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Published in:
Sustainability

Link to article, DOI:
10.3390/su12030951

Publication date:
2020

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):

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A Procedure to Support Systematic Selection of Leading Indicators for Sustainability Performance Measurement of Circular Economy Initiatives

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Received: 8 January 2020; Accepted: 22 January 2020; Published: 28 January 2020

Abstract: Circular economy (CE) is considered a vital model to tackle resource scarcity and reduce waste by promoting strategies that redefine production and consumption systems. Industrial actors integrate CE principles in their strategic and operational practices to overcome these challenges, simultaneously aiming at enhancing their sustainability performance. Despite numerous frameworks to guide organizations in innovating towards CE, very few have embedded explicit sustainability considerations to assist practitioners in understanding the potential sustainability performance of the CE initiatives early in the development process. To assist a structured process of measuring sustainability performance, the main goal of this paper is to propose a procedure for a systematic selection of suitable leading performance indicators to support an informed sustainability-oriented decision-making process. To fulfill this aim, a hypothetical-deductive approach has been followed to, firstly, develop the selection procedure, and secondly, evaluate and improve it using a case study approach. The findings reveal that the procedure enables a systematic selection of relevant indicators by taking into account the manifold combinations of CE strategies and business processes, characteristics of the company and its sustainability objective. Different from many other approaches, the novelty lies in relying on a dynamic, as opposed to 'prescriptive', indicator selection process to induce learning about sustainability considerations significant for a particular CE initiative and corporate context.

Keywords: sustainability performance; leading indicators; selection procedure; circular economy; decision-making support

1. Introduction

A challenging and fast-changing global market pushes companies to become proactive by exploring and exploiting new mechanisms to enhance their competitive advantage. Competitive advantage is rooted in a company’s capability to manage tangible and intangible resources [1], constantly responding to global demands and issues, including natural resource constraints, pollution and fair wealth distribution. It is no longer a question of whether the pursuit of an economic activity ought to be done sustainably, rather it is a process of exploring (what), planning (where) and implementing (how) various sustainability strategies. Along the process, manufacturing companies in Europe have shown a significant improvement in reducing their environmental impact per economic output generated [2], however, the challenge is still great, with respect to minimizing the impact, when taking into account upstream (e.g., supply of resources) and downstream activities (e.g., end of life processes). One promising approach to overcome these challenges is seen in a new economic model, circular economy (CE), which implies a radical innovation of production and
consumption systems with the goal of decoupling resource consumption from value creation [3]. For the European manufacturing industry, which spends an average of 40% of its costs on raw materials and about 15% on energy and water [4], adopting CE practices focused on resource productivity can positively impact economic and environmental performance. Furthermore, CE entails strategic transformation, by means of which the industries will be able to create new revenue streams and retain the value embedded in their products and assets for longer [5].

Different conceptual and practical frameworks have been proposed to guide companies on how to embed CE principles, often called CE strategies, into their business context [6], with the emphasis on the simultaneous transformation of strategic and operational practices. Acknowledging the complexity of such transformation, numerous studies have developed tools to support business model innovation for CE [7,8], product design for CE [9,10], value chain design and mapping [11,12]. Due to the inherent focus of CE on combining business logic with environmental performance (i.e., reduced burden), many studies refer to CE as one of the most important strategies to achieve sustainable development: [13] and [10] state that circularity in business models, products and supply chains is a “precondition for sustainable manufacturing and sustainable economy”. Nonetheless, to ensure a CE solution can contribute positively to sustainability, it needs to be planned with sustainability considerations and intentions in mind [14] and assessed on its sustainability performance prior, during and after implementation [15]. So far, studies have concentrated on proposing methods to assess CE performance at a corporate level [16,17], at a product level [18,19] or at a material level [20]. However, due to the intrinsic focus of CE on value and material preservation [21], most of the proposed methods focus on measuring material consumption [22], with recycling being the most dominant CE strategy considered [23]. Additionally, the challenge lies in measuring the social dimension, which remains largely uncovered by the proposed indicators and methodologies [21,23]. To address these limitations, [24] have attempted to understand whether existing leading sustainability-related manufacturing indicators can be employed to measure a wide range of CE strategies from a social, economic and environmental perspective. By being able to retrieve more than 270 indicators and categorize them according to CE strategies ranging from dematerialized and function-oriented strategies through recycling and recovery, the findings revealed that each strategy can be measured by a set of indicators that cover each TBL (triple bottom line) dimension. However, to ensure a meaningful set of indicators is applied anytime a specific CE initiative is being developed, support should be developed. Research on sustainability assessment and indicators [25,26] highlights the importance of a dynamic information selection processes as opposed to ‘prescriptive’ approaches, because, firstly, every project will have different sustainability concerns [25], and, secondly, decision makers will be able to make more informed decisions if they use information they have critically analyzed and prioritized.

The main goal of this paper is, therefore, to advance the assessment of CE by deploying leading sustainability performance indicators. This is done by proposing a step-by-step procedure to support a systematic selection of suitable sustainability-related performance indicators for CE initiative screening. The selected indicators are intended to help in measuring the potential performance of a CE solution in the early stages of its development, thus enabling identification of major areas to introduce improvements to before the implementation. A new approach to procedure development takes into account the complexity of multiple sustainability criteria to be considered whenever a new CE solution is proposed by bringing together elements of different TBL dimensions, thirteen CE strategies, and five business processes. Furthermore, the approach considers specifics of the company (its sector, processes, products, and services) to ensure the assessment process is meaningful for the decision context. Thus, this study contributes to the field of indicator-based sustainability assessment considering the innovative lens of CE, by taking into account the needs and roles of industrial practitioners in the CE transition process.

The paper is structured as follows: Section 2 explains the research method and materials, served to underpin the development of the procedure, Section 3 describes the developed procedure with detailed step-by-step elaborations, Section 4 describes the application of the procedure in the selected
companies, Section 5 provides discussions about key findings and contribution of the study, highlighting limitations and considerations for future research.

2. Research Methods

The research method adopted for this study can be described in two parts. Firstly, the research approach, including method and materials employed are detailed, before, secondly, providing an overview of the leading indicator database—previously compiled to assist selection of significant sustainability aspects and corresponding indicators—plus a summary of key recommendations that served as underpinnings for the development of the procedure to be followed, when selecting leading sustainability performance indicators.

2.1. Research Approach

A hypothetical-deductive approach [27] was followed to develop and evaluate the procedure based on a number of iterations that included a mix of research methods. This approach is used to construct an inquiry-based on existing theories and knowledge (Section 2.2), proceeding by formulating a hypothesis that is then tested to explore the consequences of the generated inquiry [28]. The theory in this study is the procedure for indicator selection, and the hypothesis to be tested is that “the classification of sustainability-related leading performance indicators according to CE strategies, business processes and TBL aspects and the corresponding procedure can support manufacturing companies in the selection of suitable sustainability indicators for CE initiative assessment”. The sustainability assessment of CE is based on an indicator approach with the foundation on the consolidated database of leading performance indicators, as a deliverable of the research Stage I, published in [24] (Figure 1). The development process, followed to create the procedure, Stage II, was initiated, firstly, by consulting the literature to identify the requirements for the indicator selection approach in the context of sustainability assessment, considering CE and business process perspectives, followed by the development of a procedure ‘prototype’ that was tested with experts and led to the conceptualization of the step-by-step procedure (presented in Section 3), which was tested with the help of case studies and iteratively improved, Stage III (presented in Section 4).

![Figure 1. Conceptual framing of the procedure development process.](image)

2.1.1. Case Study for Theory Testing

A multiple case study approach has been selected to test the usefulness of the procedure in guiding the selection of suitable indicators. The main objective of the approach was to continuously identify improvement opportunities following the feedback after each application (iterative approach). The final version of the procedure is described in Section 3. The improvement opportunities after the case study application are summarized in Table 2 Section 4.1.

To ensure the case study confirmability, transferability and credibility, the methodology provided by [29] and [30] has been followed. A case study protocol was developed, documenting the
case study design and execution (e.g., criteria for case selection, data sources, data collection methods and period, data analysis).

2.2.2. Case Study Set-Up: Case Selection, Data Collection and Analysis

To qualify as suitable case study candidates, the companies had to satisfy the two main criteria: (i) the company’s core activity is to design, develop and/or manufacture capital and/or consumer goods (i.e., belong to the secondary industry), and (ii) the company has identified one or several CE solutions to be implemented. Finally, the case selection was guided by initial contacts, which ensured the company expressed an interest in understanding the sustainability implications of the selected CE initiatives. As a result, our empirical investigation involved three Nordic manufacturing companies.

Each case study involved identical activities and similar types of data collection. The number of participants differed across cases (mainly due to company size), ranging from 2 to 6. The goal was to form a multidisciplinary team, which included participants who had expertise in the area affected by the selected CE solution (e.g., product designers participated whenever the CE solution concerned product design with circular materials) as well as those who had expertise in working with sustainability-related issues, e.g., environmental managers or sustainability ‘steward’ from the company. Data collection was initiated by using primary and secondary sources, which allowed for triangulation to elicit verification of the theory and the hypothesis [31]. Secondary data were collected by doing desk research to gain insights about the companies and their activities before meetings. Secondary data included companies’ websites, reports, and other publicly available information. Primary data were collected during face-to-face interactions during online meetings and on-site visits, designed as participatory workshops, which focused on applying the selection procedure and recording feedback, as described in detail below.

Participatory workshops were conducted in three steps: (1) initial exploration session for defining the scope for indicator selection (3-h session), (2) Workshop A on indicator selection (6-h session), (3) Workshop B on indicator application and interpretation (6-h session) (Figure A1, Appendix A). The purpose of the initial exploration session was to establish a solid ground for prospective workshops by: (i) aligning CE understanding between participants and researchers, thus ensuring the internal validity of the study [32], and (ii) defining the scope for indicator selection, i.e., elaborating on a prioritized CE initiative by exploring what CE strategies it involves and what business processes it affects. Workshop A aimed to test the procedure for indicator selection, by (i) allowing researchers to demonstrate the step-by-step indicator selection procedure, (ii) creating a room for a dialog about CE and its particularities in the specific corporate context, and (iii) assisting the participants in applying the procedure to select suitable indicators for the defined scope. Accordingly, the researchers benefitted from the participants with different competencies by getting an in-depth understanding of the organizational processes and decision context, as the discussions were held around “what are the concerns of ... where do we need the most help ... what is under our control ...”. The real-life context, despite limiting the researcher’s level of control [33], allows us to frame the picture about beliefs, assumptions and expectations of individuals and company, thus achieving an understanding of the influencing factors on the premises of the study and results [32]. Workshop B focused on: (i) discussion about particularities of data collection and indicator application, and (ii) collection of feedback (provided in Table C1 in Appendix C). All observations and dialogues were recorded in a written form after each interaction. The notes were later sent to the participants for data cross-checking and information accuracy. As a result of empirical investigation, the procedure has been iteratively revised to incorporate the feedback to account for the needs of industrial practitioners.

2.2. Conceptual Framing

2.2.1. Leading Performance Indicator Database

A ‘Leading indicator database’, consolidated as a part of the research Stage I (Figure 1), served as a foundation for developing a procedure for the systematic identification and selection of relevant
indicators to measure the sustainability performance of CE solutions. The database contains 270+ leading indicators classified according to CE strategies, business processes, and TBL dimensions and aspects (Figure 2, part (a)), which allows identifying suitable indicators available for various CE initiatives, i.e., the perspective which is required to develop a particular CE initiative (e.g., product design for repair, business model development to offer performance delivery), made up of different combinations of circular strategies and business processes (as shown in Figure 2, part (b)). Relying on leading performance indicators for sustainability measurements is advantageous because leading indicators can be used to ‘lead’ planning and monitoring of proposed actions by providing measurable and understandable information to the planners. Leading performance indicators provide early guidance about potential sustainability performance and warning about areas of concern, thus giving the possibility for companies to adjust and improve the initiative prior to its implementation to prevent any undesired impact [34,35]. The database acts as a medium to store indicators in an organized way, as well as provides clarification for each indicator in terms of its importance, plus a formula to help calculations. An in-depth review of the retrieved indicators and their classification is provided in the study by [24], with the database available in Excel format at the permalink web-address. Figure 2 shows the abstract representation of the database, with the classification criteria (a), and the logic of locating an initial set of suitable TBL indicators (Ni) (b), which works by selecting a CE strategy/ies and a business process, a specific CE initiative involves.

2.2.2. Procedure Development in the Context of Sustainability Assessment

A core consideration for the procedure was to ensure that it can facilitate a structured, yet dynamic and balanced identification of relevant sustainability indicators that can be meaningfully interpreted by the target users (e.g., industrial practitioners). The recommendations for such a process, therefore, were extracted from traditional works on indicator-based sustainability assessment. Contributions by [36] and [37] were used to construct the procedure to ensure it encourages learning and reflective analysis. To complement the procedure, guiding questions have been developed to assist the process of selection of individual indicators (similar to [38]) as well as indicator sets, as suggested by [26]. The recommendations of manageable indicator numbers have been adopted from [39] and [40]. These theoretical underpinnings contributed to understanding how to develop a procedure for meaningful indicator selection that facilitates organizational learning and ensures effective and ‘rational’ information use to support the development and improvement of CE initiatives in their early development stages.

Following the theoretical groundworks, the selection procedure ‘prototype’ was developed considering key recommendations (Table 1).

Subsequently, the ‘prototype’ was validated by several CE and sustainability experts with 10+ years of experience in both academia and industry and then tested internally with peers from the research group. Internal validations aimed at providing additional recommendations to the procedure, prior to its application in a case-study setting.
Table 1. List of recommendations as identified in the literature and how they were translated into specific features during the development process of the procedure.

<table>
<thead>
<tr>
<th>Recommendations</th>
<th>Reference</th>
<th>Explanation</th>
<th>Adopted feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce uncertainty of what has be measured</td>
<td>[25]</td>
<td>Establish a pool of indicators suitable for the exact assessment scope</td>
<td>The procedure entails application of the ‘Leading performance indicator database’, where each indicator is classified according to various circular economy strategies, business processes and TBL aspects</td>
</tr>
<tr>
<td>Dynamic and reflective process</td>
<td>[26]</td>
<td>Support dynamic and open-ended selection process, focusing on the process rather than on results</td>
<td>The procedure encourages the user to work with indicator selection in an iterative way, by encouraging to define a scope, select indicators, review indicators, and align the selection with the scope</td>
</tr>
<tr>
<td>Support review of indicators</td>
<td>[38]</td>
<td>Provide guidance for the review of individual indicators</td>
<td>The guiding questions have been developed to support the procedure of indicator review, evaluation, creation and customization</td>
</tr>
<tr>
<td>Indicator number</td>
<td>[39] [40]</td>
<td>Ensure indicator set is manageable yet provides a solid basis for decision-making</td>
<td>The procedure leads the user to defining the final set of indicators that is relevant for the screening scope yet limited to the key indicators that can support decisions</td>
</tr>
<tr>
<td>Indicator application</td>
<td>[36]</td>
<td>Ensure the information about indicator is sufficient to apply and interpret it</td>
<td>The procedure entails application of the ‘Leading performance indicator database’, where each indicator has a formula, units and purpose of measurement registered</td>
</tr>
</tbody>
</table>

Based on the consolidated recommendations, the prototype of the indicator selection procedure was developed, incorporating three steps: (i) identifying the scope by elaborating on a prioritized CE initiative to understand what CE strategies are considered and what business processes are affected, (ii) deploying the leading indicator database to locate the initial set of indicators, using a set of guiding questions to select the most relevant ones, and (iii) customizing and creating new indicators using a set of guiding questions. These steps were later elaborated on in the final version of the procedure presented below in Section 3, Figure 3.

3. Results: A Step-by-Step Procedure for A Systematic Indicator Selection

This section presents the final version of the procedure developed to support a systematic selection of leading performance indicators for CE initiative assessment. The final version of the procedure is shown in Figure 3 and comprises several steps identified through theoretical and empirical investigation. The procedure is intended to support sustainability and environmental managers and project managers in selecting the suitable set of performance indicators to be used for CE to support early sustainability performance assessment, giving a possibility of introducing improvements prior to the implementation. The procedure consists of several steps, which explain activities to be followed before, during and after the selection process. This final version of the procedure is the result of several improvement iterations, during which the initial version, based on the literature and expert review, was improved following recommendations from case study application (Table 2 in Section 4.1.).
3.1. Step 1: Scope Definition—Elaborating on a CE Initiative

3.1.1. Overview and Preparations

This step is focused on defining the scope for indicator selection, which requires identification, prioritization, and elaboration on a specific CE initiative to be screened with the help of indicators. Detailing a CE initiative is an important step because it influences the number and type of suitable indicators that will be available for the indicator review later in the process. The current procedure does not directly support the formulation of CE solutions suitable for a specific corporate context, i.e., whether a company should engage in service provision or in remanufacturing. Instead, it requires a set of solutions, including a CE one, be already outlined before the process of indicator selection. Major preparations for this step require, firstly, forming a multidisciplinary team consisting of people, who are involved in CE initiatives planning, including a sustainability manager or ‘steward’, and, secondly, selecting a specific and detailed CE initiative, which will be the scope for the indicator selection. It is important to facilitate a group discussion about what a specific CE initiative aims to achieve, what it specifically entails and what corporate (i.e., strategic, tactical and operational) decisions does it affect. The key question to be asked for this step is: “What should be measured in order to understand and potentially improve sustainability performance of the selected CE initiative?”

3.1.2. Activities

Detailing a prioritized CE initiative should be based on the identification of what CE strategies are involved and what business processes are affected. This activity is facilitated by a set of guiding questions, for instance, such as “Does the initiative involve offering ‘add-on’ service contracts including maintenance, supply of spare parts, buy-back agreement, consultancy?”, “Does the initiative require changing commercial relationships with customers and/or suppliers?”, “Does the initiative require changing or establishing reverse logistics system, and/or corresponding end of life processes and technology (e.g., technology, processes and resources (fuel, energy, water, etc.) needs for the re-processing facilities)?”, etc., which helps to define specific CE strategies and business processes. Once identified, these selections can be used as inputs to Step 2 to explore initial sets of suitable indicators. Before proceeding to Step 2, it is important to formulate key questions for each selection under the prioritized initiative. This helps in creating alignment between the selected
indicators (later in the process) and the scope, in that “... indicators of sustainability will only be effective if they support social learning by providing users with the information they need in a form they can understand and relate to” [41]. For instance, if a company’s initiative is to provide a service for a ‘full life cycle support’ for a product, it could involve offering a product through leasing contract including installation, maintenance and repair, removal at the end of life to be eventually recycled into the same product. Each intervention would require a different perspective, affecting decisions to be taken during various business processes. For instance, key questions can be formulated as: (i) what indicators to use to help understand sustainability performance of the CE initiative, when changing a business model from selling products to leasing?, (ii) what indicators to use to help understand sustainability performance of the CE initiative, when designing a product that is recyclable at the end of life, and (iii) how to measure how a specific CE strategy (e.g., repair) would affect considerations during a specific business process (e.g., product development, after-sales service, etc.)? Asking as many relevant questions as needed for each combination of a business process and a CE strategy(ies) facilitates understanding of what CE actually is, as well as what effort does it require. The reason is that CE solutions do not go in isolation: CE strategies influence each other and influence decisions taken during different business processes, likewise operationalization of certain CE strategies is enabled or constrained by decisions taken during various business processes (e.g., a product-design oriented solution has to fit a company’s business concept and vice-versa).

As an outcome of this step, the identified CE strategies and business processes can be combined to explore relevant indicators, which in turn should help in answering formulated questions.

As a part of this step, it is necessary that for each CE configuration a baseline (‘as-is’) system is defined, thus making it possible to compare a new (‘to-be’) scenario and a baseline (‘as-is’) scenario.

3.2. Step 2: Reviewing and Selecting Relevant Indicators

3.2.1. Overview and Preparations

This step requires applying the knowledge and expertise about the details of the prioritized CE initiative and specifics of the company (e.g., its sustainability priorities, specifics of the sector, facility, process, product). Similarly to Step 1, a multidisciplinary team is engaged together with a sustainability manager or ‘steward’, who can support the selection of indicators that require sustainability expertise.

Indicator review and selection are done through several sub-steps allowing to gradually select the most relevant indicators for each relevant scope (e.g., addressing key questions formulated for a combination of a CE strategy/ies and a business process) (defined in Step 1).

3.2.2. Activities

1 Sub-step 2.1. Establishing initial indicator set

In order to establish the initial indicator set, a combination of filters in the ‘leading performance indicator database’ need to be applied. Explicitly, the filtering is done by setting a ‘selection’ filter for a combination of CE strategies and business processes, which constitute the key question in focus. Filtering allows us to automatically reduce the number of indicators applicable to the selected combinations, thus removing unsuitable indicators for the scope that is in focus. For instance, a combination of CE strategy ‘repair and maintenance’ and a business process ‘after-sales service’ can be selected in the database to address the question ‘how to measure how a repair strategy would affect considerations during after-sales service?’ (discussed in Step 1). This selection would bring the initial set of indicators suitable for the selected combination and questions in focus.

2 Sub-step 2.2. Prioritizing sustainability aspects

Once the initial indicator set appears, it is further possible to refine it by setting a ‘selection’ filter for a sustainability aspect/s of higher interest or concern. Details of the selected CE initiative, industry
type, product type, location of business are among factors that impact what sustainability aspects might be prioritized [42]. Furthermore, the key question from Step 1 should be considered to assist the selection of sustainability aspects of concern. For instance, if the selected CE initiative concerns offering products for shared use, cost aspects, product durability and lifetime and resource consumption for and by the product under its use might be considered. Similarly, if a company belongs to the textile sector and is planning to change the process of dyeing, it might prioritize environmental aspects of water consumption and dye consumption, and liquid waste generation [43]. A company producing electronics might prioritize social aspects of supplier and community relationships (e.g., associated with mineral extraction coming from conflict zones) [44] and environmental aspects of energy consumption [45]. Likewise, some of the aspects might be de-selected: if a company regulates social and ethical issues through its code of conduct regularly, social aspects related to employment conditions and supplier relationships can be de-selected. Although the significance of a balanced TBL inclusion, especially for a long-term strategy, it may be beneficial for a company to decide on one dimension (e.g., environmental) at a time [42] when selecting indicators for CE screening. When focusing on one dimension, it is recommended to have indicators covering a broad spectrum of aspects (for instance, energy/waste indicators for a process, material consumption and expected lifetime of a product). These considerations should be discussed in a team to encourage dialogue about sustainability aspects significant for the selected initiative and the company. A short description of each sustainability aspect and related issues are provided in the database to assist their interpretation, which can be very useful for the project team during indicator selection process, considering that most of the companies in EU are SME’s [46] and may not have an environmental or sustainability engineer, whose expertise is essential in facilitating the selection of significant aspects and issues [47].

3 Sub-step 2.3. Reviewing and selecting suitable indicators

Once the initial indicator set is shown and sustainability aspects are prioritized, it is necessary to review the proposed set of indicators. The review and evaluation of indicators is a thorough process that requires operating with and iterating the details and key issues outlined in previous steps. The team should comprise sustainability or environmental managers and other project staff (e.g., product developers if the CE initiative involves product redesign). It is essential that the team has substantial knowledge of its own processes/products and the CE initiative. The involvement of the product and business development team can greatly impact to what extent the solution can be reached [42]. The team can consult the indicator database to understand how each indicator is measured and what data is needed. Furthermore, a set of guiding questions should be used to assist the review and indicator evaluation (with elaboration provided under each guiding question), as follows:

- How relevant is the indicator for your industry or company?

For instance, the environmental indicator available in the initial set for CE strategy ‘Reduce, Restore and Avoid impacts in Raw material and Sourcing’ and a business process ‘product development’, is ‘Pesticide use’. While this indicator is irrelevant for a heavy machinery company, it may be highly relevant for a food producing company. Similarly, the indicator ‘Ozone Depletion Substances in the Product’ is irrelevant for the textile industry, while can be relevant for the industry producing foam blown with chlorofluorocarbons (CFCs) used for thermal protection (e.g., used in aerospace industry) and for industries producing electronic and photographic equipment (e.g., cleaning fluids containing CFCs) [48].

- How relevant is the indicator for the selected CE initiative?

For instance, two of the environmental indicators available in the initial set for the combination of CE strategy ‘Reduce, Restore & Avoid impacts in Raw material and Sourcing’, CE strategy ‘Recycle’ and a business process ‘end of life operations’, are ‘Amount of Restricted Materials (REACH) in products’ and ‘Amount of Prohibited Materials (SVHC) in products’. While these indicators are very important for a company that considers open-loop recycling (i.e., recycling of one
product type to obtain material to be used as an input for another), they may be not important to measure if the company intends to do closed-loop recycling (i.e., when recycling own product into the same or similar product), because this information might already be available and used to make a decision to implement a recycling strategy. Furthermore, the importance of this indicator can only be judged by an expert (for instance, environmental, product or production engineer) as opposed, for example, by a non-expert of hazardous substances, like sales or service manager.

- How much data is required to measure the indicator and how big is the uncertainty of data collection?
- Does data collection involve significant costs or time?

For instance, to measure the indicator ‘First technological wear-out life’ (i.e., the period, which the product can be used without an upgrade, and is based on external factors, such as technology infrastructure changes and attractiveness compared with competing products (in contrast to internal factors as physical degradation and failure)), the company might need to collect data from the users, which can be time-consuming and costly, especially in the ‘business to consumer’ model. On the other hand, the company may realize that the data is available because the company already collects it as a part of their business practice.

- Is the indicator easy-to-use and understand?
- Does the use of the indicator require experts?

It may be challenging for a service manager, for instance, to work with social indicators. This would require involving experts with the knowledge to evaluate the importance of a particular indicator and its application and interpretation.

4 Sub-step 2.4. Customizing and creating new indicators

Along the evaluation process, indicators may need to be customized or created [38] to better address particularities of (i) a prioritized CE initiative and its objectives, (ii) the sector, and (iii) own processes, products, and operations. For instance, the indicator ‘Volume of chemicals and solvents used per product’ can be customized to ‘Volume and number of different chemicals used per product’ to address the company’s objective to understand what types of chemicals are used with the aim to remove them from the product. Furthermore, if the company’s objective is to reduce the maintenance costs of a product, new indicators can be created to address it. Thus, the indicator ‘Volume and number of different chemicals and solvents used for product maintenance’ can be developed, being based on the existing indicator. To complement it, an economic indicator ‘costs associated with the use of chemicals and solvents for product maintenance’ can be formulated.

Sub-steps under Step 2 are iterative steps, which allow the reiteration of key considerations and issues related to a particular CE initiative and its details. Iterations encourage learning about own operations and products and what matters the most for the particular context.

3.3. Step 3: Composing the Final Indicator Set

Once the indicators are refined, customized and created, the final indicator set can be composed of what can be called key performance indicators for the selected scope. The final indicator set should, therefore, reflect the indicators that are prioritized for data collection. It is then important to check the TBL coverage to ensure a balanced indicator set unless the specific dimension has been deselected on purpose (sub-step 2.2.). The final set should be practical to measure and consist of a manageable number of indicators, normally between 10 and 20, to provide a basis for actions [49]. The checklist below should be used to evaluate the final set on its comprehensiveness by addressing the following:

- Does the set consist of 10 to 20 indicators?
- Are all indicators relevant?
- Do indicators cover all TBL dimensions?
- Do indicators reflect life cycle thinking?
As the outcome of Step 3, a set of indicators is composed and an overview of the required data is prepared.

Implementing the Final Set of Indicators

In order to understand the performance of the selected CE initiative, it is important to implement the final set of indicators. Indicator application is the most extensive step since each final indicator would require tracking, collecting and managing data. The database provides formulas to compute each indicator, thus easing the task of identifying what data is needed. It is necessary to set a plan for data collection with a time period and responsible for data monitoring and registration. Sustainability or environmental managers, normally, already have an overview of what data the company might be routinely collecting as part of business practice. Moreover, knowledge of the indicators and necessary data allows them to identify the sources of specific data. Data collection processes, however, should ensure reliability, validity and verifiability, and requires a critical technical assessment [50]. Data quality can greatly influence the results of indicator application and compromise the decision-making process. Data can be collected from management, technical or procurement reports, existing management systems, stakeholder meetings, etc. [50]. Moreover, data needs to be collected for as many initiatives as set up in step 1 to ensure that the baseline ‘as-is’ system versus ‘to-be’ system, i.e., a new circular initiative, can be compared. Essentially, the initiatives must only be compared based on the same set of indicators, to enable understanding of sustainability performance of the proposed actions (i.e., decreasing or increasing trend). After comparison, it may be necessary to return to step 2 to select more indicators or to step 1 to refine details of the CE initiative.

4. Empirical Application in Case Study Settings

Research Step III aimed to test the procedure through case studies, which evaluated the extent to which the procedure could support the selection of suitable performance indicators. Three Nordic manufacturing companies have participated in the evaluation, varying in size (from less than 10 employees to 10000) and sector (company 1—furniture solutions for public and private spaces, company 2—manufacture and service of heavy industrial equipment, company 3—textile sector and home accessories). A detailed description of a procedure application is presented below using a case of Company 1, followed by a summary of learnings from all cases. A detailed description of the procedure application for Company 2 and Company 3 are provided in Appendix B. Condensed feedback from each company is presented in Appendix C in Table C1 with direct quotes and authors’ interpretations.

Company 1 can be classified as a micro-enterprise (<10 employees) with headquarters in one of the Nordic countries. The company designs and provides furniture solutions for public and private spaces. Since its inception around 10 years ago, the corporate strategy and objectives have been formulated around designing furniture systems that are driven by sustainability and individuality principles. Furniture systems are designed with the user in mind, modular and customizable, so to give the users the possibility of building variations of furniture from the same components, thus allowing the user to ‘design’ their own space with no need to buy more. Their strategic vision is formulated around efficient, regenerative and responsible use of resources, enhanced co-operation with local stakeholders and customers, and improving the physical and aesthetic quality of furniture.

Two company representatives participated throughout the engagement workshops: first co-founder, with expertise in sustainable and environmentally conscious product design solutions, and second co-founder, specializing in interior and furniture design. During the initial exploration session, it became clear that the company is considering several circular economy solutions to be implemented. The circular solutions, required, among others, rethinking own business model, establishment of a new value chain partnership, setting a product take-back system. For the indicator selection process, however, the ‘circular material’ initiative, in which the focus was on using the recylcate as a feedstock for a product type A, has been prioritized (Step 1). This decision mirrors the corporate environmental objective of regenerative and responsible use of resources, in that, the
‘circular material’ is to be locally “produced” from collected waste. Another driver mentioned during the session was to create awareness of waste and the ‘value’ stored in it, inspire other industries and create a new market for waste as a resource.

Consequently, the ‘circular material’ initiative was chosen as the scope to proceed with for indicator selection (Step 2). The intention of the company was to see what sustainability considerations to make and what to measure in order to support the decision. Moreover, the company acknowledged that the focus should not be solely on materials, but also on the conversion process of the material, transport, and end of life. This was explained by closer cooperation of the case company with another company responsible for waste recycling and forming of recyclates into new components. Considering this view, the initial scope for indicator selection consisted of a combination of CE strategy ‘reduce impact in raw material and sourcing’ and a business process ‘product development’, with the key question formulated as ‘what indicators to use to help understand sustainability performance of the CE initiative when designing a product with a recycled content instead of virgin material’. After applying the corresponding filters in the ‘Leading performance indicator database’, the initial indicator set comprised of 33 indicators. It was decided not to further refine indicators according to sustainability aspects, but to select the indicators one by one answering the guiding questions under sub-step 2.3. Furthermore, the information registered in the ‘Leading performance indicator database’ was used to understand each indicator and judge it against others. Specifically, the column, which described the importance of measuring an indicator, was found to be helpful in evaluating the importance of a particular indicator. For instance, for the indicator ‘Laminated or compound materials’ the purpose of indicator measurement and the significance of indicator value was stated as ‘Laminated or compound materials have limited potential for recycling. Decrease amount of Laminated or Compound Materials in a product’. As a result of the review process, 8 indicators were selected (Figure 4). During the indicator selection process, the discussion of the team unfolded around the indicator ‘embodied energy’: the participants expressed their uncertainty in how to measure it or how to get the data for it, taking into consideration the novelty of the process of waste recycling and its formation into a desired recyclate.

In addition, as the company indicated their interest in understanding the implications of the waste collection and its recycling process, another round was set up to select more indicators addressing the conversion processes of waste. Consequently, a CE strategy ‘reduce impact in raw material and sourcing’ and CE strategy ‘recycling’ were combined with business process, ‘end of life operations’ to understand what should be measured, when recycling waste and converting them to a recyclate for subsequent use in a new product. As a result, the initial set comprised 19 indicators, which were then reviewed using the procedure, resulting in 3 indicators in the final set. Accordingly, the final set consisted of 11 indicators to be implemented for sustainability screening: 8 indicators covering environmental aspects, 2—social and 1 economic (Figure 4).

It can be pointed out, that these selections were performed in an iterative way, in that, the initial scope chosen by the company allowed to navigate the database and gradually (de)select suitable indicators. During the indicator screening process, however, the participants noticed that there is a lack of social indicators, especially under the ‘product development’ process. At the same time, however, the users were overwhelmed by the number of indicators originally available in the database, referring to a challenge that a user might have if working in the database prior to defining the scope. The outcome of a case study was the application of the selected indicators and comparison of the proposed CE solution with the ‘as-is’ system. The company expressed the concern that major data was missing due to the unestablished process (i.e., conversion of waste to the feedstock material), therefore, in order to calculate the selected indicators, the company had either to contact entities, which were performing similar type of recycling and forming process or to collect data from literature. At the end of workshop B, the evaluation session focused on identifying the usefulness of the selection process and selected indicators for decision-making as well as receiving general feedback on how to improve the procedure and usability of the tools. All the comments were consolidated and used to improve the selection procedure, and the database layout.
Figure 4. Overview of activities and outcomes of the procedure application in Company 1.

Some specifics in relation to the first case study application can be pointed out. Firstly, the majority of the selected indicators are product-oriented. This selection can be attributed, firstly, to the selected scope, and secondly, to the expertise, the users from the company had, i.e., expertise in product design. It can be expected that more ‘operational’ indicators, specifically concerning the process of waste recycling, would be selected if people with suitable expertise participated. Nevertheless, the company expressed an interest in engaging value chain partners in the selection process to capture more sustainability aspects. Secondly, since little concrete details and data were available for the circular solution in focus, it was difficult to simulate the results of indicator application to be able to compare the circular and ‘as-is’ scenarios. From the application experience, the users suggested that the procedure for selection should emphasize the importance of corporate sustainability vision, so the final set of indicators can be reflected back onto it. As one of the participants suggested: “The process of indicator selection should start with aligning or defining the organizational sustainability vision and objectives. It is very important to make a company aware of why the selection of indicators is important and what the indicators can be used for. It is important to connect the final set of indicators to the corporate values”. Another suggestion was to adapt the database to smaller companies, with one user commenting: “Make the tool user-friendly for those, who may not have an expertise in sustainability assessments, but have a passion to work with indicators to make improvements”, complementing that “…the procedure requires the facilitator with sustainability expertise to facilitate the team and aid the interpretation of each indicator”, thus
making it challenging for (smaller) companies to use the database and select the ‘right’ indicators. On the other hand, the participants highlighted the importance for the user to see and evaluate the initial indicator set, stating: “It is good to have gradual steps in the database to obtain the initial set of indicators and then to select the most suitable indicators for the final set using the guiding questions. It gives a good overview of the whole process of the indicator selection, as well as tracks what indicators have been removed from the final set, but initially comprised the initial set”. The participants also emphasized the usefulness of the list of guiding questions, stating that “…they are very helpful because they “force” the user to think of every single indicator and reflect on it. Also, the indicator evaluation helped to understand the internal processes and what matters the most and what are the gaps”. It was added that, despite the presence of assisting formulas and purpose of measurement for each indicator, the process of indicator selection can be a time-consuming activity, especially for a small company with no sustainability expert that could potentially facilitate the evaluation process.

**Summary of Insights from the Case Studies**

The outcome of the procedure application in all the cases was the final set of indicators ready to be used for measuring the potential sustainability performance of the selected CE initiatives and the comparison of different alternatives. While the application procedure has been identified in all the cases, some differences could be observed. Firstly, Company 1 expressed the need to have a support step to assist in the formulation of sustainability strategy and objectives. “As a small company, we think that establishing and being clear about own sustainability goals and strategies is very crucial, also in terms of understanding why working with indicators at all”. Secondly, the participants emphasized the importance of having a facilitator with relevant expertise for the indicator selection procedure. Despite the fact that the participants selected suitable indicators for the final set, the lack of expertise of ‘broader’ sustainability created a challenge along the process, making it more time consuming, when navigating prioritization of significant sustainability aspects. It was suggested to provide more information about each TBL aspect found in the database to assist SMEs in prioritization.

Company 2, on the contrary, was very determined in limiting the scope for the screening as well as in their decision on what type of indicators to focus on. This can be ascribed to the competence and experience within sustainability the participants possessed as well as to the ‘insider-like’ (i.e., internal manufacturing) CE scope selected. Furthermore, the participants, knowledgeable of other sustainability assessment techniques, e.g., LCA, highlighted the importance of addressing trade-offs during indicator selection and, consequently, the decision-making process. Key remarks from Company 2 concerned the usefulness of the database and the procedure in selecting a set of key indicators for each project the company initiates. As emphasized, the key indicator sets can be used across projects to identify improvements and monitor changes. One of the key suggestions was to guide the users in the possibility of limiting the scope to certain key sustainability aspects, to reduce the complexity of operating with too many indicators simultaneously. It was also suggested to state the recommended number of indicators for the final set, so as to assist the user in defining when ‘enough is enough’.

Company 3 recognized the suitability of indicators for the scope selected, however, pointed out the importance of ‘allocating’ indicators to the specific users, who have the competence to evaluate and validate every single indicator. In that, the participants stressed the need to engage experts from several corporate departments, where the sustainability manager would be responsible for identifying the key experts based on the type of CE initiative in focus. Moreover, the participants commented on the usefulness of applying filters to de-select certain sustainability dimensions and aspects. As pointed out, going from a smaller to a larger set by gradually adding more indicators can reduce the complexity of decision-making, when evaluating the importance of each indicator. In addition, key recommendations concerned the conditions of working with the selection procedure, in that, it is critical to define the scope for which the indicators will be selected as well as the baseline, which the new initiative will be compared against. All the comments were consolidated and used to
improve the selection procedure, and the database layout and content. Table C1 in Appendix C provides quotes from discussions in case companies. Table 2 presents a summary of key improvement opportunities, labeled as recommendations, which have been identified through the empirical evaluation and incorporated in the final version of the procedure as presented in Section 3.

Table 2. Summary of the key recommendations to improve the procedure based on the empirical application.

<table>
<thead>
<tr>
<th>Recommendations</th>
<th>Case company</th>
<th>Explanation</th>
<th>Adopted feature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C1</td>
<td>C2</td>
<td>C3</td>
</tr>
<tr>
<td>Strategic consideration</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scope definition</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Baseline identification</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Multidisciplinary team</td>
<td>√</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Triple bottom line aspect navigation</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Indicator number</td>
<td>√</td>
<td>√</td>
<td>√</td>
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<tr>
<td>Account trade-offs</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
</tbody>
</table>

5. Discussion
The case study evaluation of the procedure and corresponding indicator database presented positive results, indicating their support to companies in the selection of suitable leading indicators to measure the performance of CE initiatives. Furthermore, the empirical settings allowed us to identify opportunities to improve the usefulness of the presented tools. Main learnings from the empirical investigation are as follows:

- it is essential to set the scope for indicator selection by outlining a CE initiative and elaborating on its details by explicating what corporate decisions it affects (e.g., business process orientation) and what specific CE focus it has (e.g., CE strategy view) prior indicator selection process,
- it is necessary to set a baseline scenario, upon which a CE initiative scenario can be compared,
- it is important to involve a multidisciplinary team to support the selection of suitable indicators, including a sustainability ‘steward’ to facilitate the interpretation of indicators and an expert team who is engaged in the development of the CE initiative into focus (e.g., product designers, after-sale managers),
- availability of indicator attributes, such as formulae, units and purpose of measurement, eases the interpretation of each indicator, which facilitates the selection process. This is important especially for SMEs, which might not have a sustainability manager to support indicator interpretation, similarly, availability of elaborations on sustainability aspects and what they entail facilitates their interpretation and prioritization,
- it can be beneficial to work with indicators from one sustainability dimension at a time, however, a final set should comprise a balanced number of TBL indicators,
- the iterative selection procedure seems to help in arriving at suitable indicators, the suitability of which is judged by the users who are to operate with indicators and relate to their results.

The learnings also highlight limitations. Firstly, the procedure and database were tested in a limited number of companies from specific sectors, thus limiting the evaluation of their usefulness for other contexts. Furthermore, testing in more companies could allow us to look into cases, where the scope for indicator selection is expanded to include more combinations of CE strategies and business processes, for instance including those requiring simultaneous changes in business models, product design and operational activities. Secondly, the procedure does not address how to resolve situations, when trade-offs between indicators arise, which is essential in providing assistance in the decision-making process. Therefore, future work should evolve around developing a support tool to guide decisions in trade-off situations. Thirdly, the ‘Leading indicator database’, used to retrieve indicators, contains non-sector-specific indicators. The procedure accounts for this by providing examples of how to customize and create indicators, however, it may be a time-consuming process that could possibly hinder the easiness of the procedure application and indicator selection in the industry. Future research could address the development of indicators that are sector-specific or providing sector-specific guidance for indicator selection. Furthermore, future work could include analysis of relationships between the identified indicators and recognize the most common variables used to calculate the indicators. It would also be beneficial to consider aggregating indicators for simplicity and diffusion in the industry. However, some caution must be taken due to the potential drawbacks of using composite indicators or indices to measure complex phenomena, such as sustainability and CE [37]. It can be pointed out that the indicator database could be enhanced by developing more indicators to cover social aspects and indicators suitable for the business model development process, as discussed in the study by [24].

To indicate the contribution of this study to the context of CE development and indicator-based sustainability assessments, we identify several criteria to provide its comparison against other works. We selected several works that satisfy the following criteria: (i) they provide examples or propose indicators for assessment, (ii) they provide a reasonable categorization of indicators, and (iii) they focus on the early stages of decision-making. The identified works include recent studies on employing indicators to support the development of sustainability-oriented strategies, CE being one of them, and discussed by [38,51][52][52][52–53] as presented in Table 3.

Table 3. Comparison of present research with similar works based on a range of criteria.
<table>
<thead>
<tr>
<th>Reference</th>
<th>Considers all dimensions of sustainability</th>
<th>Considers a variety of circular economy strategies</th>
<th>Considers a variety of business processes</th>
<th>Considers a dynamic life cycle perspective</th>
<th>Encourages a practical application in industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present research</td>
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<td>✓</td>
<td>✓</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>[52]</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>[38][38][38][38]</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>[53]</td>
<td>✓</td>
<td>✓</td>
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<td>✓</td>
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</tbody>
</table>

Particularly, [51] propose environmental and functional indicators to measure the performance of a product family, considering a wide range of CE strategies. The authors aggregate a set of indicators into several ‘prescribed’ indices to evaluate the circularity of proposed product designs. [52] propose a methodology for designing a sustainable recycling process supported by indicator-based measurements. Their approach is limited to recycling only, although with a three-dimensional sustainability consideration, where four indicators for each dimension are prescribed. Work by [38] provides a procedure to select product-oriented indicators, based on the life cycle orientation and environmental aspect(s) of main concern under the product development process. [53] provide a set of three-dimensional indicators classified according to life cycle stages to be used during product development and manufacturing to evaluate the sustainability performance of products and processes. Whilst they refer to several resource-efficient strategies (e.g., remanufacture), the indicators are not accordingly classified.

Summarizing the above-mentioned studies, it is evident that more research is needed to account for the myriad of perspectives when it comes to the application of leading sustainability performance indicators to support the development of CE solutions. In this sense, current research presents a significant contribution by the fact that it takes into account all dimensions of sustainability, a comprehensive selection of circular economy strategies and a holistic set of business processes (from business modeling, through product development, to end-of-life operations) (Table 3, present research) to allow filtering and pre-selection of classified indicators, to support the development of several CE solutions simultaneously, whilst considering their sustainability performance. Although the study does not have a distinct classification of indicators according to life cycle stages, it takes this perspective into account, when, for instance, presenting indicators selected under the product development process (follow the web address as presented in Section 2.2.2). Importantly, the procedure encourages a dynamic selection of indicators, to avoid the prescription of indicators that may be irrelevant for some business contexts. Noteworthy, the approaches that ‘prescribe’ indicators imply that some criteria are more relevant than the others, which seems counterintuitive in such complex and multi-faceted concepts as sustainability and CE [54,55].

A few implications of this study exist. From the theoretical view, firstly, despite a very high level of details provided about each indicator and related sustainability aspect, there is still an assumption that users of the indicators in the industry can interpret indicators and relate them to potential sustainability impacts. To address this, prospective research could focus on establishing a link
between leading indicators and related sustainability impacts. Secondly, the database and the procedure do not support supplementary use of CE-specific indicators, i.e., the ones measuring the rate of resource recirculation. The research could advance by developing a procedure to support complementary use of sustainability performance indicators for CE and CE-specific indicators, so as to explicate the link between the implemented CE solutions and the achieved TBL performance, which is currently quantitatively unreported in by industries [56]. From the empirical perspective, the procedure requires a CE initiative to be already planned, thus providing no support on how to approach ideation and development of a specific initiative relevant for a specific corporate context.

6. Conclusions

This research aimed to develop, evaluate and enhance a procedure for a systematic indicator selection to measure the performance of CE strategies from a TBL perspective. The procedure provides guidance for industrial practitioners in selecting a suitable set of performance indicators for measuring the potential sustainability performance of CE strategies prior to their implementation. The procedure was tested with the help of case studies, contributing to its enhancement and consolidation into the final version as presented in previous chapters. The main contribution of this study is the procedure for a systematic indicator selection that is based on the rationale of stipulating a dynamic and flexible selection process. This is to ensure that the selection process accounts for the diversity of CE perspectives and applications and the context they are positioned in (e.g., product, process, sector). The construct of the ‘Leading performance indicator database’, which is used as a tool to extract the indicators from, eliminates the complexity in searching for indicators and making judgments of their suitability for the assessment. In that sense, the classification of indicators according to a variety of CE strategies, business processes and TBL dimensions allows us to retrieve an initial indicator set for each possible CE initiative. The initial indicator set is not prescriptive, however, but rather indicative, with procedure encouraging the user to evaluate each indicator, and customize or create new if needed. Although this process might seem challenging, the advantage is to induce learning and engage more profoundly with sustainability considerations during the CE initiative development process, as one of the case participants commented: “Also, the indicator evaluation helped to understand the internal processes and what matters the most and what the gaps are”. From a practical point of view, the procedure intends to reduce the complexity and uncertainty of a decision-making process in companies, which arises from a complex interplay of CE and sustainability domains. Consequently, this minimizes the challenge of operating with too many or too irrelevant performance indicators, contributing to a more structured and informed performance measurement using leading indicators. The procedure should be used in the early stages of CE planning and development, to ensure industrial practitioners use the ‘best’ knowledge of potential sustainability outcomes of their initiatives to make the decisions.

From a theoretical point of view, our aim is to advance theory on CE development support using leading sustainability-related performance indicators. So far, the literature has either proposed newly developed indicators for CE, which mostly measure the intrinsic performance by accounting for the rate of resource recirculation[21] or focus on impact assessments. While being useful, the former do not account for a wide range of aspects related to sustainability (social implications, land use, etc.) [21], while the latter, despite well established and robust methodologies, either cannot assess dematerialized or performance-based CE strategies or provide results that are easily understood by industrial decision-makers [57]. The advantage of leading TBL indicators is in their ability to be understood, hence used, by industries, and to give early warning about potential sustainability impact of CE solutions. The practical contribution of the study is in its support for industrial practitioners in finding boundaries of what sustainability aspects should be considered and in structuring the process of selecting relevant indicators for sustainability performance measurement of CE initiatives.

Supplementary Materials: The following are available online at http://www.mdpi.com/. Appendix A: Figure A1. Case study set up: main activities and actors involved. Appendix B: Application of Indicator Selection Procedure in Company 2 and Company 3: Figure B1. Overview of activities and outcomes of the procedure
application in Company 2. Figure B2. Overview of activities and outcomes of the procedure application in Company 3. Appendix C: Table C1. Consolidation of key discussion points at the case companies.

Author Contributions: Conceptualization, M.K., D.C.A.P. and T.C.M.; expert review, D.C.A.P. and T.C.M.; case study investigation, analysis and data interpretation, M.K.; validation, M.K., D.C.A.P. and T.C.M.; writing first manuscript, M.K.; review and improvement suggestions for first manuscript, D.C.A.P. and T.C.M.; supervision, D.C.A.P. and T.C.M.; funding acquisition and resources, D.C.A.P. and T.C.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by NordForsk, Nordic Energy Research, and Nordic Innovation under the Nordic Green Growth Research and Innovation Programme, grant number 83144.

Acknowledgments: This article is one of the outcomes of the research project CIRCit (Circular Economy Integration in the Nordic Industry for Enhanced Sustainability and Competitiveness). The authors would like to thank the CIRCit consortium—Research Institutes of Sweden (RISE), Technology Industries Finland, Innovation Center Iceland, Norwegian University of Science and Technology (NTNU) and colleagues from the Technical University of Denmark—for facilitating the engagement with companies and participating in enriching discussions about Circular Economy. Special acknowledgments go to the participating companies and their engaged participation.

Conflicts of Interest: The aforementioned funding institutions had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References


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