Criteria to Support the Transition Towards Circular Supply Chains – Integrating Legal, Practical and Academic Perspectives

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Circular Economy (CE) has emerged as a trend in both practical and academic discourse and has recently been adopted into core EU sustainability legislation such as the Eco-Design Directive. Redesigning supply chains to incorporate principles of circularity bears the potential to enhance sustainability performance. However, to date, holistic, inclusive, and versatile frameworks that support this redesign are missing. Based on this, the present paper introduces such a framework and discusses the current state and comprehensiveness of its included metrics. An analysis of documents stemming from academic, practical and legal discourses was conducted in order to identify CE criteria and indicators, and consequently, these were synthesised in an integrated framework. The framework contains 29 categories, 73 criteria and 408 potential indicators assigned to the four dimensions: "Environmental", "Economic", "Social" and "Governance". The integration of the different discourses enabled the development of a comprehensive set covering a wide range of metrics. Still, some important content gaps and methodological limitations have been identified that should be rectified to further refine the framework.

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1 Introduction

In today's interconnected economy, companies across various sectors participate in global supply and value chains (GSVCs). This poses different sustainability challenges and therefore, various stakeholder groups as well as core legislative frameworks of the EU Green Deal increasingly demand the reporting, monitoring and enhancement of the sustainability performance in GSVCs. Related to this, the circular economy (CE) has been introduced as a normative framework in both practical and academic sustainability discourse. CE-related aspects have also been recently adopted into core EU sustainability legislation, such as the Eco-Design Directive or the Corporate Sustainability Reporting Directive (CSRD). Therefore, companies nowadays are increasingly challenged to enhance both the overall sustainability performance of GSVCs as well as integrating CE-related principles into their operations.

While redesigning supply chains to incorporate principles of circularity bears the potential to enhance sustainability performance (Agyabeng-Mensah et al., 2023), the pursuit of such transformation mandates a deeper understanding of the environmental, social and economic aspects and measures decision-makers need to consider and prioritise in global supply chain management. The importance of key performance indicators (KPIs) and measurement frameworks to assess and enhance sustainability performance in supply chain management has been widely acknowledged (Panigrahi et al., 2019). However, existing assessment frameworks often exhibit critical shortfalls, such as inadequate adaptability to specific industry needs (Toubolic & Walker, 2015) or a lack of consideration of particular sustainability dimensions (Negri et al., 2021). Also, assessment frameworks for general sustainability performance and circularity performance seem so far to be somewhat disconnected (Allen et al., 2021) as sustainability frameworks fail to integrate circularity metrics comprehensively. These gaps highlight the pressing need to develop more holistic, inclusive, and versatile frameworks that support the transition to circular supply chains.

This paper aims to contribute to fulfilling this need. It presents an integrated framework, developed by identifying and synthesising currently discussed CE criteria and indicators in both academic literature as well as documents stemming from the practical and legal realm, and discusses the current state and

comprehensiveness of included metrics. The framework can serve as a basis for industry-specific performance measurement sets and further development of strategies for circular supply chain (CSC) management. The rest of the paper is structured in the following way: First, the core concepts of CE and CSCs, which serve as a background for the research, are discussed (Ch. 2). Then, the methodology (Ch. 3) and the results of the study (Ch. 4) are presented, before the paper ends with a discussion (Ch. 5) and conclusion (Ch. 6).

2 Core concepts: circular economy and circular supply chains

There are different approaches to conceptualising the CE, but most definitions focus on the minimisation of waste and resource use by circulating products and materials within the economy for as long as possible. In accordance with this, Kirchherr et al. (2017, p. 229) define CE as "… an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes." Furthermore, CE operates at the micro, meso and macro level and is enabled by novel business models and responsible consumers (Bressanelli et al., 2019). The so-called '10R-imperatives' prescribe a hierarchical order of strategies for the transition towards a CE (see Figure 1). According to this concept, strategies that aim towards a reduction of resource use and waste generation right from the beginning of a product's lifecycle should be prioritised. Therefore, the highest priority is given to those strategies that lead towards a minimum use of resources by either refusing unnecessary products, intensifying product use or reducing the material intensity of production. In the next step, strategies such as reuse, repair, refurbishment or remanufacturing should be applied to prolong the use of a product or its components before the return of materials through recycling or recovery is considered.

The transition towards a CE has been framed as one of the main strategies for achieving sustainable development (e.g., Murray et al., 2017). In CE literature, supply chains are seen as a key enabler of the CE transition (Lahane et al., 2020). CSCs aim to close, slow and narrow resource loops in their direct or broader realm of activities (Farooque et al., 2019). However, while existing literature mostly provides knowledge on the implementation of CE practices from a micro-perspective (e.g., the company-level) (Ünal et al., 2019), as well as on the barriers and enabling factors from a macro-perspective (e.g., on a policy-level) (Urbinati et al., 2021), the adoption

of CE principles at the level of supply chains is still a poorly explored management topic. A key question in this regard is how supply chain managers can evaluate circular performance and create internal incentives that support the shift towards CSCs (Ellen MacArthur Foundation, 2024). Notably, the development of robust and standardised KPIs for CSCs is still in its infancy. In a literature review of CE indicators for supply chains, Calzolari et al. (2022) indicate a lack of consensus on which metrics and methods best capture circular performance, signalling a need for research into adaptable, industry-specific KPIs that can reliably drive circular practices. With CE indicators for supply chains stemming from different academic threads, the literature on CSC indicators is still very fragmented. In addition, Morseletto (2020) points towards the necessity of investigating not only existing but also possible or advisable CE targets which have not yet been applied in practice. Arguably, new targets are needed because existing ones only generally cover limited arrays of CE solutions, such as recycling or efficiency improvement.

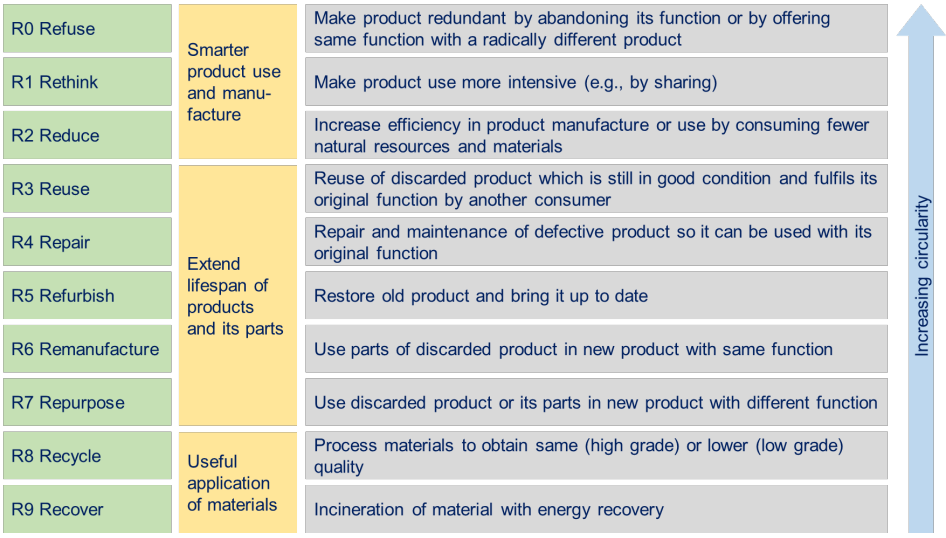

Figure 1: 10R-Strategies (Kirchherr et al., 2017)

3 Methodology

The framework development comprised a three-step procedure: First, a collection of relevant documents from the political, practical and academic CE discourse serving as a basis for the extraction of criteria and indicators took place. The final

selection included four legal regulations, two practical and six currently published academic frameworks. Second, these documents were analysed with regard to the included criteria and indicators and the information identified was listed. Third, the listed aspects were synthesised in an integrated framework covering four different levels: dimensions, categories, criteria and indicators. While dimensions represent overarching fields of topics in the area of sustainability, categories designate individual subject areas contained in these dimensions. Based on widely used concepts such as the Triple-Bottom-Line and the ESG principles, the four dimensions "Environmental", "Economic", "Social" and "Governance" have been incorporated into the framework. Criteria show targets within the individual categories that are aimed at improving sustainability, and indicators represent information that can be used for their measurement. After the framework development, additional analyses were conducted in order to assess the current state and comprehensiveness of included metrics: The numbers of categories, criteria and indicators were determined and evaluated on an overall and dimension-specific level. Beyond that, the CE specificity of each indicator, as well as its affiliation to the R-strategies, was assessed and the assessment results analysed descriptively.

4 Results

The integrated framework developed in this study contains 29 categories, 73 criteria and 408 potential indicators assigned to the four dimensions "Environmental", "Economic", "Social" and "Governance". Table 1 presents the concrete numbers of categories, criteria and potential indicators assigned to each dimension. The *environmental dimension* deals with topics such as material resources, waste, water, and energy, as well as products and services offered. It comprises criteria, for example, as reduced waste generation and use of material resources, as well as an environmentally friendly and circular product design. The material intensity represents an exemplary indicator identified in this dimension. The categories within the *economic dimension* are addressing classic economically relevant topics such as costs, revenues and efficiency. The associated criteria cover goals such as a reduction of costs and risks, an increase of revenues and the efficient use of supply chain assets. A potential indicator is the revenue generated from upgrade, repair and maintenance services of products. The *governance dimension* covers topics such as sustainable management, strategy and planning as well as external engagement. It comprises criteria, for example, as an alignment of the company strategy to CE and an

engagement with policymakers to support the transition to a CE. The latter can be measured, for instance, by the existence of verifiable engagement formats. Finally, the *social dimension* comprises the subject areas of health and safety, people and skills, as well as a contribution to the local economy. The criteria assigned to these include aspects such as the provision of decent work, training and other benefits for employees or the safe and reliable product use for customers. An example of the identified indicators is the number of fixed and variable jobs created by the CSC. A summary of the framework can be found in the Appendix.

Table 1: Number of categories, criteria and potential indicators included in framework (own analysis)

Dimension	Categories	Criteria	Potential indicators
Environmental	10	30	228
Economic	11	16	89
Governance	5	18	49
Social	3	9	42

Measured against the numbers presented in Table 1, it can be seen that the CE discourse, when viewed holistically, to date has focused especially on environmental aspects, while social factors have received the least attention. Furthermore, economic and governance aspects seem to be taken into account, however, to a lesser extent than environmental ones. Besides that, when comparing the academic, practical and legal discourse, it is noticeable that the scientific literature has produced the most comprehensive frameworks to date, followed by the practical approaches and finally the legal regulations. While all three strands cover the environmental dimension, albeit to varying degrees, the economic and social dimensions in particular appear to have received little consideration in the practical and legal frameworks. In addition, gover-nance aspects appear to have been addressed relatively comprehensively only in the practical discourse. Finally, only a small number of criteria have been taken up in all three different discourses, primarily stemming from the environmental (e.g., increase of material circularity) and partially from the governance dimension (e.g., setting targets for CE transition).

Table 2: Distribution of indicators with regard to reference levels (own analysis)

Level of reference	Absolute frequency	Relative frequency
CE-specific assessment	152	37%
General sustainability assessment	142	35%
Both	114	28%

The investigation into whether the identified 408 indicators relate more to a CE-specific or general sustainability assessment reveals the following (see Table 2): More than a third of the indicators can be assigned to one of the two categories. In addition, just under a third of the indicators relate to both approaches.

Finally, when analysing the relation of each indicator to the ten R-Strategies described in chapter 2, the following picture appears (see Table 3): Although the first two R-Strategies (R0-Refuse and R1-Rethink) represent the most important from a CE perspective, up to now they are essentially not covered in legal, practical and scientific frameworks. No indicator related to R0 was present; only three indicators related to R1 have been identified. Furthermore, all other strategies that are lower in the hierarchy than these two (R2-R9) receive more attention, with strategies R4 (Repair) and R8 (Recycle) having the greatest prominence.

Table 3: Indicators' relations to R-Strategies (own analysis)

Relation to R-Strategy	N/A	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9
Absolute frequency	218	0	3	61	54	89	68	63	60	81	48

5 Discussion

The integrated framework described in the previous chapter presents a broad set of criteria and indicators to support the transition to circular GSVCs. By bringing together different discourses with different foci in relation to CE criteria and indicators, it has been possible to develop a comprehensive catalogue that addresses various relevant dimensions. In addition to CE-specific aspects, the framework also includes more general sustainability-related aspects. This counter-acts the disconnection problem between general sustainability performance and circularity performance assessment frameworks and enables a synergistic consideration of circularity and other sustainability aspects. The integration of legal, practical and

academic perspectives has thus proven to be an effective approach to provide a more holistic view.

Despite these positive aspects and the existing breadth of the set, some gaps have been identi-fied. On the one hand, this concerns the need for greater elaboration of the social dimension. On the other hand, further criteria and indicators need to be integrated that relate to the most important, but so far hardly considered, R-Strategies R0 and R1. The latter underlines the already emphasised need in literature to integrate new targets that go beyond recycling and efficiency improvement approaches. However, it should be noted that these strategies are associated with business model transformations, and therefore, the extent to which supply chain management is a good starting point for this must be examined. Beyond that, when looking more detailed at the level of indicators, it becomes obvious that some indicators are not yet specified enough to enable clear measurement and therefore need specification (e.g., "water emissions"). In addition, there are sometimes only subtle differences between various indicators, highlighting the need to identify the most suitable ones. While the breadth of the existing set can certainly be seen as a strength in the sense of comprehensiveness, it also represents a challenge for implementation in business practice. A future reduction of the framework to prioritised aspects, determined, for example, with the help of a participatory research approach, could provide a remedy here. Besides these content-related challenges, some methodological limitations are also present: As the framework developed is based on a limited selection of 12 documents, it is possible that additional important aspects from other references have not been included. Furthermore, all statements made in the previous and this chapter refer to the analysis of these selected sources and therefore only hold true for them. An enrichment with other documents is therefore advisable. In addition, when considering the demarcation of the foci of the academic, practical and legal discourse, it should be kept in mind that these also have links to each other. Another important methodological limitation is the subjectivity in the formation of clusters and assignments to them as part of the framework creation. This could be counteracted with a future external validation with experts. Finally, in very rare cases, it was not possible to incorporate identified information into the framework due to its lack of clarity. This could be rectified in future by contacting the original authors and consulting with them.

6 Conclusion

This paper dealt with the presentation and analysis of a framework to support the incorporation of circularity principles in GSVCs. It was shown that the framework covers a wide range of metrics (73 criteria and 408 potential indicators in 29 categories and four dimensions), which was made possible by the integration of three different discourses (science, practice, law). In the medium term, the framework can serve as a basis for developing industry-specific performance measurement sets and/or deriving management strategies. However, before this is implemented, future work should refine the framework by addressing important content and methodological limitations identified during the analysis. In the long term, the use of such a framework has important implications for the GSVC practice. It goes hand in hand with changes in various areas such as product design, procurement or cross-industry collaboration. Overall, the authors hope to have created a good basis for promoting more circularity and sustainability in GSVCs in the future, even if the framework still needs further refinement and therefore represents a work in progress.

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Appendix: framework summary

Category	Criterion	Exemplary indicator
Material resources	Reduce use of material resources in general	Material intensity: Amount of kg materials per product
	Decrease use of harmful/hazardous/ critical materials	% Critical inflow: (Mass of inflow defined as critical/ total mass of linear inflow) * 100
	Decrease materials' environmental impact	Materials environmental impact: Average eco-cost per kg of material
	Decrease processing environmental impact	Processing environmental impact: Average eco-cost of processing per kg of material
	Increase use of recyclable material	Fraction of cost spent on recyclable material to total cost of material
	Increase material circularity	Material circularity: (Weighted) average percentage of circular inflow and percentage of circular outflow
	Increase overall circularity	Number of circular processes/circularity gaps
Waste	Reduce waste generation	Amount of kg waste directed to disposal for landfilling, incineration or other disposal operations
	Implement environmentally sound waste management	Use of best available techniques in waste management as guiding principles
Water	Reduce water use	Water use
	Increase water circularity	Circular water use: % (by volume) of water annually used reused elsewhere
	Improve water treatment	Existence of plans to extract surplus nutrients, metals, chemicals, heat and similar valuable resources before discharging the water used
Energy	Decrease energy consumption/use of energy	Cumulative energy use
	Increase energy efficiency	Fraction of energy loss
	Use energy from renewable sources	Fraction of energy purchased from renewable sources
Land & biodiver-sity	Reduce land use change impact	Impact on deforestation
	Reduce soil use/depletion	Soil use in production
Air	Reduce air emissions	Total eco-cost of fine dust and summer smog
Plant, property, equipment and assets	Decrease inventory	Amount of inventory in kg materials at a specific point in time
	Use “green” equipment/technology	Acquisition of long-lasting and durable equipment
	Use plant, property, equipment and assets that support circular products and services	Description of management status on digital systems that support circular products or services
	Use circular assets	Acquisition of second-hand equipment
	Apply circular asset management	Policies or agreements in place that enable recirculation for the end-of-use of assets in practice
Carbon footprint	Reduce CO_2e emissions	Total GHG produced per kg product

Category	Criterion	Exemplary indicator
Product	Environmentally friendly and circular product design	Product lifetime: The time period the product functions as desired by the user
	Environmentally friendly product delivery	Number of empty trips in delivery
	Environmentally friendly product use	Availability of environmental instructions
	Maintenance of functional performance	Precautions for use
	Product recovery	Rate of actual product recovery by recovery type
Services	Availability of services to enhance environmental sustainability and circularity	Provision of technical support
Costs	Reduce costs	Average materials price per kg of material
Revenues	Increase revenues	Revenue from upgrade, repair and maintenance services of products
Profits	Increase profits	Profits from recovery activities, including remanufacturing, recycling and disposal
Growth	Increase market share	Market share
Profita-bility	Increase profitability	Rate of return on capital
Risk	Reduce risks	Availability of assets/equipment
Efficiency	Increase the efficient use of supply chain assets	Capacity utilisation: Output in kg materials per time period/Total available capacity in kg materials per time period
	Increase time-efficiency	Production time
Producti-vity	Decoupling of financial performance and linear resource consumption	Circular material productivity: Revenue/Total mass of linear inflow
Quality	Increase quality	Quality level of production
Customer	Increase customer satisfaction	Customer satisfaction
	Increase customer loyalty	Customer loyalty
	Increase customer purchase intention	Customer purchase intention
	Increase customer retention	Customer retention
Finance & invest-ments	Sustainable investments	Capital invested in sustainable solutions
	Finance for circularity	Fraction of cost spent on CE technology to total cost of investments
Health and safety	Employee-related health and safety compliance	Number of accidents/incidents in manufacturing
	Safe and reliable product use for customers	Number of incidents of consumer complaints
People and skills	Increase in training	Amount of training provided on CE
	Provision of employment opportunities	CSC jobs created: Number of fixed and variable jobs
	Provision of decent work	Fair wage level
	Provision of benefits for employees	Expenditure on benefits for employees
Contribu-tion to local economy	Increase ethical and local sourcing	Fraction of local suppliers
	Increase donations to local communities	Donations to local communities

Category	Criterion	Exemplary indicator
	Foster socially compatible recovery processes	Fraction of domestic value recovery
Sustain-able manage-ment	Implement economically sustainable management (of CSC)	Identification of explicit economic performance goals
	Implement environmentally sustainable management (of CSC)	Identification of explicit environmental performance goals
	Implement socially sustainable management (of CSC)	Identification of explicit social performance goals
Communi-cation	Sensibilise workforce about CE-related topics	Internal communication channels used for CE messaging
Innovation	Involve leadership in supporting CE innovation/development projects	Individuals leading innovation projects have the mandate from top management to work on CE innovation and regularly report to top management on circular innovation KPIs
	Embed CE principles in innovation/development projects	Existence of tools for supporting CE innovation/development projects
	Collaborate on circular innovation/development projects	Existence of formal collaboration structures
	Integrate relevant data into circular innovation/development projects	Existence of data systems for supporting circular innovation/development projects
Strategy and planning	Centrality of CE to the CEO's agenda	Mentioning of CE (or relevant concepts) in external communication
	Align company strategy to CE	Mentioning of CE (or relevant concepts) in strategy documents
	Set targets for CE transition	Identification of explicit circular performance goals
	Support CE implementation	Corporate Circular Reporting (Y/N)
	Be transparent	Public availability of CE-related company documents
External engage-ment	Engagement with suppliers to increase sourcing based on CE principles	Existence of verifiable formats of engagement
	Engagement with customers advancing CE topics	Existence of verifiable formats of engagement
	Engagement with policymakers to support the transition to a CE	Existence of verifiable formats of engagement
	Engagement with external investors and/or financiers on CE topics	Existence of verifiable formats of engagement
	Membership or active engagement with CE-related initiatives	Proof of membership or active engagement
Legend: Green = Environmental dimension; Grey = Economic dimension; Orange = Social dimension; Blue = Governance dimension		

Category	Criterion	Exemplary indicator
References: *Legal regulations* – ESRS 5 of CSRD (European Commission, 2022); EU Regulation on Shipment of Waste (European Commission, 2024a); Ecodesign Directive (European Commission, 2024b); EU Right-to-Repair Directive (European Commission, 2024c); *Practical frameworks* – Circulytics (Ellen MacArthur Foundation, 2020); CTI (World Business Council for Sustainable Development, 2023); *Academic frameworks* – Calzolari et al., 2022; Lahane et al., 2024; Lee et al., 2024; Montag & Pettau, 2022; Primadasa et al., 2024; Vegter et al., 2023		