Research article

Process Performance Measurement Framework for Circular Supply Chains: An Updated SCOR Perspective

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Abstract

This paper presents a theoretical and conceptual approach for measuring the supply chain’s performance in the circular economy era. Since not only economic but also environmental, social, and especially circularity performance must be measured within circular supply chains, adapted performance measurement systems are required. The proposed performance measurement system is based on a SCOR model adapted for circular supply chains (including the processes use and recover) and provides a comprehensive composition of indicators to holistically measure the supply chain’s performance from an economic, environmental, social, and circular perspective.

Keywords: Circular supply chain, performance measurement system, SCOR model

INTRODUCTION

Circular supply chains (CSCs) systematically incorporate circular strategies into the management of the supply chain (SC) and are often perceived as new path toward sustainable supply chain management (SCM) and sustainable development (Farooque et al., 2019). However, CSCs are not necessarily more sustainable than other SC concepts in the sustainability discourse (Sehnem et al., 2019). Too often, circular economy (CE) is equated with sustainability and the specific impacts of circular strategies on the three dimensions of sustainability, especially the environmental perspective, are not considered.

Managing a SC generally requires detailed information about its performance, especially in terms of its processes and relationships. Performance measurement systems (PMSs) help decision-makers quantify the SC’s efficiency and effectiveness and enable successful management (Maestrini et al., 2017). To comprehensively and holistically measure SC performance in the CE era, it is necessary – and in current literature uncommon – to assess its performance in the three sustainability dimensions as well as in the circularity dimension (Vegter et al., 2021). Therefore, new and adapted PMSs are needed that can meet the higher requirements of CSC management (Blum et al., 2020; Vegter et al., 2021).

Since literature on PMSs for CSCs is scarce and too often neglects key aspects of the CE, this research paper follows the call of Vegter et al. (2021) and develops a theoretical and conceptual framework for measuring the performance of CSC in a holistic manner. As the SC’s transition from linearity to circularity plays a decisive role in achieving a more sustainable production and consumption, its performance – particularly with respect to circular performance – must be measured accordingly to support a successful transition. Therefore, the research question is formulated as follows: Which are the key performance measures that adequately and holistically depict the circular supply chain?

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The main contribution of this study is the proposal of a conceptual framework that provides a basis for the comprehensive and holistic measurement of CSCs’ performance. The novelty of this framework is that it incorporates the three traditional dimensions of sustainability – economic, environmental and social – as well as the new circular perspective of performance, thus reconciling the goals of sustainability and circularity.

Since the literature on PMS for CSCs is still in its infancy, the study can be classified as a state-of-the-art review that aims to address a current topic in a qualitative and narrative form (Grant and Booth, 2009). By synthesizing the existing literature within this framework, future research opportunities in the field of CSC are illuminated.

This paper first presents the theoretical background on CSCs, PMSs and the SCOR model. Following this, the four performance perspectives of the developed PMS are shortly described and a clear distinction between circular performance and environmental performance is provided. The last section presents the conceptual framework with its four dimensions and possible performance measures. Lastly, the findings and contribution of this study are summarized and possible future research opportunities for PMSs are briefly discussed.

THEORETICAL BACKGROUND

Circular Economy and Supply Chains

The integration of circular thinking into the management of SCs is one of the emerging research streams of the sustainability discourse in SCM (Farooque et al., 2019; Farooque et al., 2022). In the last five to ten years, the number of published scientific papers focusing on the CSC and its management has increased significantly (Lengyel et al., 2021; Montag, 2022). Although the link between CE and SCM was mentioned as early as 2006 (Farooque et al., 2019), publication data show that a differentiated field of research has only recently been established (Montag, 2022).

Given the lack of conceptual consensus on the underlying parent concept of the CSC and the resulting inconsistencies and divergence in the understanding as well as application of the CE concept (Kirchherr et al., 2017), it is of great importance for the CSC to have its concept more clearly framed and differentiated from other related sustainable SC concepts. Farooque et al. (2019) proposed an early formal definition that focuses on the restoration of technical materials and regeneration of biological materials, aiming toward a zero-waste ideal by a system-wide inclusion of all stakeholders, including the end-user. Vegter et al. (2020) define the CSC as one that “strives for economic, environmental and social benefits by reducing, maintaining, and recovering resources” (p. 12), thus clearly addressing the three dimensions of sustainability. However, to differentiate the CSC concept and fully capture the unique characteristics that set it apart from previous concepts by going beyond green, closed loop, or sustainable SCs, a more holistic definition is needed. To counter this criticism, Vegter et al. (2021) very recently extended their previous definition and added the key characteristic of restorative and regenerative cycles.

To fill this gap in the conceptualization of the CSC, Montag (2022) synthesized in a previous work six archetypal characteristics that aim to provide transparency for the CSC concept:

- **R-Imperatives**: implementation of a waste hierarchy and value retention strategies
- **Restorative and Regenerative Cycles**: differentiation between restoration of technical materials and regeneration of biological materials
- **Sustainability Framework**: aims to contribute to all three dimensions of sustainability (economic, environmental, and social wins)
- **Value Focus**: implementation of a value logic framework to propose, create, deliver and capture value in the SC
- **Holistic System-Thinking**: transition toward circularity requires thinking in systems and the integration of all actors along the SC
- **Paradigm Shift**: holistic transformation of the linear SC to fully adopt circular principles

This understanding follows the one from e.g., Batista et al. (2018), Farooque et al. (2019), Hussain and Malik (2020), Vegter et al. (2020), Vegter et al. (2021) and Farooque et al. (2022) that CSCs should be recognized as major advancements in the sustainable SCM research field. However, the relationship between CSC and their sustainability potential is complex, and thus adequate measurement systems are
required, assessing not only the circular, but also the economic, environmental, and social performance of the CSC (Vegter et al., 2021; Blum et al. 2020).

Supply Chain Performance Measurement
In a globalized world that is characterized by increased performance-based competition, systemic and strategic management of the SC and all its business functions and processes is required so that the long-term performance of both the individual company and the SC is improved (Mentzer et al., 2001). To evaluate how well a SC is managed, PMS play a vital role by quantifying the efficiency and effectiveness of the SC’s processes and relationships (Maestrini et al., 2017). A PMS can further be characterized as a set of measures that provides information on the multiple organizational functions and firms, enabling decision making and deployment of the SC strategy (Maestrini et al., 2017).

While the initial focus of performance measurement (PM) was on measuring the economic performance and therefore, the development of economic measures (Eccles, 1991), the field has increasingly expanded to include environmental and social measures (Vegter et al., 2020). These measures provide important information on current performance levels and ensure comparability between this current and the desired future performance level of a SC. The latter, in particular, is the key to initiating actions for a transition toward an improved state of performance (Elgazzar et al., 2019; Vegter et al., 2021). This transformative nature of PMS has implications for decision-makers and their managerial mindsets: new strategic priorities and consequently different ways to measure performance will be the result (Eccles, 1991).

As the CE is currently the most considered concept in sustainability and SCM research, PMSs no longer need to measure only the economic, environmental, and social performance of SC, but also need to integrate the circular performance perspective and thus measure, evaluate, and control more measures. These higher requirements represent a current challenge in the field of PMS research, especially with regard to the selection, number, and the specific formulation of circularity and sustainability measures for CSCs (Vegter et al., 2021).

SCOR Model in the Circular Economy
When measuring the performance of a SC, the horizontal integration - namely the alignment of measures along all SC processes – is a key requirement to identify, evaluate and link the measures, aiming to identify the processes that need improvement (Elgazzar et al., 2019; Vegter et al., 2021). Besides the Balanced Scorecard, the renowned SCOR model – as a framework for SC processes and performance objectives – is one of the most frequently used tool for developing performance measures in the SC context (Elgazzar et al., 2019), being considered as a useful framework both in academic and business communities (McCormack et al., 2008).

SCOR recognizes six major processes that are executed to meet the goal of fulfilling the customer’s need (APICS, 2022): plan, source, make, deliver, return and enable. While these may be sufficient to describe the mostly linear activities in traditional SCs, they do not adequately express the activities, and thus processes, in a CSC. Vegter et al. (2020) recently updated the SCOR framework for SCs in circular business models by adding two processes: use (by the customer) and recover (e.g., reuse, remanufacture, refurbish, recycle). Table 1 presents a characterization of this circular SCOR framework. Figure 1 depicts the CSC, including the circular SCOR processes.
Table 1 – Circular SCOR Processes (APICS, 2022; Vegter et al., 2020)

<table>
<thead>
<tr>
<th>SCOR Process</th>
<th>Main Objective</th>
<th>Characterization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan</td>
<td>Development of plans to operate the SC</td>
<td>All activities associated with determining requirements, collecting information on resources, balancing of requirements and resources, determining capabilities and gaps, and identifying counteractions.</td>
</tr>
<tr>
<td>Source</td>
<td>Acquisition of goods and services</td>
<td>All activities associated with procurement, e.g., ordering, deliveries, receipt and transfer of raw materials, products, or services.</td>
</tr>
<tr>
<td>Make</td>
<td>Transformation of products and services</td>
<td>All activities associated with production and manufacturing, e.g., assembly, processing, manufacturing, and other material conversions to create content for orders.</td>
</tr>
<tr>
<td>Deliver</td>
<td>Fulfillment of customers’ demand</td>
<td>All activities associated with order and distribution management, e.g., scheduling order deliveries, picking, packing, and shipping.</td>
</tr>
<tr>
<td>Use</td>
<td>Use/consumption of products</td>
<td>All activities associated with the use phase of the product, e.g., controlling the quantity, quality, and location of the product as well as prolonging lifetime through maintenance and repair.</td>
</tr>
<tr>
<td>Return</td>
<td>Management of reverse flows</td>
<td>All activities associated with reverse movements of goods, services, and information, e.g., take-back of used or defective products as well as collection for maintenance, repair, and overhaul.</td>
</tr>
<tr>
<td>Recover</td>
<td>Value retention within and across the SC</td>
<td>All activities associated with preserving content and value within and across the SC, e.g., reuse, remanufacturing, refurbishing, upcycling, recycling, downcycling.</td>
</tr>
<tr>
<td>Enable</td>
<td>SC management</td>
<td>All activities associated with business management, e.g., performance, data, resources, facilities, contracts, compliance, and risk as well as customer management.</td>
</tr>
</tbody>
</table>

Performance Perspectives for Circular Supply Chains

As Vegter et al. (2021) have stated in their literature review, PMS for CSCs are faced with higher requirements due to the complex relationship between circularity and sustainability. According to them, two key requirements that a PMS should meet are the inclusion of multiple dimensions of performance and a horizontal integration. In the context of CSCs, the former refers primarily to the distinction between the three dimensions of sustainability and the circularity dimension. The latter refers to the PMS containing measures for all processes along the CSC.

The conceptual PM framework that will be presented in the next section thus consists of four performance perspectives that cover the circular as well as the sustainable dimension of the CSC. They can be briefly characterized as follows (Blum et al., 2020):
- **Circular performance**: aims for more material circulation (at highest possible quality level) by applying circular strategies such as reuse, repair, refurbish, remanufacture, recycle.
- **Economic performance**: aims for positive economic value generation and economic sustainability of the CSC (e.g., costs, profits).
- **Environmental performance**: aims for a positive environmental development through less harm to the environmental ecosystem (e.g., reduction of climate change).
- **Social performance**: aims for positive social conditions for humans (e.g., better and safer working conditions, employee benefits, no child labour).

Within their discussion, Vegter et al. (2021) mention that current PMSs for CSCs do not yet provide a clear distinction between circularity performance and sustainability performance. Too often, these two perspectives overlap and create confusion, hindering the further development and implementation of effective PMSs. To propose a theoretical framework to measure the performance of a CSC, this section makes the attempt to provide a clear and intuitive distinction between circularity and environmental performance.

The assumption that circular products or circular production are also sustainable in terms of economic, environmental, and social impacts is not per se correct (Braun et al., 2021; Kravchenko et al., 2019). Although many conceptualizations understand CE and the application of circularity as a step toward sustainability, CE does not necessarily lead to more (environmental) sustainability, either way (Blum et al., 2020; Braun et al., 2021; Vegter et al., 2021). In particular, the distinction between the environmental and circular perspective is critical to the goal of a sustainable CE, as they share common goals but use different methods, leading to conflicting goals. While the CE aims for keeping products, components and materials in circulation for as long as possible and with highest value as possible through strategies such as reuse and recycling, environmental sustainability’s goal is to reduce the harm on the earth’s ecosystem by reducing waste and other negative outputs, such as CO₂ emissions (Blum et al., 2020; Lieder and Rashid, 2016).

This conceptual difference could lead to undesired outcomes when applying circular strategies. For example, the processing of an end-of-life product must be considered from both perspectives: From a circular one, it is desirable to maximize the circulation of this product, e.g., through closed-loop reverse flows (e.g., repair, recycling) or open-loop forward-cascaded flows into other SCs (Batista et al., 2018), aiming for a reduction in virgin material use. Indeed, even longer-existing waste that cannot yet be recycled could later become a new resource source as new technologies are developed and adopted in the CSC (Burlakovs et al., 2018). These processes may require additional transportation, have higher energy consumption, use new materials, apply toxins or produce waste that should be minimized from the environmental perspective (Braun et al., 2021). While the circular performance perspective strives to maximize the circulation (for the most part regardless of the environmental outcomes), the environmental performance perspective aims to minimize the damage on the earth’s ecosystem. Only when both perspectives and their goals and methods are considered simultaneously (in addition to the economic and social perspective) can circular actions be truly sustainable (Blum et al., 2020).

Figure 2 shows a graphical illustration of this alignment between these two different goals and provides a reference for harmonizing the two perspectives of circular and environmental performance.
Conceptual Framework for Performance Measurement for Circular Supply

Based on the circular SCOR processes and the differentiation between circular and environmental sustainability, Table 2 presents the proposed framework for measuring the performance of CSCs. This table illustrates the measurement approaches for each circular process in each performance perspective. It follows the same rationale as the initially developed SCOR processes, providing a process attribute or objective and possible measures to assess the performance of the respective perspective.

It is important to emphasize that the developed framework is of conceptual nature and therefore should be understood as a generic framework that can be used as guidance for measuring the performance of CSCs. It is the first step toward developing a necessary PMS that takes all four dimensions into account and forms a basis for further development (Blum et al., 2020). The measures developed represent approaches to performance evaluation and need to be adapted to the CSC by decision-makers in specific use cases. Some of the measures will be more applicable than other, more specific measures.

Considering the requirements for PMSs for CSCs (Vegter et al., 2021), the framework proposed here has strengths and weaknesses. By including a perspective for CE and a perspective for each sustainability dimension, the PMS holistically captures the specific characteristics of the CSC. Especially the clear differentiation between circular (maximizing material circulation) and environmental (minimizing harm on the earth’s ecosystem) performance represents a step beyond other PMSs. Furthermore, the framework also includes a set of social measures that are so far underrepresented and thus fills a critical gap in PMS research.

In addition to that, the PMS aims for a systematic horizontal integration that aligns measures along all processes of the CSC. As Vegter et al. (2021) criticize, so far, no PMS for CSCs includes the processes plan and enable into its PM. Since the proposed framework is based on the adapted SCOR processes for CSCs, various measures per process are developed, covering the entire SC in its circular characteristics.

Nevertheless, not all requirements developed by Vegter et al. (2021) were met. For once, the range of measures is not limited, nor is it very balanced. Yet, the PMS proposed here is to be understood as a generic framework that is still in the development phase, intended to build the basis for further research. Same applies for the – at least not clearly explicitly mentioned – vertical integration.
### Table 2 – Conceptual Performance Measurement Framework (Source: Authors)

<table>
<thead>
<tr>
<th>Process</th>
<th>Attribute / Objective</th>
<th>Measures</th>
<th>Sources</th>
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<tbody>
<tr>
<td><strong>Circular Performance</strong></td>
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<tr>
<td><strong>Plan</strong></td>
<td>Plan for circularity implementation along the supply chain</td>
<td>Procedure Reliability, Availability of assets/equipment, Possibility of ad-hoc decision making, Capacity utilization rate</td>
<td>Ghazoul et al. (2021)</td>
</tr>
<tr>
<td></td>
<td>Sourcing of compatible inputs for circularity with minimized resource extraction</td>
<td>Source cost, Sourcing costs secondary inputs + products, Fraction secondary sourcing + primary sourcing costs, Input availability, Reliability and quality of supply (primary + secondary)</td>
<td>Calciati et al. (2022), Faneque et al. (2022)</td>
</tr>
<tr>
<td></td>
<td>Manufacturing of products capable being circulated</td>
<td>Production costs; Production time; Standardized production (process + product); Flexibility of material input; Substitution ability of inputs; Dependency on products/inputs</td>
<td>Kalimahono et al. (2018), Calciati et al. (2022), Faneque et al. (2022)</td>
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<tr>
<td></td>
<td>Efficient combination of delivery and take-backs</td>
<td>Routing costs; Packaging costs; Delivery time / delay; Flexibility of order scheduling</td>
<td>Kezenko et al. (2019), Ansell et al. (2020), Calciati et al. (2022)</td>
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<tr>
<td></td>
<td>Prolonging product life and use</td>
<td>Amount of needed repairs; Warranty replacement costs; Repair, upgrade and maintenance services; After-sales-service costs</td>
<td>Kezenko et al. (2019), Ansell et al. (2020), Burm et al. (2020)</td>
</tr>
<tr>
<td></td>
<td>Reclaiming of end-of-life products</td>
<td>Amount of returned products; Recovery costs; Energy costs</td>
<td>Kezenko et al. (2019)</td>
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<tr>
<td><strong>Economic Performance</strong></td>
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<td></td>
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</tr>
<tr>
<td><strong>Plan</strong></td>
<td>Plan for economic sustainability along the circular supply chain</td>
<td>Process Reliability, Availability of assets/equipment, Possibility of ad-hoc decision making, Capacity utilization rate</td>
<td>Ghazoul et al. (2021)</td>
</tr>
<tr>
<td></td>
<td>Sourcing of cost-efficient and reliable inputs for circular production</td>
<td>Source cost, Sourcing costs secondary inputs + products, Fraction secondary sourcing + primary sourcing costs, Input availability, Reliability and quality of supply (primary + secondary)</td>
<td>Calciati et al. (2022), Faneque et al. (2022)</td>
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<tr>
<td></td>
<td>Cost-efficient manufacturing of high qualitative, circular products</td>
<td>Production costs; Production time; Standardized production (process + product); Flexibility of material input; Substitution ability of inputs; Dependency on products/inputs</td>
<td>Kalimahono et al. (2018), Calciati et al. (2022), Faneque et al. (2022)</td>
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<tr>
<td><strong>Source</strong></td>
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<tr>
<td><strong>Make</strong></td>
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<td><strong>Deliver</strong></td>
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<td><strong>Use</strong></td>
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<td><strong>Return</strong></td>
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<tr>
<td><strong>Recover</strong></td>
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<tr>
<td><strong>Enable</strong></td>
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<tr>
<td></td>
<td>Enabling circular management of the supply chain</td>
<td>Corporate Circular Reporting (VNI); Identification of explicit circular performance goals, Identification of circular performance barriers, Circular product design, PA2 for further regeneration/reconstruction; Fraction of shared SC assets; Technology application &amp; IT implementation readiness; Increase of usability of waste and by-products; Implementation of reverse take-back systems</td>
<td>EMA Foundation (2019), Kalimahono et al. (2018), Ansell et al. (2020), Lenesa &amp; Manoos et al. (2022)</td>
</tr>
</tbody>
</table>
Although a certain hierarchical structure has already been created through the SCOR processes (e.g., the process plan was interpreted more operational than strategic, especially compared to the process enable), it was not yet possible to assign the measures to the different hierarchical levels. This will also be a future research opportunity. Lastly, apart from the distinction between circularity and (environmental) sustainability, possible interdependencies among measures and perspectives were not yet critically investigated. In the context of process recover, for example, the measures from the four...
perspectives may have conflicting goals. From a circular perspective, one goal is to maximize the reprocessing of waste generated in previous processes. From an economic perspective, one goal is to minimize the costs incurred by these reprocessing activities. Both the environmental and social perspectives aim to minimize the harmful consequences of this regeneration. To reconcile these conflicting goals, interdependencies or perhaps even complementarities must be explored to holistically improve CSC performance.

Conclusion and Future Research Opportunities

PM for SCs in the CE era is – despite its relevance for the transition from linearity to circularity – an underexplored research field and literature on explicit PMSs for CSCs is scarce (Vegter et al., 2021). This paper is an attempt to fill this gap by conceptualizing a PMS that holistically depicts the CSC. Based on adapted SCOR processes for circularity, it provides a horizontally integrated composition of performance measures to comprehensively assess the CSC’s performance from an economic, environmental, social and circular perspective. Additionally, an attempt was made to clearly differentiate circular and environmental performance perspectives, enabling a clarification for the complex relationship between circularity and sustainability.

The conceptualized framework can serve as guidance and help practitioners to rigorously evaluate the performance of a CSC. By doing so, it supports the further transition from linearity to circularity. The framework can also support other researchers by supplying a theoretical concept for conducting empirical research on this matter, further driving the theoretical knowledge base of the CSC.

Future research opportunities lie in the adoption of a digital performance perspective, depicting the impact of digital technology on the CSC performance. In particular, the blockchain technology, which enhances the SC transparency and traceability to support the performance monitoring and reporting (Esmaeilian et al., 2020) and thus provides better assurance of fair labor and human rights practices (social perspective) (Saberi et al., 2018) is a promising digital technology within the CSC context. Nevertheless, digital technologies also have drawbacks like the huge energy consumption (Esmaeilian et al., 2020) and consequently high CO$_2$ emission (environmental perspective). Another interesting aspect is the role of digital platforms for business collaboration, where the holistic perspective of sustainable performance could be integrated as a sustainability guide for decision makers.
DECLARATIONS

Competing interests The author declares no competing interests.

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