef]
50. Urban Mining Index. The Urban Mining Index Pursues the Aim of Keeping Building Materials in as Closed Cycles as Possible. 2022. Available online: <https://urban-mining-index.de/> (accessed on 28 July 2022).
51. Rosen, A. Urban Mining Index: Entwicklung Einer Systematik zur quantitativen Bewertung der Kreislaufkonsistenz von Baukonstruktionen in der Neubauplanung. Dissertation. 2020. Available online: <https://www.irbnet.de/daten/rswb/21049001601.pdf> (accessed on 30 July 2022).
52. Heisel, F.; Rau-Oberhuber, S. Calculation and evaluation of circularity indicators for the built environment using the case studies of UMAR and Madaster. *J. Clean. Prod.* **2020**, *243*, 118482. [CrossRef]
53. Madaster. Madaster-Das Kataster für Materialien. 2022. Available online: <http://madaster.de> (accessed on 9 July 2022).
54. HOP. The French Repairability Index. A First Assessment—One Year after Its Implementation. 2022. Available online: <https://www.halteobsolescence.org/wp-content/uploads/2022/02/Rapport-indice-de-reparabilite.pdf> (accessed on 28 July 2022).
55. Ellen MacArthur Foundation. Method Introduction. 2021. Available online: <https://emf.thirdlight.com/link/hpqc2c2qdako-v1xw8g/@/#id=0> (accessed on 30 July 2022).
56. Ellen MacArthur Foundation. Circulytics: Resources. 2022. Available online: <https://ellenmacarthurfoundation.org/resources/circulytics/resources> (accessed on 29 July 2022).
57. UNEP. The New Plastics Economy Global Commitment. Available online: <https://www.unep.org/new-plastics-economy-global-commitment> (accessed on 9 July 2022).
58. Ecovadis. Materials. 2022. Available online: <https://resources.ecovadis.com/ecovadis-solution-materials> (accessed on 28 July 2022).
59. Tashkeel, R.; Rajarathnam, G.P.; Wan, W.; Soltani, B.; Abbas, A. Cost-Normalized Circular Economy Indicator and Its Application to Post-Consumer Plastic Packaging Waste. *Polymers* **2021**, *13*, 3456. [CrossRef]
60. Harris, S.; Martin, M.; Diener, D. Circularity for circularity’s sake? Scoping review of assessment methods for environmental performance in the circular economy. *Sustain. Prod. Consum.* **2021**, *26*, 172–186. [CrossRef]
61. STAR-ProBio. Sustainability Transition Assessment and Research of Bio-Based Products. 2020. Available online: <http://www.star-probio.eu/> (accessed on 30 July 2022).
62. Ladu, L.; Morone, P. Holistic approach in the evaluation of the sustainability of bio-based products: An Integrated Assessment Tool. *Sustain. Prod. Consum.* **2021**, *28*, 911–924e6. [CrossRef]
63. ADB/ILO. Core Labour Standards Handbook. 2006. Available online: https://www.ilo.org/wcmsp5/groups/public/---asia/--ro-bangkok/---ilo-manila/documents/publication/wcms_126253.pdf (accessed on 30 September 2021).
64. BMJV und Bfj. Gesetz zur Förderung der Kreislaufwirtschaft und Sicherung der Umweltverträglichen Bewirtschaftung von Abfällen (Kreislaufwirtschaftsgesetz-KrWG). 2021. Available online: <https://www.gesetze-im-internet.de/krwg/BjNR021210012.html> (accessed on 26 July 2022).

65. BMJV/BfJ. Bundeshaushaltsordnung (BHO): Bundeshaushaltsordnung vom 19. August 1969 (BGBl. I S. 1284), Die Zuletzt Durch Artikel 2 Des Gesetzes Vom 1. Juli 2022 (BGBl. I S. 1030) Geändert Worden Ist. 2022. Available online: https://www.gesetze-im-internet.de/bho/_7.html (accessed on 26 July 2022).
66. BMU. Umweltfreundliche Beschaffung. 2020. Available online: <https://www.bmu.de/themen/nachhaltigkeit-digitalisierung/konsum-und-produkte/umweltfreundliche-beschaffung> (accessed on 1 November 2021).
67. European Commission. Life Cycle Costing. 2022. Available online: <https://ec.europa.eu/environment/gpp/lcc.htm> (accessed on 22 September 2022).
68. Axsen, J.; TyreeHageman, J.; Lentz, A. Lifestyle practices and pro-environmental technology. *Ecol. Econ.* **2021**, *82*, 64–74. [[CrossRef](#)]
69. FEMNET. Möglichkeiten Einer Ökologisch Und Sozial Nachhaltigen Öffentlichen Beschaffung. Leitfaden Erstellt im Auftrag von FEMNET e.V. 2019. Available online: <https://femnet.de/download/send/22-beschaffung/98-moeglichkeiten-einer-oekologischen-sozial-nachhaltigen-beschaffung-femnet-leitfaden.html> (accessed on 27 September 2021).
70. DIN. DIN SPEC 77234:2013-09 Leitlinien für die Bewertung von Lebenszykluskosten in Produkt-Dienstleistungssystemen. 2013. Available online: <https://www.beuth.de/de/technische-regel/din-spec-77234/189457814> (accessed on 1 August 2022).
71. VDI. VDI-Richtlinie VDI 2884, Beschaffung, Betrieb und Instandhaltung von Produktionsmitteln unter Anwendung von Life Cycle Costing (LCC). 2005. Available online: <https://www.vdi.de/richtlinien/details/vdi-2884-beschaffung-betrieb-und-instandhaltung-von-produktionsmitteln-unter-anwendung-von-life-cycle-costing-lcc> (accessed on 1 August 2022).
72. Sonigo, P.; Bain, J.; Kong, M.A. *Policies to Encourage Sustainable Consumption: Full Report*; European Communities: Luxembourg, 2012.