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A Classification Tool for Circular Supply Chain Indicators*

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Abstract. The Circular Economy approach has gained attention recently. Supply Chains have an important role in the transition to a more circular economy. Thus, being able to assess structurally the circularity of multi-activity Supply Chains is essential to help Supply Chain managers to decide in this transition. An important number of Supply Chains' indicators are proposed in the literature in the context of sustainability. However, to the best of our knowledge, there is no tool, which specifically classifies those indicators according to Circular Supply Chain structures, involving circular activities such as reuse, remanufacturing, refurbishing and repurposing. The aim of this work is to develop such a classification tool for indicators in order to assess the circularity of Supply Chains at the strategic level. This classification tool relies on the three main principles of circular value creation of Ellen MacArthur Foundation. These principles are converted into different dimensions that could be applied to the structures of Circular Supply Chains. These dimensions constitute classification criteria for our tool. In this work, new potential Circular Supply Chain indicators are also proposed and classified by the tool. This tool allows and facilitates academics and Supply Chain managers categorizing and choosing appropriate indicators to assess circularity within Circular Supply Chains.

Keywords: Circular Economy · Supply Chain · Classification · Circularity Indicator.

1 Introduction

In order to achieve the goals of sustainability, the world is moving towards a more circular economy. The Circular Economy (CE) allows an integrated way to handle the Triple Bottom Line of sustainability (economic, environmental and

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social). Moreover, Supply Chains have an essential role in the transition to a more circular economy [2]. CE involves the transition from the management of linear activities to multiple circular activities running simultaneously [5]. This results in new and complex Circular Supply Chain (CSC) structures, which are much more challenging to manage, evaluate and improve.

Supply Chain Management regarding conceptualization within CE is still at an early stage [12]. Indeed, the need for research on the application of the CE from the Supply Chain perspective has been highlighted [15] along with the need for a measurement methodology to assess circularity performance in Supply Chains [8]. Moreover, CE definitions and what to be measured need to be explored due to the lack of consensus [25]. Furthermore, new CSC structures required by CE bring new factors that could be measured to express circularity.

Therefore, a new framework is needed for academics and Supply Chain managers to understand Supply Chain circularity as well as to support the development and the classification of circularity indicators for new CSC structures. This work aims to fill the aforementioned lack by proposing a classification tool for indicators that are relevant in the assessment of the Supply Chain circularity, based on their structures. This tool is designed relying on the main principles of circular value creation prescribed by the Ellen MacArthur Foundation (EMF) [10,11]. These principles are adapted to the Supply Chain context by proposing different dimensions for each of them regarding the possibilities of CSC structures. Some new potential indicators for each dimension are also proposed in order to illustrate the classification.

The rest of the paper is structured as follows. Section 2 provides a literature background and our positioning. Section 3 introduces our classification tool of CSC indicators illustrated on some CSC structures. Finally, Section 4 concludes the paper and gives some insights for future works.

2 Background and Positioning

2.1 EMF Principles and CSC Structures

The CE concept has received increasing attention worldwide in the latter years [15,24]. Ellen MacArthur Foundation (EMF) has emerged as a respected reference in this topic and published different studies about the concept of CE since 2013 [11,10]. The latter proposed four principles of circular value creation: (1) the power circling longer, (2) the power of inner circle, (3) the power of cascaded use, and (4) the power of pure inputs [11,10]. These principles, which have previously been stated in academic publications [29,28], have been gathered by EMF and taken into consideration in recent CE studies [7,30].

On the one hand, the first three principles concern material flows and Supply Chains explicitly. On the other hand, the last principle (the power of pure inputs value creation) is obtained by improving the product's design and the collection activity [11,10]. Therefore, the latter does not directly impact the structure of a Supply Chain, so it is not considered in this work.

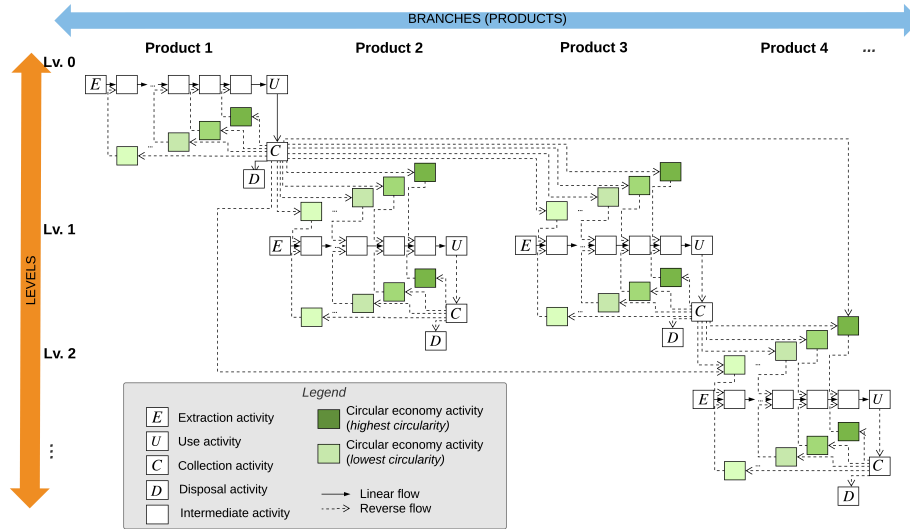


Fig. 1. Circular Supply Chain Structure

Besides, the notion of CSC is relatively recent concerning Supply Chain literature as well. Several studies have been conducted to explore the links between CSC and related concepts such as Eco-Industrial Parks, Environmental, Sustainable and Green Supply Chains, Reverse Logistics and Closed-Loop Supply Chains [23,24,4]. Moreover, some specific works defined the CSC structure as a combination of closed- and open-loops [21,4,7,12]. Closed-loops concern the integration of forward and reverse flows for a specific product. Indeed, used products turn back to the same Supply Chain through CE activities such as direct reuse, reuse with repairing, reuse with refurbishing, reuse with remanufacturing, and recycling [21]. Open-loops allow the integration of different Supply Chains. Used products are introduced in a different Supply Chain through repurposing activities [21]. Repurposing refers to the use of products or materials for a different purpose than the original one.

To clarify CSC structures, we made a further generalization of the Extended Model [21], by adding a flexible number of activities (including the CE ones) and the possibility of integrating multiple Supply Chains to conceptualize CSC structures. Fig. 1 presents a CSC structure that contains the integration of several Supply Chains. Each Supply Chain is composed of a material extraction activity (E), a collection activity (C), a use activity (U), a disposal activity (D), as well as a set of manufacturing and distribution activities (blank white squares) and different CE activities (green squares). These activities are connected to each other by direct (solid arrows) and reverse (dashed arrows) flows. The different Supply Chains are connected by open-loops. The integrated Supply Chains have two attributes: branch and level. Branch refers to the type of products produced throughout the Supply Chain (e.g., Product 1, Product 2, etc.). Level refers to

the level of requirements of the product produced throughout the related Supply Chain (e.g., Level 0, Level 1, etc.).

Hereafter, we relate the considered EMF principles with the structure of CSCs, in order to highlight value creation potentials through their structures:

The power of circling longer concerns keeping products, components and materials in use as longer as possible. Through a Supply Chain structure, the length of use of products, components or materials could be increased by multiple consecutive closed- or open-loops of circular activities such as reuse, repair, remanufacture, and recycle, etc.

The power of inner circle concerns potential savings on different dimensions: material, energy, labor and pollution. In other words, when the loop is short (with fewer manufacturing activities in the loop), the less a product has to be changed during reprocessing. Having shorter closed- or open-loops means more potential savings in terms of labor, material, energy and pollution and thus, higher circularity. For example, the reuse loop is more circular than the recycling loop as the first one is shorter. Reusing a used product requires few changes. Indeed, the closed-loop related to reuse contains 3 activities: collection, reuse and distribution, while the closed-loop related to recycling contains 4 activities: collection, recycling, manufacturing and distribution. Therefore, choosing the CE activity that creates the shortest loop for a used product allows creating more value by keeping the value already created as long as possible without destroying it. However, we note that returned products and components are not all eligible for all CE activities due to the state of the products or components. Therefore, it is interesting to have multiple CE activities through a CSC, because it may allow choosing among different CE activities to handle used products according to their states in order to provide more savings.

The power of cascaded use concerns material flows across distinct Supply Chains. This could be possible by repurposing the products within different purposes. For example, repurposing electric vehicle batteries in stationary applications. This principle is therefore related to open-loops.

2.2 Indicators and Classifications considering CE

Indicators that are used in performance measurement influence the decisions to be made at strategic, tactical, and operational levels [16]. These levels concern respectively long-term, mid-term and short term decisions. In Supply Chain Management literature, indicators are classified according to these levels [17]. The strategic level indicators influence the top level management decisions [17], such as Supply Chain design [19] or selection of CE activities [22] that creates closed- and open-loops.

Concerning the classification of CE indicators, significant works have been devoted recently [9,25,27]. However, these works do not focus specifically on Supply Chains. Besides the circularity indicators' taxonomies, other classifications of indicators related to CE from different schools of thought are found.

Concerning Green Supply Chain Management Kazancoglu et al. [20] proposed an assessment framework. Concerning Sustainable Supply Chain, the in-

dicators are usually classified according to the Three Bottom Lines (TBL) of sustainability (economic, environmental, and social) [6,14,26]. Besides the TBL of sustainability, some frameworks consider other criteria [1] such as Sustainable Supply Chain characteristics (*e.g.*: volunteer focus, resilience focus, long-term focus, flow focus, relationship focus, etc.).

3 A Classification Tool for Circular Supply Chain Indicators

In this section, we introduce a classification tool for CSC indicators relying on the three principles of circular value creation [11,10] from EMF and the CSC structure. New circularity indicators and some others taken from the literature are classified with our tool in order to illustrate the purpose of our classification tool. We summarized the classification tool with the potential indicators (bold elements) in Fig. 2. As mentioned before, the figure also includes illustrative examples on the right side of the figure. These examples conform to the CSC structure presented in Fig. 1. Hereafter, we will elaborate each value creation principle and the related dimensions.

The power of circling longer promotes the increase of the time of use of a product within one and/or multiple consecutive loops. This concerns the whole CSC, including closed- and open-loops. The determined dimensions for this principle are described as follows.

Number of consecutive loops is the number of consecutive use through a loop. Having multiple consecutive uses through a loop brings more circularity as the CE promotes keeping resources in the use phase as long as possible [11,10]. Figure (a) in Fig. 2 illustrates a Supply Chain where three (3) consecutive loops are performed. This could correspond to the consecutive recycling of a product in the same Supply Chain. Another example of an indicator in this dimension is the Circularity [13]. However, the scope of this indicator of Circularity from the literature is tighter than ours, as it covers only one of our dimensions.

Length of use is the length of use of a product obtained as a result of a CE activity. If a CE activity provides an increase in length of use, this results in a more circularity. This aligns with the CE principle to keep resources in use as long as possible [11,10]. This dimension concerns both closed- and open-loops. The example of figure (b) in Fig. 2 illustrates a scenario where we assume that the closer circular activity to Use adds one (1) unity to the length of use (*e.g.*, years of use) and the other circular activity adds three (3) unities. These values could correspond to a mean of added value for each activity for a product, known by the Supply Chain manager. Another example of an indicator of this dimension, is Longevity [13].

The power of inner circle principle concerns both closed- and open-loops. This principle deals with savings in terms of energy, material, labor, and pollution. These savings are enabled by shortening loops and having multiple loops in the CSC. Note that other related works treat in much more details the savings dimension on looking at different levels of performance resulting in some specific

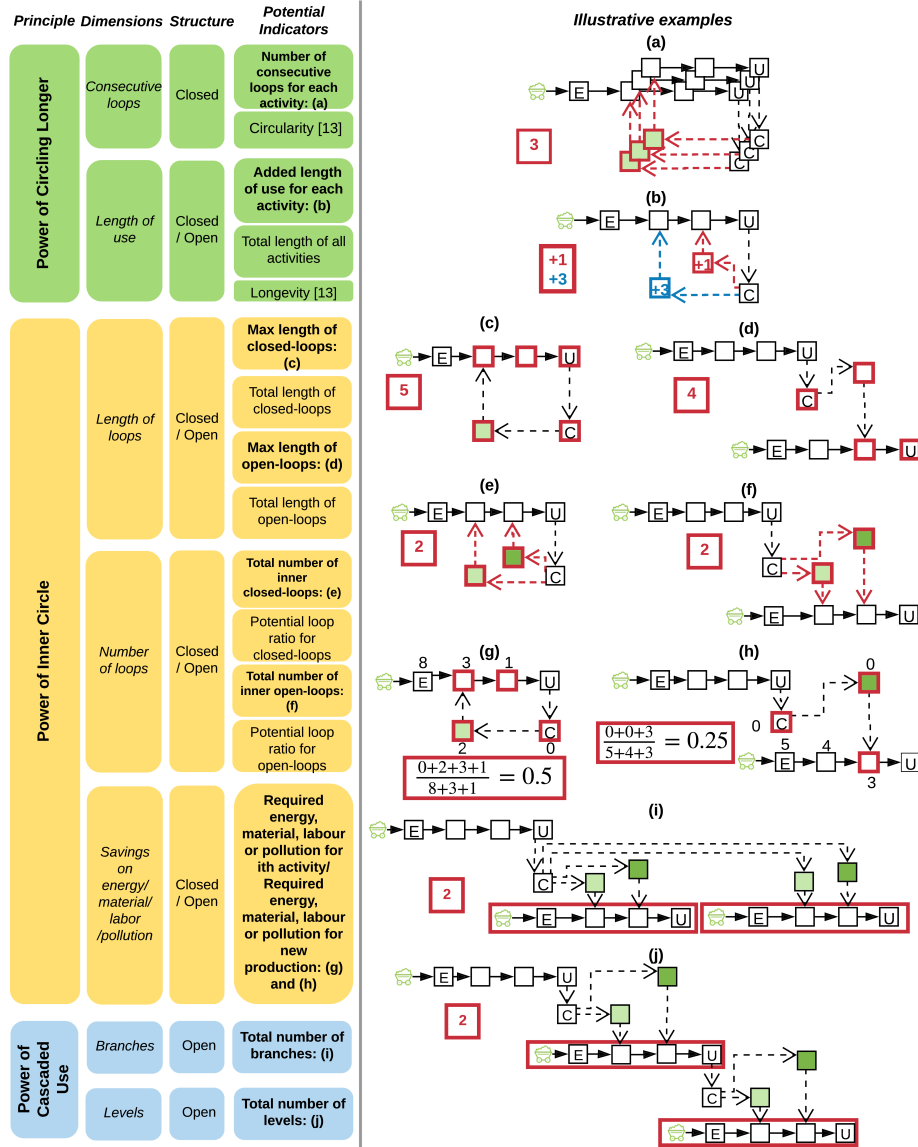


Fig. 2. The classification tool of circularity indicators for Supply Chains

saving indicators [9,18,20]. The dimensions related to this principle are described as follows.

Length of loops considers the number of activities of the loop until the Use activity. It is considered that shorter loops result in more circularity [11,10]. For example, direct reuse (the CE activity that is considered to be "closer" to Use) needs fewer activities to generate new products. This implies that it is more circular than recycling (CE activity "further" from Use) that needs more activities. Recycling has thus a longer length of the loop. Fig. 2 illustrates a first Supply Chain where the length of the closed-loop is five (5) (figure (c)) and a second Supply Chain where the length of the loop is four (4) (figure (d)). Note that different potential indicators concerning this dimension could be proposed, such as the maximum length of the loops or the total length of the loops. Length of loops is calculated for one loop; however, the maximum length of the loops and the total length of the loops could be calculated for a Supply Chain (focusing on the output flows of its collection activity) or the whole CSC network (focusing on all the collection activities of the network).

Number of loops considers the number of closed- and open-loops in a specific Supply Chain's product (i.e., not all the network is considered but only the Supply Chain of a specific product). The increased number of loops results in more circularity in CSCs in general. Indeed, the CE should transit to a more complex system, where multiple different CE activities are applied simultaneously through multiple loops [5]. Fig. 2 illustrates two examples of Supply Chain where the number of closed-loops and the number of open-loops are calculated (figures (e) and (f)). The number is two (2) in both cases, which correspond to the number of simultaneous CE activities involved in each case. The number of open-loops could be calculated for an individual Supply Chain (focusing on the output flows of its collection activity) or for the whole network (focusing on all the collection activities of the network).

Savings concerns savings obtained in terms of energy, material, labor and pollution as a result of a CE activity or a CSC compared to new production process of a product. This dimension is important since CE seeks to minimize the use of aforementioned resources [11,10] and it is treated in detail in [9,18,20]. Moreover, our classification tool adds savings on the labor dimension, which is scarcely explored in the literature. A possibility to calculate the savings concerning energy, material, labor, or pollution is illustrated in Fig. 2 as the ratio between the sum of saving values of the linear path and the sum of values of the circular path. The saving values for each activity regarding energy, material, labor, or pollution should be known by the Supply Chain designer beforehand. Therefore, savings' values could be calculated for only one loop, for an individual Supply Chain, or the whole CSC network depending on the quantities of the flows in the considered system. Fig. 2 illustrates two examples of closed- and open-loops (figures (g) and (h)).

The power of cascaded use concerns the integration of distinct Supply Chains. This principle concerns the number of levels and the number of branches (ex-

plained below) and relates to open-loops as we focus here on repurposing activities. These dimensions are defined as follows.

Number of branches concerns the number of integrated Supply Chains with different product branches. Fig. 2 illustrates an example of a Supply Chain with two branches (figure (i)), which means that a repurposed product (or material of a product) could be redirected to two different other Supply Chains.

Number of levels concerns the stages where a product or material could be repurposed with a decreasing requirement level. Figure (j) of Fig. 2 illustrates an example of a Supply Chain with two levels. Note that, different branches could place in the same level, since the related products could have the same requirement level.

The indicators considered in our classification tool allow measuring circularity at the strategic level. In addition, some of the indicators could be applied at all levels (Circularity [13], Longevity [13], Added length of use for each activity and savings dimension's indicators). For instance, indicators in savings dimensions could be calculated at strategic level by using material flow capacity of CSC, and at tactical level by using actual material flow quantity.

Fig. 2 only proposes some examples of potential indicators concerning each dimension. Note that some aggregated indicators could consider different dimensions. Our vision is that in order to have a meaningful assessment of CSC, either an appropriate global indicator to measure the circularity of a CSC should cover all the presented dimensions, or a multi-criteria approach is needed. However, the proposed indicators concerning only one dimension are also helpful to give some insights in the comparison and assessment of CSCs. Moreover, these indicators could support selection of CE activities [22] in Supply Chain design. For example, a Supply Chain designer could compare the CE activities by added length of use for each activity (figure (b) of the Fig. 2).

4 Conclusion

In this work, we proposed a classification tool for CSC indicators based on EMF circular value creation principles. This tool can help academics to analyze existing or new circularity indicators according to CSC structures by using the proposed dimensions as classification criteria. It can also facilitates Supply Chain managers categorizing and choosing appropriate circularity indicators to assess the circularity of CSCs. Moreover, we proposed new potential circularity indicators along with some from the literature (e.g., Longevity) for each dimension in order to illustrate our classification tool. The proposed indicators could support strategic decisions such as selecting CE activities in Supply Chain design.

Nevertheless, this classification tool still needs some improvements. First, while developing this proposal, we did not include the fourth principle of EMF, which is the power of pure inputs. This principle concerns the design process of a product, which we consider out of the scope of the analysis of CSCs. The power of pure inputs also increases collection efficiency [10]. Therefore, a new dimension could be set up to consider the collection and sorting efficiency in-

dicators. Moreover, the design of products is a factor that influences the choice of implementation of CE activities. For example, with the eco-conception approach, the products could be designed for some special CE activities. In this context, Asif et al. [3] proposed product design attributes such as reusability, remanufacturability, and recyclability indexes. These indexes could be helpful to determine a CSC structure as circular as possible according to the design of a product. Second, this classification tool does not include pure economic indicators and social sustainability indicators. Possible integration in the classification tool of these two other dimensions will also be explored. Finally, a future work using the classification tool to categorize more extensively existing indicators in the literature is planned.

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