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29th CIRP Life Cycle Engineering Conference

Sustainable performance of circular supply chains: A literature review.

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Abstract

The rapid increase in consumption of products and services is leading to the scarcity of resources and environmental crisis. The circular economy was born as a new economic model to solve these problems. It explores new techniques to rethink and redesign products and services and extend their useful life through reusing, remanufacturing, recycling, etc., to maximize the value of resources. The implementation of the circular model entails the adaptation of supply chains. In connection with sustainability, we also need to consider economic, social and environmental dimensions. This makes the evaluation of the circular systems more complex. In the past, various means are presented in the literature to evaluate and understand the sustainable dimensions for the development of the circular economy. However, the evaluation methods and the indicators are heterogeneous. Thus, it is very challenging to obtain standardized information that the different stakeholders will understand. In this paper, through a literature review, we seek to understand the measurement of the sustainable dimensions in the performance of the circular supply chains. This research is part of a thesis work, which aims to study sustainable performance in circular supply chains, grouping economic, management and industrial engineering aspects.

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Keywords: Circular Economy; Circular Supply Chain; Sustainable Performance.

1. Introduction

In recent years, there has been a progressive shift towards more sustainable development. This is due to the increase in the consumption of goods and services, which brings as a consequence the depletion of resources and the environmental crisis. From this problem, the Circular Economy (CE) was born as a new economic model based on rethinking and redesigning products and services, implementing the recirculation of resources, in order to regenerate natural systems and reduce the generation of pollution and waste [1].

Despite the growing interest in CE, the concept has garnered relatively little attention in the supply chain management literature [2], while SCs are the key unit of action with regard to CE implementation and success and will be the foundation for driving needed change[3].

However, some prominent literature reviews have begun to explore the link between SC management (SCM) and CE. For example, de Angelis et al. [4] reveal the need for more practical information regarding how to introduce circular supply chains (CSC) into existing context. Farooque et al. [5] identified the different drivers, enablers and inhibitors that influence the success of a CSC. Mangla et al. [4] explored the barrier related to the CSC implementation. Notwithstanding the aforementioned reviews, there remains a lack of detailed understanding in the literature regarding how to measure sustainable circular SC performance for its design or its deployment and execution to be competitive. Developing this understanding is the primary aim of the present paper. This research is part of a thesis work, which aims to study the assessment approaches of sustainable performance in CSC, grouping economic, management and industrial engineering

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aspects.

2. Theoretical Background

This section aims to introduce the key concepts of this paper: Circular Economy, Sustainable Performance and Circular Supply Chains, to provide a direction for the literature review.

2.1. Circular Economy

Most of authors reported three main principles taken into consideration in the concept of CE, these principles correspond to: (a) rethinking and redesigning products and services, (b) keeping products and materials in use and (c) regenerating natural systems [1,5–7].

Moreover, in the literature, it was found that the application of CE is related to 4 objectives [8]: (a) CE aims to become the replacement of the current linear system with the intention of being regenerative and restorative. (b) The immediate objective is to decouple economic growth from natural resource depletion and environmental degradation. (c) Increasing the resilience of the systems. (d) Create and preserve economic, social and ecological value to maximize ecosystem function and human well-being.

For the definition of the CE, end-of-life strategies (R-Principles), which encompass operational principles for closing different loops in circular systems, were also considered. In the literature there are several definitions of these principles, which take different forms depending on the strategy of the authors, such as reduce, reuse, recycle, remanufacture, refurbishment, repair, resell, repurpose, recover, [1,4,9–12], among others.

On the other hand, the following definition of CE was found “an economic system that replaces the ‘end of life’ (EoL) concept with reducing, alternatively reusing, recycling, and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks), and macro level (city, region, nation) to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity, and social equity to the benefit of current and future generations” [13]. This is the concept on which the CE will be based for the purposes of this article, as it shows the integration of the CE principles, the objectives of the model and the R-principles in order to achieve sustainable development. Subsequently, in section 4.2, this definition will be applied to the characterization of the attributes that will later allow the analysis of the results of the literature review.

2.2. Sustainable Performance

When referring to the CE, it is common to find links to the concepts of sustainable development [4,14]. Therefore, the relationship of this economic model with the three sustainable dimensions (society, environment and economy) is evidenced [6].

However, when talking about sustainable performance within the CE model, the literature shows that there are partial and total measurements in terms of sustainable dimensions, and in turn these dimensions may have different weights in terms of their importance [15]. While the social dimension is the one

that is less taken into account [5,10]. And furthermore, when referring to indicators, there is a great diversity of indicators, methods of measurement and evaluation of CE in terms of their specificity, scale, input elements, units of measurement, etc. Such heterogeneity makes it difficult to obtain standardized and replicable information [5,10,15,16]. Therefore, this paper seeks to explore the measurement of the sustainable performance of CSCs.

2.3. Circular Supply Chains

When referring to CSC, several terms have been associated with this concept, such as open-loop and closed-loop SC, green SC and reverse SC, and although these are not exactly CSCs, together they contribute to the construction of the concept [4,17].

In addition, Hazen et al. [3] exposes 5 principles concerning Circular Supply Chain Management (CSCM), which correspond to closing loops (based on the recirculation of materials), slowing loops (referring to the extension of the useful life of products), intensifying loops (involving more value-intensive use phase of materials), narrowing loops (referring to the efficient use of materials) and dematerializing loops (based on the substitution of products for services).

In the case of this article, the concept that will be used for CSCM is the one presented by Farroque et al. [17] in which it is defined as “the integration of circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems. It systematically restores technical materials and regenerates biological materials toward a zero-waste vision through system-wide innovation in business models and supply chain functions from product/service design to end-of-life and waste management, involving all stakeholders in a product/service lifecycle including parts/product manufacturers, service providers, consumers, and users”.

Figure 1 shows the structure of the CSC adapted from the literature [17]. This scheme will be applied to the characterization of the attributes that will later allow the analysis of the results of the literature review in accordance with the different stakeholders (section 4.2). In the upper part of Figure 1 we have the raw materials extractor or supplier, which start the flow of primary resources through a conventional linear supply chain (producer, sales channels, customers). To represent a circular system, it is necessary to consider the waste management and the different ways of return the circular resource flow with the ultimate goal of zero waste. In the case of the circular flow of closed loops (right side), it can be seen that it flows in several directions, since the exchange of circular resources can occur between any SC stakeholder. On the left side are the open loops, which represent the flow of by-products and waste out of the system to external SCs of the same sector or other sectors. On this side, it can be seen that there are circular flows that can come from external SCs, which corresponds to waste and by-products that serve as raw material for this CSC.

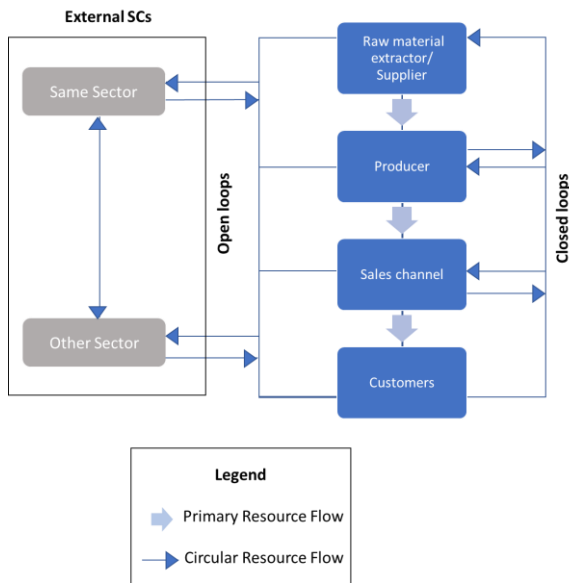


Fig. 1. Opened and Closed loops in the CSC adapted from [17]

3. Review Methodology

For the development of this work, a systematic literature review was carried out, considering academic literature composed of review articles, research articles and conference papers. And grey literature, composed of reports and manuals. For this, the search was focused on documents and articles that would support the measurement of the circular supply chain in terms of sustainable performance, in a partial or total way.

The process of searching for academic literature was carried out through Science Direct and Web of Science. This search was narrowed down to publications published in the last 5 years, and the combination of 4 areas of study (Circular Economy, Circular Supply Chain, Sustainability and Performance Evaluation) was considered. In the case of CSC, it was noted that some elements could be found related to micro-level, business model and inter-firm networks and in the case of performance evaluation, assessment, indicators, measurement, index and metrics were associated to ensure the inclusion of all possible methods. This search was carried out in titles, abstracts and key words.

At first, 214 articles were obtained, which were then filtered according to the following selection criteria: a) the articles had to mention loop closure or an R-principle; b) they had to be associated with the application of a case study or statistical field data; c) they had to address at least one of the sustainable dimensions (social, economic or environmental); d) they had to be associated with some phase of SC in relation to some stakeholder. After applying the aforementioned selection criteria, 23 academic articles and 2 grey literature reports corresponded to indicators for assessing the sustainable performance of CSCs were obtained.

4. Results

The results obtained from the literature review are shown below. This review was based on 25 publications of methods and indicators for evaluating CSC. First, section 4.1 describes

the results obtained in relation to general attributes, such as type of publication, year of publication and journal. Secondly, section 4.2 shows the results related to the methodological attributes, such as unit of analysis, relationship with the CSC stage and their stakeholders, sustainable dimension evaluated, perspective of its application and R principle covered.

4.1. Descriptive results

Of the 25 articles of CSC assessment methods and indicators studied, 23 corresponded to scientific articles and 2 to grey literature on indicators for the transition to the CE, associated with the Ellen MacArthur Foundation and the World Business Council for Sustainable Development. Publications in the last 5 years were studied, of which 11 were published in 2018, 8 in 2017, 3 in 2021, 2 in 2020 and 1 in 2019, being 2018 the year with the highest number of publications. With respect to the journals in which this literature was published, the results are shown in Table 1. The *Journal of Cleaner Production* is the one with the highest number of publications, followed by the *Journal of Resources, Conservation and Recycling*. The grey literature is shown at the end of the table, which was published in report format.

Table 1. Journals and their number of publications

Journal	Number of Publications
Journal of Cleaner Production	7
Energy	1
Science of the Total Environment journal	1
Resources, Conservation and Recycling	6
Ecological Economics journal	1
sustainability	2
International Journal of Sustainable Engineering	1
Buildings	1
International Journal of Production	1
Journal of industrial ecology	1
Resources	1
Grey literature	2

4.2. Analysis of Sustainable Assessment in Circular Supply Chains

This section presents the results in relation to the methodological attributes of the literature reviewed. For this, 5 attributes were studied, corresponding to unit of analysis, sustainable dimension, perspective, stakeholder involved and R-principle covered.

4.2.1. Unit of Analysis

In our sample of papers, 5 different units of analysis were adopted by the authors: a) a material, for example the analysis of the flow of a specific material of the final product, as the evaluation of gold in the life-cycle of mobile phones [18], b) an entire product, as the evaluation of the design of prosthetics fingers to the application of CE practices [19]. c) one firm, related to its business model and processes [20]. d) dyadic relationship, whether the relationship and sustainable performance between two firms of the SC are evaluated, as the study of the interaction between the supplier and the producer in the plastics industry[21]. Or e) the entire SC, as in the case of the environmental-social-economic indicator framework for

biomass sustainability assessment [22]. With respect to the unit of analysis (Figure 2), it is observed that most of the literature reviewed corresponds to the evaluation of 1 firm (14 publications) within the SC. This is followed by the evaluation of the whole SC under a global vision without specifying the interactions between stakeholders (4 publications). Then 3 publications to the evaluation of a specific product, 3 publications to the evaluation of a specific material within a product and finally 1 publication corresponding to the analysis of 2 firms interacting in the same supply chain.

4.2.2. Sustainable Dimension

The sustainable dimensions (social, economic, sustainable) refer to whether one or more of these dimensions are considered in the publications. When analysing the sustainable dimensions treated in the literature, it is observed that the highest number of publications is associated with two dimensions, the environmental dimension (9 publications) such is the case of the analysis of the environmental impact of plastic production and the use of plastic waste in different scenarios [21], and environmental-economic dimension (9 publications), as in the case of the Eco-efficiency index (EEI) [23] which relates economic value to environmental impacts. Followed by the integral evaluation of all dimensions (social, environmental and economic) with 6 publications and finally only the social dimension (1 publication) (Figure 2).

With respect to the sustainable dimensions, it is observed that at a more operational level, focused on the product, there are partial measures of the environmental and economic dimensions, while as the level goes beyond the boundaries of the organization and the SC is considered as a whole, these dimensions are treated integrally. On the other hand, it is observed that the interest of the literature continues to be focused towards the economic and environmental dimensions, leaving the social dimension neglected, which could be due to the difficulty in defining and measuring this dimension.

4.2.3. Perspective

It corresponds to the perspective given by the authors of the literature reviewed, which may correspond to the design of the CSC, or the monitoring of an existing CSC on the transition of the system towards the CE. In terms of perspective (Figure 2), most of the publications focus their evaluations on the monitoring and follow-up of the circular system (14 publications). 6 of these publications do not specify the perspective of the evaluation method, which are usually related to the evaluation of different scenarios through simulations and statistical data. 4 publications are oriented towards both, the design and monitoring of the circular system, while only one publication focuses on the design of the system or product.

With respect to the perspective of the publications, it was observed that most of them are oriented to the monitoring of circular systems, where the word "transition" is mentioned on several occasions to refer to the evolution of the systems towards the CE [22,24–26]. On the other hand, the design perspective is mainly related to the stages of product development and design. In other cases, the perspective could

not be placed in a monitoring or design perspective, especially in publications in which the authors evaluated different scenarios without specifying their subsequent usefulness[21,23,27–30].

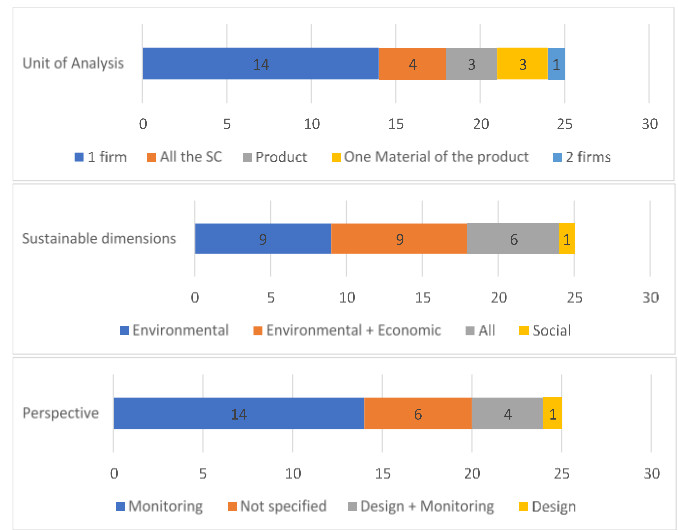


Fig. 2. Numbers of literatures reviewed according with the attributes Unit of analysis, sustainable dimension and perspective

4.2.4. Stakeholder Involved

Associated to the stakeholder to whom the evaluation method is addressed, which can be the supplier or extractor of the raw material, the producer, the sales channels and/or the customers. In the case of the stakeholders involved, the CSC assessment methods reviewed in the literature are mostly oriented towards producers (23), followed by raw material suppliers (19), consumers (13), sales channels (12) and finally all stakeholders (7). (Figure 3).

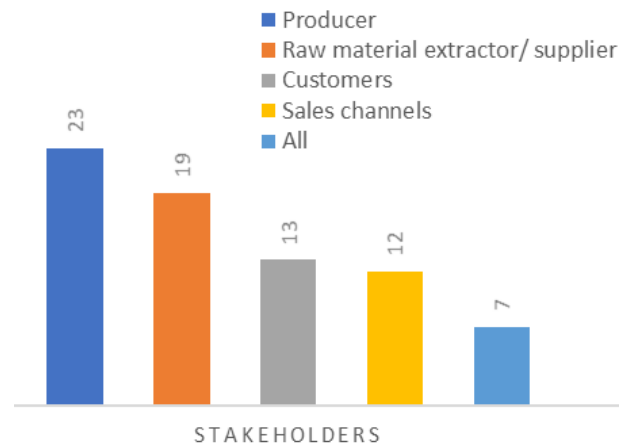


Fig. 3. Number of appearances of stakeholders involved in the literature review.

In addressing the stakeholders involved in the literature review, it was found that most of the literature is focused on methods such as Life Cycle Assessment [23,28,31,32] and Material Flow Analysis [25,27,28,33], which does not allow for a full understanding and usefulness of the methods regarding stakeholder’s roles and interactions.

4.2.5. R-principle covered

These principles correspond to the processes that allow loop closures. According to the R-principles covered in the literature, 19 publications consider the recycling process, such as the case of the longevity and circularity indicators developed for the analysis of the flow of gold in the life cycle of mobile phones, which take into consideration the recycling process to recirculate the material in the production process [18]. Followed by the reuse process with 11 publications. Subsequently, the reduce process with 7 publications, which, although it is not a loop closure, is taken into consideration, as it is based on the efficient use of resources and is mentioned in the principles of the CE in section 2.1. Remanufacture with 4 publications, refurbishment and loop closure in general (without specifying the process) with 3 publications each one. And recover and repair with 1 publication each one. (Figure 4).

with regard to the R-principles, it was observed that their definition varies according to each author, and that there is no agreement in the literature as to the limits of each of these principles. For example, the concepts of remanufacturing and refurbishment [26,34–36] may present similar characteristics that make their use vary according to each author. On the other hand, the term reuse is implemented generically to refer only to the closing of loops in general in one of the publications [37]. In addition, the term reduce has a special connotation in these principles, because although it does not represent a loop closure, it is a fundamental principle in the concept of CE.

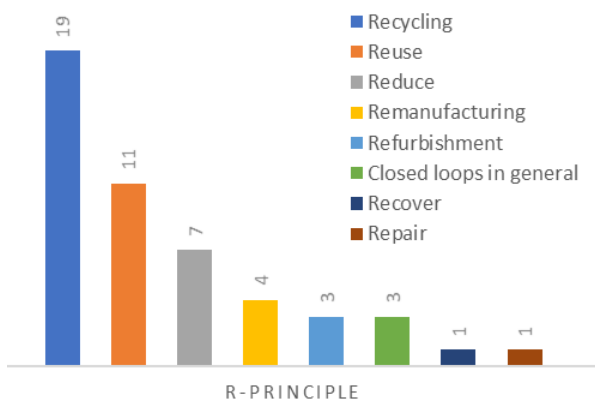


Fig. 4. Number of appearances of R-principles covered in the literature review.

5. Discussion and Conclusions

Our article presents a review of the literature on the evaluation of the sustainable performance of CSCs, in which the understanding of CSCs is developed through the analysis of 25 publications that present different methods and indicators for this purpose.

In the development of the literature review presented above, it was observed that according to the unit of analysis, the sustainable dimensions are studied in greater or lesser proportion. For example, with respect to the indicators oriented towards materials or products, they presented a strong tendency to measure the environmental and economic dimensions, where the environmental part was partially measured, especially through the efficiency of resources and their subsequently

recirculation into the SC, taking into account concepts such as circularity and longevity [18,19,38]. Furthermore, this same unit of analysis was found to be strongly focused on the use of indicators for product design (perspective) and end-of-life disposal methods, which are oriented towards suppliers and producers [18,19,32,35].

On the other hand, it was observed that most of the publications are oriented to the evaluation of a single firm, with emphasis on the producer as the main stakeholder, with a strong orientation towards the measurement of environmental and economic performance, where only 4 articles considered the 3 sustainable dimensions [20,38–40]. With respect to R-principles, publications related to a single firm consider a greater diversity of R-principles with respect to the other units of analysis [20,36].

The dyadic type relationship was found in only one publication, in which post-industrial plastic waste is studied to obtain various products through the quality and purity of the waste used as raw material. This case study, through scenarios, shows the different interactions between the supplier and the producer, with a purely environmental approach, considering only the principle of recycling [21].

With respect to SC as a unit of analysis, it was observed that the four publications [22,27,28,37] base their evaluation proposals on a global vision of SC, mostly based on Life Cycle Assessment and Material Flow Analysis methods, which leads to a focus on processes and product life phases and not on the study of stakeholders and their interactions. Under this unit of analysis, more consideration was given to the systems and their impact on the three sustainable dimensions [22,27]. The R-principles were treated in a more general way, in which only recycling, reuse, and reduction are generically mentioned.

As mentioned above, this article is part of a thesis work, which aims to study the assessment approaches of sustainable performance in CSC, grouping economic, management and industrial engineering aspects. Therefore, this literature review served as a starting point for the analysis of the sustainable performance of CSCs which is then expected to be further developed on the perspectives and analysis of stakeholder interactions.

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