H2020 MSCA-ITN-2018

ReTraCE Project

Realising the **Tra**nsition towards the **C**ircular **E**conomy

D1.1

Measuring the transition towards circular supply chains: insights from academic literature and industrial practice

This project has received funding from the European Union's Horizon 2020 research and innovation proframme under the Marie Sklodowska-Curie Innovative Training Network (H2020-MSCA-ITN-2018) scheme, grant agreement number 814247 (ReTrace)

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List of acronyms

CE – Circular Economy

CLSC – Closed-Loop Supply Chain

CLSCM – Closed-Loop Supply Chain Management

CS – Corporate Sustainability

CSC – Circular Supply Chain

CSCM – Circular Supply Chain Management

DST – Decision-Support Tools

GRI – Global Reporting Initiative

GSCM – Green Supply Chain Management

KPI – Key Performance Indicator

LCA – Life Cycle Assessment

EMA – EMergy Accounting

EoL – End of Life

MNE – Multi-National-Enterprise

RL – Reverse Logistics

SCM – Supply Chain Management

SCN – Supply Chain Network

SSCM – Sustainable Supply Chain Management

TBL – Triple Bottom Line

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1. General purpose and objectives of the report

In the last decades, supply chains have operated according to a very linear paradigm, based on the extraction and unsustainable use of natural resources. Such a mode of production has been causing irreversible ecological damage, as half of the total greenhouse gas emissions and more than 90% of biodiversity and water losses are related to resource extraction and processing (European Commission, 2020).

In the new Circular Economy Action Plan, which constitutes one of the main building blocks of the Green Deal (European Commission, 2020), the European Union recognises a primary role for bottom-up industrial initiatives in order to build a *greener and more competitive* Europe. Organisations are encouraged to drive the transition towards the Circular Economy (CE) in supply chains through the adoption of appropriate practices. Recommendations include: the manufacturing of sustainable goods that should be easy to repair; the adoption of solutions aimed at extending product life-time; the promotion of remanufacturing and recycling in subsequent feedback loops. The expected results from these policies include a sharp increase in materials reuse and recycling in the next decade, which could potentially contribute to the *climate neutrality* objective by 2050.

Circular Supply Chains (CSC) constitute the operational backbone of the CE concept at the micro- and meso-level. The complex transition of supply chains from a linear configuration to a more circular one should take into consideration all related environmental and social impacts. Indeed, there are many metrics available to measure resource productivity, waste generation, energy consumption, and greenhouse gas emissions. However, existing metrics do not fully cover the adherence of supply chains to the CE paradigm. Also, there is not an established measurement approach that can be used to comprehensively evaluate the 'degree of circularity' of a supply chain and the benefits of alternative CSC configurations.

The ReTraCE project aims to progress understanding of how the transition towards a CE can be successfully realised in the European context, not only through innovative and sustainable business models, but also through the transformation of the current supply chain structure. A critical evaluation of the outcomes of CE implementation represents one of the major research gaps that will be addressed by this project. It is therefore important that we have models and tools to compare and assess the performances of linear and circular production systems using a wide range of sustainability indicators. The proposed approach within the ReTraCE project is multi-disciplinary, drawing upon different work packages that will significantly advance the CE paradigm from an economic, environmental and social standpoint.

This report is part of the Work Package 1 (WP1: Circular Production and Consumption Systems) of the ReTraCE project, which focuses on Supply Chain Management (SCM) aspects within the CE paradigm. CSC management (CSCM) carries several economic, social and environmental issues and implications as the operationalisation of a CSC entails the involvement of multiple actors which operate across global value chains and production systems. This drives the complexity of the effective design and operation of CSC.

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This analysis represents a first step towards the development of decision support tools for designing and evaluating CSCs, by pointing out the research gaps in the literature and identifying the practitioner's requirements. As such, it will contribute towards the first objective (O1.1) of WP1, which is to establish a decision support framework aimed at measuring the 'circularity quotient' of a supply chain. In this context, the report also represents the first Deliverable (D1.1) of WP1 and provides a starting point for ReTraCE's efforts on advancing knowledge on CSCM. This report will directly support ReTraCE deliverable D1.5, regarding the development of a decision-making tool to measure the 'circularity quotient' of a supply chain. It will also inform a set of modelling tools for the design and planning of CSCs (D1.6).

The document is organised as follows: the aim of Section 2 is to provide an overview of the emergence of the CE discourse in supply chains. In section 3, CE practices implemented in the main industries in Europe are discussed. Section 4 introduces how CE is measured in supply chains considering both academic literature and industrial practice. In section 5, some final insights are provided, including the proposal of an ideal composite CE indicator for a supply chain.

2. Circular supply chains and production systems: an overview

In the CE paradigm every economic activity is designed and planned to maximise ecosystem functioning and human well-being (Murray et al., 2017). As such, the frontiers of environmental sustainability are pushed forward, and products are transformed in such a way that there are workable relationships between ecological systems, economic growth and human well-being. Therefore, CE is not just concerned with diverting society from using the environment as a residual sink, but rather with the creation of self-sustaining production systems in which materials are used over and over again (Genovese et al., 2017a). Circular production systems should also take into consideration the environmental and social costs of the externalities associated with the depletion of resources that are used (Andersen, 2007). However, the fact that these costs are not usually incorporated in prices and in market transactions constitutes a significant barrier to implementing circular production systems (Webster, 2017).

Because of the benefits of circular supply chains, it is unsurprising that manufacturing industries have recently been placing more emphasis on achieving sustainable production, by shifting from simple mitigation actions to a focus on prevention of environmental damages, based on whole lifecycle assessments and integrated environmental strategies and management systems. This trend has become apparent also in the academic literature focused on supply chain management (Genovese et al., 2017a).

This chapter provides an illustration of the emergence of CE discourse in the supply chain management domain. It then provides a brief overview of the academic literature, focusing on approaches which have been developed in order to measure the transition towards CSCs, highlighting related research gaps.

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2.1. The origins of the CE discourse in supply chains

Several research streams have contributed to the emergence of the CE discourse in the Supply Chain Management literature, namely Industrial Ecology (IE), Green and Sustainable Supply Chain Management (from now on also GSCM and SSCM) and Closed-Loop Supply Chain Management (CLSCM). Many scholars claim that the first elements have arisen in the IE literature (Kohrnen et al., 2018). Focusing on the interchange of resources and waste streams within clusters of firms, IE gave rise to Industrial Symbiosis networks, which are considered an early prototype of closed-loop supply chains (Ghisellini et al., 2016).

Also, in the last decades, GSCM and SSCM practices have emerged, trying to integrate environmental and social concerns into organisations by reducing unintended negative consequences of production and consumption processes. GSCM practices include five major elements: green purchasing, eco-design or design for the environment, internal environmental management, customer cooperation for environmental concerns, and investment recovery (Liu et al., 2018a). Green Supply Chains are an important unit of action towards CE (Aminoff and Kettunen, 2016), even if an explicit mention of CE practices was absent in this sub-field in the literature, until recently.

At the micro level of a single organisation, CE interventions support the design of reverse supply chains, recycling, reusing or remanufacturing end-of-life products (Stahel, 2016). This has been reflected in another literature stream, concerned with reverse logistics (RL) and closed-loop supply chains (CLSCs). CLSCs deal with the practice of taking back products from customers and returning them to the original manufacturer for the recovery of added value by reusing the whole product or part of it (Batista et al., 2018). The original objective of the RL and CLSC management literature is strictly related to the economic dimension: to manage the recovery of after-use products (or even, in the case of the fashion industry, the recovery of returned products) in order to capture additional economic value, which can be obtained by keeping resources in use.

As such, advanced CSCs should incorporate elements from all the literature streams discussed above, in an attempt to:

- Operationalise production methods that account for the full life cycle cost (including environmental and social dimensions) for goods and services;
- Developing a holistic system perspective, enabling full visibility for all actors, processes and materials involved in the manufacturing process, in order to understand hotspots in terms of environmental impacts, resource consumption and waste creation;
- Enable regenerative and restorative processes to valorise material flows and waste as a resource according to an Industrial Ecology view. CSCs have the ambition of extending resource exchange and efficiency dynamics even outside the border of localised Industrial Symbiosis networks.

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2.2. Circular Supply Chains: Key definitions

Circular supply chains, which are illustrated in Figure 2.1, can activate metabolisms that allow for methods of production that are self-sustaining and in which materials are used multiple times. This is possible by emphasising: product, parts and material reuse; material recycling; the use of renewable energy sources throughout supply chains (Bocken et al., 2015).

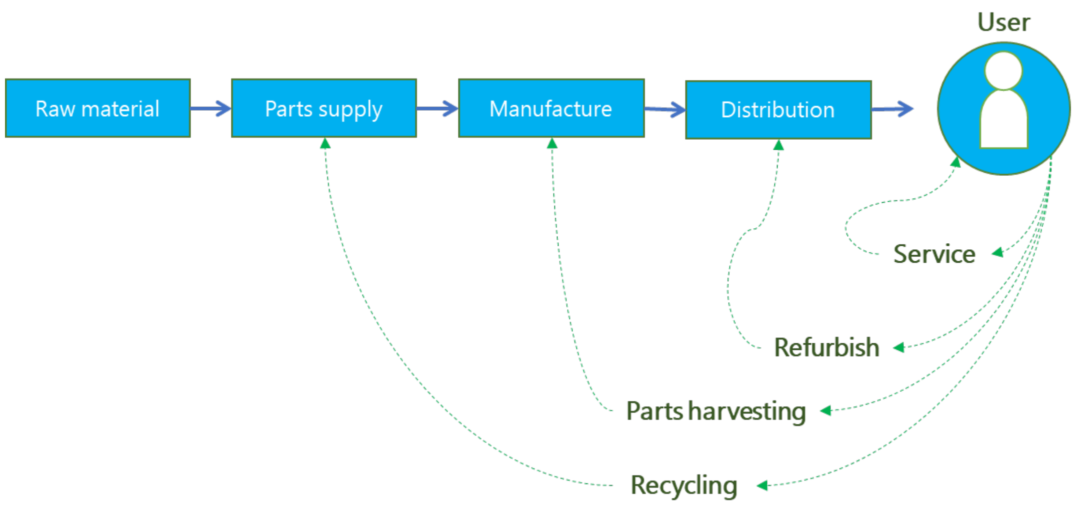

Figure 2.1 – Forward and reverse activities in a Circular Supply Chain

According to Batista et al. (2018), CSCs can be viewed as systems based on:

- the minimisation of waste disposal processes through reusing, repairing, remanufacturing and recycling processes;
- the delivery of functionality and experience (value in use), rather than product ownership;
- the promotion of management approaches that build upon a collaborative or shared consumption model.

While the literature recognises many other frameworks to classify CE practices (e.g. 3R, 9R), the 4R framework represents the core of the European Union Waste Framework Directive (European Commission, 2008). The first R identifies r*educe* practices, which prevent resource use, either by redefining product functions, or through rethinking and redesigning goods and services. Examples of such practices include: the redesign of products or their packaging; the promotion of modular product design; the redesign of manufacturing infrastructure; the promotion of collaborative consumption practices (e.g., those based on a 'sharing economy' paradigm); the move towards a performance-based or service-based business model, rather than one based on simple products.

Reuse practices include repairing, preventive maintenance and refurbishing actions and generally aim to reutilise products (or components) in their original function.

Recycling practices aim at recycling and reprocessing materials from parts or products. Also, the remanufacturing of parts and components falls into this category. Common practices involve: the

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reutilisation of by-products; recycling of parts, components and materials; utilisation of recycled materials; packaging recycling; and investments in recycling infrastructure.

Recover practices involve energy recovery from by-products or waste, either directly or through the production of alternative fuels like biofuels.

2.3. Literature Gaps

The crucial role of supply chains and of inter-firm relationships to support the transition towards the CE has been recognised both by the academic literature and by practitioners (Batista et al., 2018; Aminoff et al., 2016; MacArthur et al., 2015). Nevertheless, previous literature reviews show that most of the research contributions about CE have been mainly focusing on either the macro level (e.g. country, city) or on the micro level (the single firm) (Merli et al., 2018, Ghisellini et al., 2016).

As regards the meso-level, inter-firm relationships have been considered in relation to Eco-Industrial Parks and Industrial Symbiosis networks, where companies that belong to different supply chains become engaged in complex interplays of resource exchange (material, water, energy and by-products).However, Eco-Industrial Parks are not the norm in the European context, which characterised by free-market policies and global, fragmented, and multi-tier supply chains (Cordón et al., 2012). For these reasons, there is a need for further investigation into the potential implementation of circular dynamics in supply chains and the challenges associated with this.

When it comes to the CE implementation in supply chains, a first gap in the current literature includes the lack of standard methods and decision-making tools for identifying CE opportunities within CSCs, and for measuring their performances while designing, planning and managing their operations. Also, there is limited theoretical understanding and discussion of the antecedents (e.g. mechanisms and factors) that could influence the adoption of CE practices in industrial organisations. Established theories in the field of SCM could help researchers to evaluate the effects of both hard (e.g. technology adoption) and soft (e.g. risks and relationships management) aspects in supporting the transition of supply chains towards a more circular configuration.

In the next sub-chapters, these gaps will be examined further in relation to the objective of this report, as well as future objectives associated with ReTraCE WP1.

2.3.1. Establishing TBL indicators for CSCs

The complex transition from linear supply chain configurations to more circular ones requires a variety of impacts to be accounted for, concerning every dimension of sustainability i.e. economic, environmental and social. Existing decision support tools (DSTs) from the traditional SSCM literature constitute a valuable starting point since they incorporate a triple bottom line (TBL) approach and adopt a life-cycle perspective in the evaluation of impacts. Indeed, in the GSCM and SSCM literature, the evaluation of environmental

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impacts makes extensive use of established methods found in environmental science (e.g. LCA, LCC). Some variants of these methods (e.g. hybrid LCA, Multi Regional I/O Frameworks) are also able to rigorously assess the environmental performance of complex and global supply chains (Genovese et al., 2017a; Acquaye et al., 2018). Thanks to these methods, it is possible to determine supply chain *hotspots* (in terms of environmental impacts) using relevant key performance indicators (KPIs), thus identifying areas to be prioritised for action.

However, existing frameworks and current metrics do not fully capture the adherence of supply chains to the CE paradigm. In a CE context, indicators should be able to capture the value of restorative loops to be shared among the supply chain actors (Govindan & Hasanagic, 2018, Aminoff & Kettunen, 2016; MacArthur et al., 2015). Indeed, the primary concern of CE is the creation of metabolisms in production and consumption systems according to a more regenerative and restorative paradigm (Webster, 2017). A higher circularity in the use of materials in supply chains gives organisations access to a wide range of economic benefits: reduced materials costs, greater value extraction from resources and greater resilience thanks to the reduction of the exposure to the risks deriving from linear economic practices (such as the utilisation of scarce and non-renewable virgin resources) (WBCSD, 2019). The environment and society as a whole could also benefit from less energy intensive and less wasteful methods of production; also, shorter supply chains might provide opportunities for local jobs creation (Stahel, 2016).

Nevertheless, the implementation of CE practices in supply chains still requires energy inputs, and could cause non-negligible environmental impacts (Helander, 2019). As such, increased rates of re-use and re-cycling might not correspond to reduced environmental pressures. It must be highlighted, inded, that the operationalisation of CE feedback loops require the activation of facilities (such as processing and disassembling centres, along with remanufacturing plants) and, possibly additional transportation flows. All these activities employ resources, energy, and cause emissions in the environment; all this could give rise to *rebound* effects (promoting, overall, higher resources consumption rates).

Looking at the existing CSCM literature, there are many metrics available to measure resource productivity, waste generation, energy consumption, and greenhouse gas emissions. However, there is no established composite indicator (nor a set of indicators) that evaluates how good different CSC configurations might be with respect to set criteria or goals. Also, there is a lack of decision support tools which could define desirable levels of circularity and establish an ideal direction of evolution for production and consumption systems. In synthesis, a DST for a CSC should be able to:

- identify potential for the regenerative and restorative use of resources;
- measure the key economic, environmental and social impacts of CSCs;
- evaluate opportunities for the reduction of waste streams at different stages of the supply chain.

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Such a DST could have practical implications in supply chain optimisation problems, which deal with the design and the operation of CSCs. More detailed discussion about the indicators used in DSTs for CSCs in the academic literature is provided in Chapter 4.

2.3.2. Employing CE indicators in the design of CSC

An extensive body of the literature (mainly in the field of Operational Research) deals with network design and planning models for CLSCs. An analysis of the literature performed in the context of ReTraCE WP1 shows that, while the number of academic papers published in this sub-field is very large, there are several theoretical and practical gaps.

Most of the existing studies are concerned with strategic decision-making problems, such as the design of product and material flows and the location of facilities (e.g collection facilities). Strategic issues in CLSCs appear to be generally well integrated with tactical ones, like the allocation of flows among different facilities. However, operational issues (e.g. disassembly planning and scheduling) remain disjointed and are not integrated in design problems. Therefore, the development of novel approaches to incorporate all three types of decisions seems to be a considerable gap in the literature. This is particularly relevant considering that most of the studies are not implementing solution approaches to genuine industrial cases and might lack ignore real-life constraints.

Furthermore, most of the papers deal with economic objectives, while environmental objectives are implemented through very simple measures, and social aims seem to be completely absent from the literature. The absence of specific CE indicators in network design models can be considered a serious weakness of the existing models. While they might be effective at satisfying multiple and conflicting objectives linked to designing sustainable operations, they might not optimise the regenerative capability of the supply chain in the use of resources.

2.3.3. Explaining the performance of CSC

Another important gap in the CSCM literature is represented by a limited theoretical understanding of the antecedents behind the adoption of CE practices. The consideration of some organisational or structural factors might be able to explain the higher inclination to implement CE practices in organisations which are accompanied by better sustainability performance according to related indicators. Moreover, certain factors or configurations of supply chains could facilitate the transition towards a CE in supply chains, while others could constitute a barrier.

Softer aspects related to the implementation of CSCs, such as risk and relationship management could play an important role. Nonetheless, while risk management in supply chains is a well-researched topic and research on risk issues in sustainable supply chain management has recently started to emerge, the link to CSC management has not been explored so far. Yet, the implementation of CSCs carries several risk management implications. For instance, making sure that flows of products to be recovered and remanufactured are predictable might be a challenging proposition. This also includes social aspects, such

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as the potential of stable job creation within such production systems. Furthermore, the value of leadership and relationship management in the transition towards a CSC is rarely taken into consideration. While some early studies are available (Mokhtar et al., 2019), these are generally focused on simple 'dyadic' buyer-supplier relationships, failing to analyse the multi-tier nature of CSCs. Relationships among the different stakeholders and multiple tiers of companies in a CSC are often less stable and much harder to plan than in standard supply chains, as product returns are depending on product life-cycles and specific customers' needs and preferences. Specific emphasis will be devoted to these aspects in the context of ReTraCE WP1.

3. Towards CSCs: an overview of industrial applications

Having provided an initial overview of the academic literature, this chapter turns to the practical applications of CE in industrial organisations. It describes how the largest European Multi-National-Enterprises (MNEs) have implemented the CE concept. Some insights are also provided regarding the drivers behind the implementation of CE practices, and the different implementation approaches that have been pursued in the main sectors.

3.1. A study on CE applications in European industries

European directives recognise a very important role for existing organisations, which, through bottom-up initiatives, will drive the transition towards the CE in supply chains. Such interventions have emphasised product and material reuse and recycling and the use of renewable energy sources throughout supply chains (Genovese et al., 2017a).

While some initial studies have tried to review the uptake of CE in some industries (Stewart & Niero, 2018), the actual extent to which CE principles are operationalised and the real impact of changes in legislation have yet to be investigated on a larger scale. This is even more crucial when dealing with large MNEs, which for decades have been operating according to a very traditional linear model based on complex and global multi-tier supply chains.

An ideal platform for evaluating the adoption of CE practices in industry is represented by Corporate Sustainability (CS) reports. These reports can be seen as the most direct statement concerning sustainability practices (and, more specifically, CE practices) adopted by a firm. The following results refer to an analysis of the CS reports of the Top-50 companies from the European Economic Area (EEA[1]), according to the

[1] EEA includes EU countries and also Iceland, Liechtenstein, and Norway. The list of companies was compiled on the 1st of January 2019; it reflects, then, EU membership at that date.

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Global Fortune 500 list[2] (2019 edition). As shown in Table 1, the sample includes very well-known organisations and represents different countries and industries.

Table 1 – The Sample of organisations analysed

The sample			
1. Royal Dutch Shell	14. Carrefour	26. Airbus Group	39. Unilever
2. Volkswagen AG	15. Bosch Group	27. Peugeot	40. Auchan Holding
3. BP plc	16. Banco Santander	28. BASF	41. Vodafone
4. Daimler	17. Deutsche Telekom	29. Royal Ahold Delhaize	42. Telefonica
5. EXOR Group (FCA)	18. Credit Agricole	30. Deutsche Post DHL Group	43. Anheuser-Busch InBev
6. AXA	19. Enel	31. Munich Re Group	44. ING Group
7. Total	20. Uniper	32. Societe Generale	45. Legal & General Group
8. Allianz	21. ENI	33. ArcelorMittal	46. Louis Dreyfus
9. BNP Paribas	22. HSBC Holdings	34. Renault	47. Lloyds Banking Group
10. Prudential	23. Electricite de France	35. Aegon	48. Bayer
11. BMW Group	24. Tesco	36. Aviva	49. Finatis
12. Assicurazioni Generali	25. Engie	37. Equinor	50. CNP Assurances
13. Siemens		38. BPCE	

Most of the companies (37) disclosed their sustainability performance in a dedicated CS report, as summarised in Table 2; the remaining organisations included these results in a section of their Annual Report. A first aspect that has been tested is the adherence of the 2018 reports to the most commonly used standard for sustainability reporting, the Global Reporting Initiative (GRI) framework. This approach is thought to help businesses to understand and communicate their sustainability results, structuring their presentation in a standardised way. GRI reporting standards seem to be widely accepted, as more than half of the organisations, (27), are compliant with its guidelines in their 2018 reporting and 8 of them make a clear reference to the GRI structure, while only lacking a GRI index. The remaining 15 organisations do not mention or use the GRI. The detail can be observed in Table 3.

[2] Global Fortune 500 list is a ranking of the top 500 global corporations compiled by Fortune magazine. The 2019 edition collects the Top-500 international corporations in terms of turnover generated during the 2018 year.

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Table 3 – Compliance of Reports to GRI Standards

Table 2 – The Type of Report analysed

Reporting Standards	No of Organisations
Dedicated Sustainability Report	37
Sustainability information in the Annual Report	13

Type of Reporting	No of Organisations
Compliance to GRI (Standards or GRI- G4)	27
Non GRI - Only citing GRI	8
Non GRI	15

3.2. Drivers behind increased private sector interest in CE

Figure 2.2 shows the interest that is devoted to CE in CS reports. It has been observed that an increasing number of organisations are including CE practices in their CS report. The numbers refer to the incidence of the keywords 'Circular Economy' in Corporate Sustainability reports. It can be observed that the sample of firms under investigation exhibit a growing interest towards CE, with a peak in 2018, when the 50% of the firms under investigation mention the CE concept at least once in their sustainability reports. It can be further observed that such interest in CE is a recent development (in 2015 just 3 out of 20 companies where citing CE). This can be seen as a direct consequence of the European directives mentioned earlier (e.g EC CE Package 2015, EC CE Action Plan 2018), and of the emergence of a public debate that has sparked increasing interest from companies in the integration of CE principles in their operations (Widmer & Prior, 2019).

Most of the analysed reports mention the economic and the environmental benefits which can be obtained thanks to the implementation of such practices (see Table 4). Companies claim that the implementation of CE practices can help reduce waste and the consumption of virgin resources. Further, environmental benefits are provided by less energy intensive production processes that are able to re-use available parts, components and by-products and avoid the extraction of virgin raw materials.

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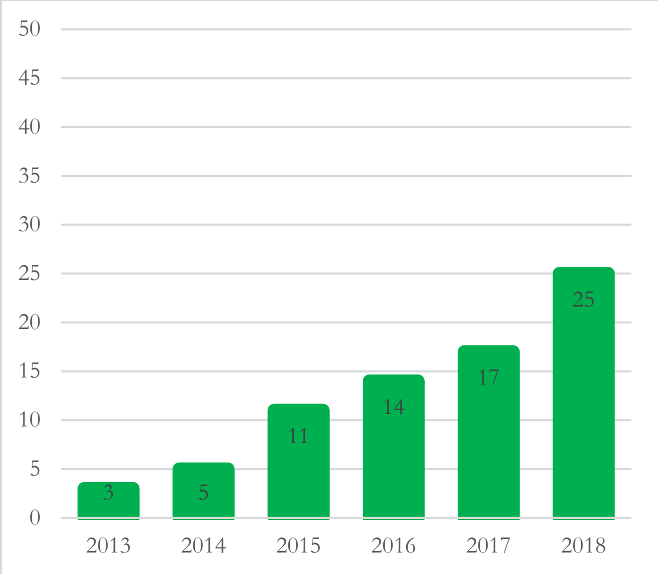

Figure 2.2 – Number of organisations that include CE practices in their CS reports

Economic drivers are well represented and they are mainly linked with increasing the amount of value that can be further extracted from products by keeping resources in use. Legal constraints, such as compliance with current or future regulations is also a common reason for adoption. Social drivers are generally overlooked and linked to the more traditional Corporate Social Responsibility agenda.

Driver	Companies	Examples of practices	Sample Organisation
Economic	14 out of 50	Extract the maximum value from resources	**BP**
		R&D Investments to support CE	**Total**
Environmental	22 out of 50	Reduce the environmental footprint of product	**FCA**
		Adopt a more regenerative utilisation model of natural resources	**BNP Paribas**
Legal	3 out of 50	Complying with regulation and requirements of a more circular economy supporting new standards and regulations	**Carrefour**
Social	2 out of 50	Co-development of social innovations related to a circular economy of plastics	**Volkswagen AG**

Table 4 –Main drivers mentioned in the CS reports

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3.3. Cross-sector comparisons

The identified CE practices have been classified according to their type and level of implementation. Figure 2.3 provides an overview of identified CE practices in four industries, namely manufacturing, energy, services and agri-food sector. Practices linked to *reduction* along with *recycling* are the most popular, while developments linked to product *reuse* are currently overlooked. In general, CE does not seem to have a prominent role in the process of value creation of organisations. While the necessity of closing material loops is often recognised, the adoption of CE practices seems linked to few sporadic initiatives. Their level of implementation is either still at a conceptual stage, with no evidence of an implementation, or at an early one. In most cases, the expected results and impacts of CE practices are not disclosed, and when reported, they are negligible and far from affecting the overall business performance.

As highlighted by Figure 2.3, the CE implementation strategy changes depending on the focal industry, and is subject to sector specific challenges. In the manufacturing industry (including companies from automotive and related industries), the identified CE practices pertain to the ability to close the loop for valuable components and key materials which can be reused and recycled after the end of their product life. Such materials include aluminium, steel, plastics, batteries, electrolytes and graphite.

	Reduction – Prevention	**Reuse**	**Recycle**	**Recover**
M	Design for resource recovery Modular design Product-as-a-Service	Reuse of parts and components (batteries)	Closing the loop for products/materials	
E	Redesign packaging		Investments in recycling technologies	Energy Recovery from by-products
S	Disinvesting from coal energy sources Investments in sustainable solutions Design of 'green' products		Materials recycling (paper)	
A	Dynamic product pricing to reduce waste Prioritise regenerative & less impactful resources Refuse packaging	Reuse packaging	Recycled materials utilisation	

Figure 2.3 – CE practices classification in selected industries (M=Manufacturing, E=Energy, S=Services, A=Agri-food). Practices have been classified and evaluated according to their type (Reduce, Reuse, Recycle, Recover) and their level of implementation (Green: high level of implementation, Yellow: early implementation, Red: no implementation)

An increased interest in the mobility-as-a-service concept has been reported in the last years, even though most of the existing projects are still at an early implementation stage. Mobility-as-a-service concepts include ride sharing (*Volkswagen*, *FCA*) and on-demand mobility services (i.e. car sharing, including with electric

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vehicles) (*Volkswagen*, *Daimler*, and *FCA*); all these services promote a more collaborative consumption model that can result in environmental benefits.

In the energy industry the concept of the CE is interpreted as closely related to waste management (with specific reference to plastic waste), as opposed to divestment from fossil fuels and a transition towards renewable energy. This first assessment, however, seems to confirm that firms from this industry are not implementing the full spectrum of CE practices. As such, currently, CE is viewed by these companies (which operate in the extractive industry, which is still fossil fuel-dominated) as a tool to perform some remedial actions which could mitigate the negative externalities of their core business.

Shell and *Total* are among the founders of the Alliance to End Plastic Waste, committing themselves to invest more than $1 billion, and with the goal of investing $1.5 billion over 5 years to develop solutions in this field. At the same time, this problem is being addressed through the acquisition of technological start-ups; *Total*, for instance, acquired the French company *Synova*, a leader in the manufacture of high-performance recycled polypropylene. Some recovery practices are also present. For example, *BP* has recently acquired *Neste*, a leading producer of renewable energy products, to explore opportunities to increase the supply of sustainable fuel for aviation.

The financial sector (and the service sector in general) demonstrates a general lack of clarity when dealing with CE as well as with the potential role that banks and insurance companies could have in supporting the transition towards an economy of services rather than products. Some banks are pioneering the offer of financial instruments to finance the transition of companies, both for industrial organisations and for consumers. *BNP Paribas* has committed to support the implementation of CE practices through a dedicated fund aimed at targeting CE players (particularly innovative start-ups). *Banco Santander* and *Credit Agricole* are concentrating their efforts on shifting the automotive sector towards a low-carbon economy through services such as vehicle leasing and renting, to promote the use of hybrid or electric cars in the countries where they operate. *Deutsche Telekom* reports growth in the usage of leasing models for devices like routers and media receivers. These devices are refurbished for reuse entailing better results in terms of recycling rate and duration of use. Other common practices adopted by other companies in the financial sector include the divestment from carbon fossil fuels and the investment in sustainable solutions (mainly renewable energy for both households and firms).

The agri-food sector presents a good adoption level of CE practices, which range from the implementation of dynamic product pricing policies to reduce food waste, to the rejection of packaging for some product lines. Some of these practices are linked to stringent legislative requirements that ban supermarkets from throwing away or destroying unsold food waste, e.g. *Carrefour* and *Auchan* in France. Figure 2.4 represents the case of *Carrefour*, which is one of the companies which exhibits a very high level of adoption, applying at least one CE practice of each type at high levels of implementation.

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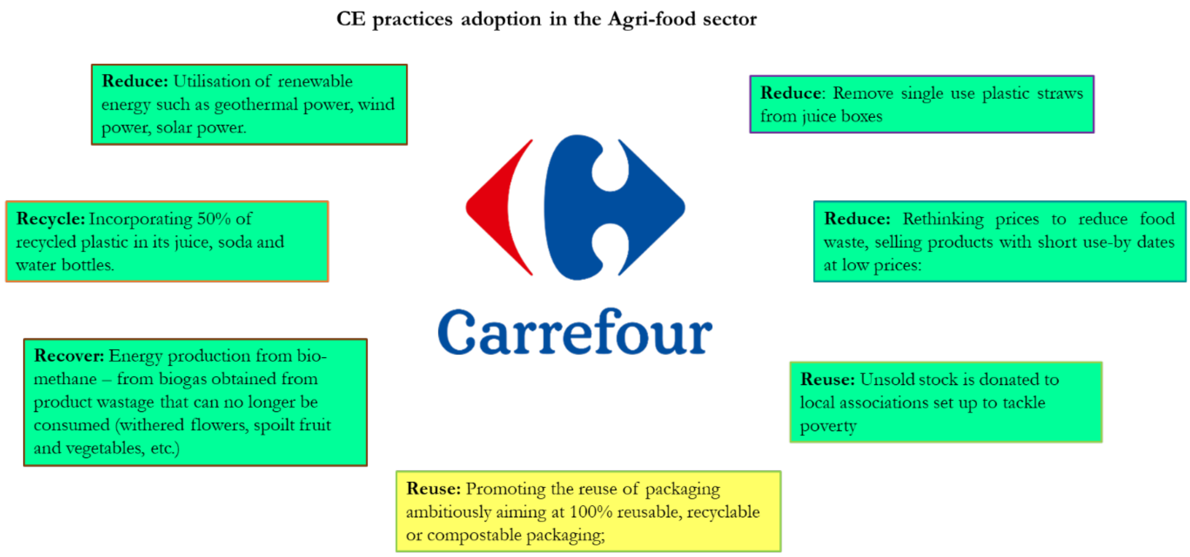

Figure 2.4 – CE practices adopted by Carrefour. Practices have been classified and evaluated according to their type (Reduce, Reuse, Recycle, Recover) and their level of implementation (Green: high level of implementation, Yellow: early implementation, Red: no implementation)

4. Measuring the transition towards Circular Supply Chains

This chapter identifies the current indicators found in the CSCM literature as well as company CS reports. These indicators are then characterised according to the dimensions they consider and the decision they aim to support. Work presented in this chapter provides a basis for understanding the current gaps in both literature and corporate practice, identifying avenues for future research.

4.1. Evaluating the CE potential of supply chains

CSCM literature includes models and decision-making tools, which aim to evaluate CSC performance according to numerous sustainability indicators. Such research contributions utilise distinct research methods and employ several metrics to keep track of the performance of supply chains and their alignment to CSC standards. Evaluation should be conducted across every dimension of sustainability (i.e. economic, environmental and social) although many models adopt a single-dimension approach. The aim of measuring CSC performance is generally linked to informing decision-making processes, either directly or indirectly.

There are no previous literature reviews which deal with the assessment of the state of the art of existing CE indicators for supply chains. For this reason, the whole body of literature has been examined. A total of 208 articles has been analysed in order to discover the most popular indicators employed by SCM scholars in order to characterise performance evaluation in a CSC context. The selection of sources followed a strict protocol as set out below, while the detail of the systematic literature review (SLR) is included in Appendix I.

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The review was conducted using two of the most prominent academic search engines, namely *Scopus* and *Web of Science*. Keywords have been chosen to maximize the number of articles to be included in the analysis. A total of 976 articles were collected. Then, articles were screened based on their abstract. Studies contributing to the CE literature without taking the supply chain as a level of analysis have been *excluded*. Studies contributing to the CSC literature without developing and/or utilising any indicator have been *excluded*. Studies developing or using an indicator/multiple indicators in order to explicitly evaluate the performance of CSCs have been *included*. Studies employing an indicator/multiple indicators for CSCs in the context of wider decision-making models and problems have been *included*.

Finally, a critical analysis of the 208 shortlisted articles was performed, with the aim of summarising the relevant findings and highlighting the key messages. Existing models were surveyed, on the basis of the research method employed, the types of decision supported, the indicators employed and the sustainability dimension considered. Indicators were classified according to their popularity and on their capacity to measure relevant aspects in the transition towards CE in supply chains.

4.2. TBL Indicators employed in the existing literature

The TBL approach is a central concept in sustainability studies, where performance standards need to be achieved across environmental, economic and social dimensions. Following the inclusion of environmental and social issues in the public agenda, SCM scholars have gradually incorporated adequate indicators in their models (Seuring & Mueller, 2008).

The articles reviewed have been classified according to the sustainability dimensions they consider. Figure 2.5 shows that only 15% of the 208 papers integrate the three dimensions simultaneously. The great majority of the papers (82%) do not integrate social indicators, favouring the economic and the environmental dimensions. An interesting result is that 34% of the papers do not consider, in an explicit manner, environmental issues; many of these papers incorporate reverse logistics considerations, which (as explained in Section 2), are mainly based on economic aspects. However reverse supply chain activities (e.g. the establishment of collection facilities, the transportation of recovered products and materials backward in the supply chain, the remanufacturing processes) employ resources, labour and energy; as such, a careful evaluation of the negative impacts of those processes should be taken into account and evaluated from the design stage.

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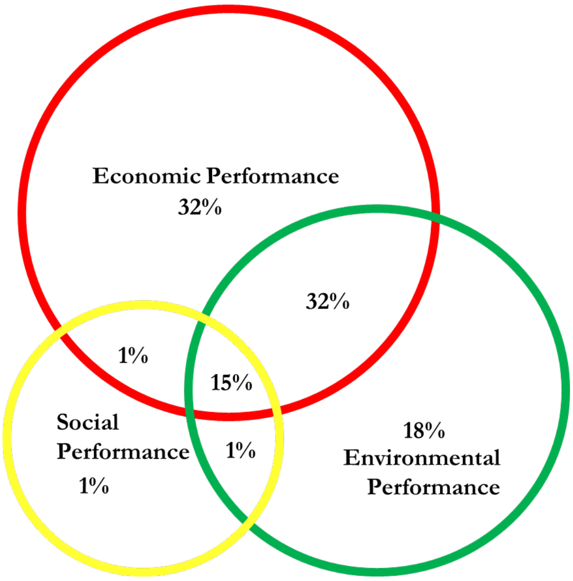

Figure 2.5 – Dimensions considered by the existing models and tools in the literature (percentages refer to analysed papers)

Half of the articles in the sample adopt a single-dimension perspective, mainly favouring the economic (32%) and the environmental dimensions (18%). Nevertheless, looking at how the consideration of sustainability dimensions has evolved over time, it can be seen that an increasing number of studies account for at least two dimensions as in Figure 2.6.

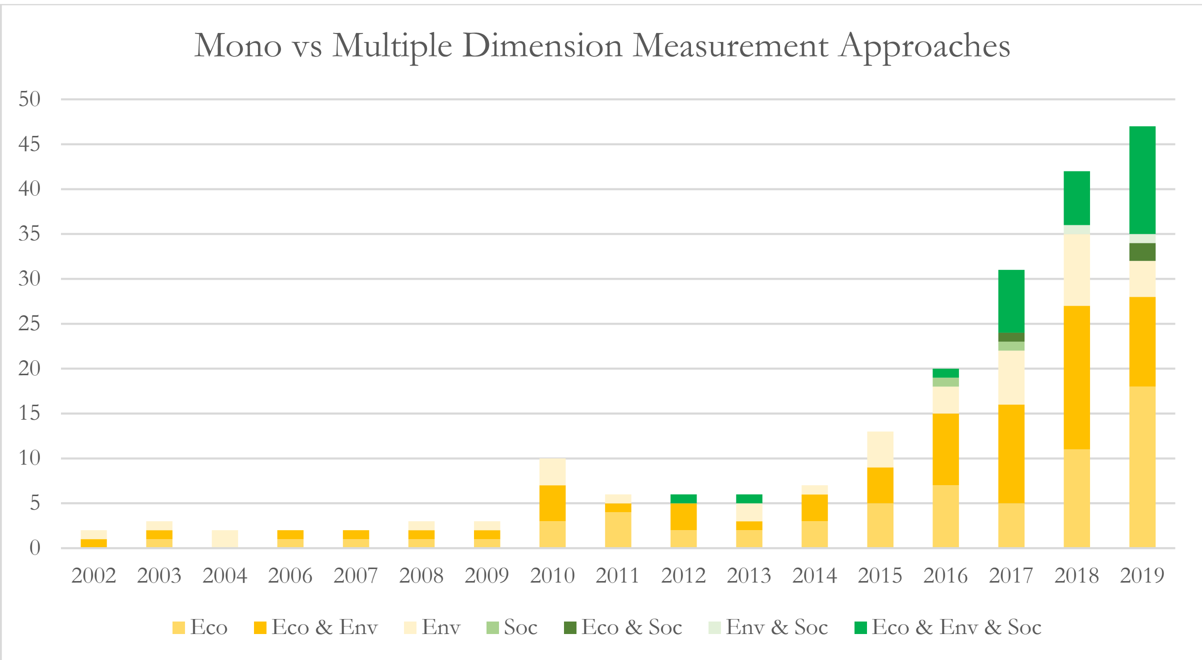

Figure 2.6 – Interactions between the different methods considering sustainability dimensions and scale of interest.

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4.2.1. Economic indicators

80% of the studies in the literature employ economic indicators. As highlighted in Table 5, there is a clear prevalence of cost-based measures. Notable examples include cost of production, transportation cost, facility location cost. These considerations are very common in CSC Network Design Optimisation models. Indicators related to the time responsiveness of the CSC and to the quality of the products are less common. Some CE indicators can common to the different categories of measures. Notable examples are the cost of the reverse supply chain, the profits associated with recovery activities, including remanufacturing, recycling and disposal, and the quality of the recovered products after the end of their life.

Table 5 – Most commonly employed economic metrics

Category	Examples	Description	Occurrences	%
Costs	• Operational costs • Facility location costs • Transportation cost • Reverse supply chain cost	Cost-based indicators, both at a company and at a supply chain level	108	52%
Profits	• Total CSC profits • Profits from recovery activities including remanufacturing, recycling and disposal	Profit-based indicators, both at a company and at a supply chain level	46	22%
Time	• Time responsiveness of the network • Delivery reliability of suppliers	Time responsiveness-based indicators, both at a company and at a supply chain level	16	8%
Quality	• Reliability of supply • Quality level of the production • Quality of the returns	Quality-based indicators, both at a company and at a supply chain level	11	5%
Risk	• Financial risk • Value at risk • Conditional value at risk • Variability index • Downside risk	Risk-based indicators associated to uncertainty (e.g. of demand, collection)	11	5%
Profitability	• Net Present Value • Return on Equity • Return on Assets	Profitability-based indexes, measuring	8	4%

4.2.2. Environmental indicators

The greatest part of the studies that consider the environmental dimension utilise indicators based on Global Warming Potential, Greenhouse Gas Emissions and Climate Change. This seems to confirm that the SCM literature has an established carbon centric point of view (Table 6). Indeed, emission equivalent (such as

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CO_2-eq) metrics are three times more likely to be employed than any other category of environmental indicators.

Table 6 – A list of the most commonly employed environmental metrics

Category	Examples	Description	Occurrences	%
Emission equivalent	• Climate Change • Greenhouse gases • Global Warming Potential	CO_2 eq. emissions associated with supply chain	92	45%
Energy usage	• Energy use • Cumulative energy demand	Energy-based indicators associated with supply chain	28	14%
Virgin resources usage	• Abiotic depletion of resource • Mineral, fossil & renewable resource depletion	Virgin resource use associated with supply chain material consumption	27	13%
Waste	• Waste Landfilled • Recycled waste • Recyclability and ease of disassembly	Residual waste produced and landfilled or recovered by supply chain activities	23	11%
Air emissions	• Particulate Matter • Respiratory inorganics	Other air emissions associated with supply chain	22	11%
Acidification	• Terrestrial acidification • Marine acidification	Acidification potential associated with supply chain processes	19	9%
Water	• Water depletion • Water emissions • Water use	Water used or contaminated	17	8%

Other commonly utilised indicators focus on use of energy across supply chains. Cumulative energy demand (CED) considers the energy consumed throughout the product lifecycle, including the energy consumed during the extraction, manufacturing and disposal of the raw and auxiliary materials. Only the 13% of the articles measures the quantity of virgin resources (e.g. minerals, fossil fuels, renewable resources) that are depleted throughout the supply chain. Even a smaller portion of the sample concentrates on indicators related to the residual waste that is incinerated or landfilled (11%), or on waste recovered thanks to CSC feedback loops.

In total, 77 different environmental indicators are employed; this denotes the lack of an agreed standard for measuring the environmental performance of CSCs, or the transition of supply chains towards CSC configurations. Many studies use traditional Life Cycle Assessment frameworks, in this way taking into

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account a wide variety of impacts across the whole product supply chain. Another relevant gap is the absence of explicit metrics regarding process or material 'circularity'. Only a very small minority of papers employs specific indicators to measure the proportion of waste and by-products reincorporated in the supply chain. One of these indicators is the 'reuse rate of resources'.

4.2.3. Social indicators

Only 18% of the sample analysed consider the social dimension within the definition of the objectives. It can be observed that there is no agreement on the stakeholders to be involved. Some measurement approaches only consider employees, whilst others consider customers and as well as suppliers, organisations or communities (see Table 7).

The most common indicator (which appears in 7% of the papers included in the sample) is represented by the employment opportunities generated within the supply chain (i.e. the total number of jobs created by the CSC). Whilst not common, some metrics representing the 'quality' of the jobs created are also considered; these indicators mention aspects such as the presence of decent work conditions (3%), employee training opportunities (2%) and other benefits for workers (2%).

A less common indicator (which appears in just 1% of the papers considered) measures customers' environmental awareness, related to their willingness to return used products at the end of their life. Another notable indicator describes the social cost of waste (1%), defined as a penalty cost assigned to companies for disposal of materials throughout the supply chain.

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Table 7 – A list of the most commonly employed social metrics

Category	Examples	Description	Quantity	Fraction
CSC job created	• Number of fixed and variable jobs • Number of drivers hired for transportation	Employment opportunities provided by the CSC	15	7%
Organisations H&S compliance	• Compliance with the ILO guidelines	Measures of compliance to H&S Guidelines for the jobs created in the CSC	8	4%
Quality of work	• Work damages • number of accidents, lost • Employee turnover	Measures of quality of the jobs created	7	3%
Training	• Average hours of training • Training on skills for employability	Indicators of the training provided to workers	4	2%
Spending on Benefits for employees	• Food • Transportation • Pension	Indicators of benefits provided to the workers	4	2%
Customer environmental awareness	• Enlightening customers to return end of used product • Customer incentives for recovery from discarded product	Indicators of environmental awareness of the customers	3	1%
Social cost of waste	• Penalty cost of disposal	Social cost of waste produced. Sum of disposal cost and of the cost for the recycler	2	1%

4.3. A classification of existing measurement approaches

Looking at the research method adopted, the objective of the articles and the sustainability dimension considered, three homogenous classes of problems could be identified. Each one of these classes adopts a different focus and measures different aspects of CSC operations, by employing different indicators.

As shown in Table 8, the three main classes of studies can be defined as follows:

1. *CSC Optimisation*: This class encompasses articles from the Operations and Supply Chain Management domain. Such papers deal with decision-making problems, which are typically modelled through mathematical programming approaches (dealing with both single- and multi-

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dimensional problems). Usually, they employ simplified environmental indicators, mainly based on carbon emissions, without considering any issue related to the circularity of material flows or to waste creation at the different stages of the supply chain.

2. *CSC environmental profile evaluation*: This class collects articles from environmental sciences, mainly employing the LCA method. Their aim is to assess the environmental impact of CSCs and to highlight supply chain hotspots. Usually the objective of these analyses is to inform some kind of uptake of mitigation strategies aimed at reducing the negative environmental impact of the supply chain. Common indicators include carbon emissions, energy use, as well as acidification and eutrophication potentials.

3. *Material flows analysis in CSC*: This class collects articles whose objective includes quantifying flows and stocks of materials within the supply chain system. The methods employed are mainly Material Flow Analysis (MFA), hybrid LCA, I/O methods. Common indicators include the consumption of virgin materials, the utilisation of by-products, the generation of waste.

All these approaches could contribute from different angles to the definition of an ideal CE indicator:

CSC Optimisation articles can provide whole-supply chain visibility of the processes and materials involved in the manufacturing process, as well as different actors' preferences and utility functions. In this way, it could be possible to model CE benefits and negative impacts across more dimensions and more supply chain stages.

CSC environmental profile evaluation articles can provide an accurate estimation of environmental impacts thanks to a life-cycle perspective. This can help CSC decision-making processes to move away from the mainstream perspective of accounting just for the economic cost of production of goods and services.

Material flows analysis in CSC articles can provide insights on how to measure and visualise the CE potential related to regenerative and restorative flows of resources in supply chains, in order to re-use material flows and waste as a resource according to an Industrial Ecology view.

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Table 8 – Attributes, Advantages and Disadvantages of different classes of articles in the literature

	Objective	Research methods	Dimensions	Economic indicators	Environmental indicators	Social indicators	Advantages	Disadvantages	Example works
CSC Optimisation	Wider SCM decision-making	Optimisation (MILP, MINLP, Stochastic optimisation); Simulation; MCDM	Both Single (Eco) and Multi-Dimension (Eco-Env-Soc)	Mostly cost based	Simplified version of environmental indicators (mainly emission based). Rare incorporation of waste creation measures	Mostly CSC jobs created	Detailed evaluation of: flows among SC stages; actors' utility functions	Unable to highlight the systemic impacts of CSC.	Taleizadeh et al., 2019 van Loon & Van Wassenhove, 2018
CSC environmental profile evaluation	Evaluate the life-cycle environmental pressure of the CSCs	LCA	Only Environmental	-	Multiple indicators, mainly standard LCA based metrics	-	The negative environmental impact is determined with precision	Inability to measure and visualise the CE potential related to regenerative flows of resources	Krystofik et al., 2018 Niero & Olsen, 2016
Material flows analysis in CSC	Tracking the resources flows (materials, energy, waste) circular flows of materials	MFA; I/O Analysis; Hybrid I/O LCA	Mainly Environmental	-	Primary/secondary material inflow/ outflow, waste outflow	-	Ability to measure and visualise the CE potential related to regenerative flows of resources	Not always able to take into account the environmental impact associated with circular flows	Liu et al., 2018b Sgarbossa & Russo, 2017

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4.4. CE indicators from industry practitioners

Industry practitioners keep track of the impact of CE practices that are implemented. In CS reports, sustainability results related to the previous financial year are communicated on a yearly basis and structured in similar way to economic results. The most common indicators used by the same set of organisations considered in Chapter 3, are reported in Table 9.

Table 9 – Commonly used economic, environmental and social KPIs for European MNEs

Dimension	Category	Examples	Description	Adopting Companies
Economic	Revenues	• Revenues from remanufactured products • Revenues from 'green products'	Revenues associated with CSC activities	3/50
	Investments	• Capital invested in sustainable solutions • Capital dis-invested from carbon intensive assets	Investments associated with CSC activities	15/50
Environmental	Emissions equivalent	• CO2eq per functional unit • Absolute CO2-eq	CO_2 eq. emissions associated with the supply chain	44/50
	Energy Usage	• Energy intensity • Cumulative energy use • Energy from renewable sources	Energy-based indicators associated with the supply chain	44/50
	Water	• Water used • Wastewater production • Discharges to water	Water used or contaminated	42/50
	Waste	• Waste sent to landfill • Waste recovered	Residual waste produced or recovered by supply chain activities	36/50
Social	Social Impacts associated with CSC	• 'Green' jobs created	Employment opportunities provided by the CSC	4/50
CE	Overall Circularity	• CE Score • Parts Collected and Remanufactured	Indicators of environmental awareness of the customers	3/50

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While the objective and the scope of these indicators are different from the modelling seen in academic literature, it is interesting to perform a comparison between the industry and the academics perspectives. Most of the indicators that are employed do not differ from the ones which can be found in the sustainable supply chain management literature, with no specific emphasis on circularity issues.

Indicators of the economic impact of CE practices adoption vary according to the industrial sector and to the type of practice. 'Revenues from remanufactured products' is a common indicator among the manufacturing companies that built an infrastructure to recover end of life parts to be sold in the secondary markets (*Renault, FCA, PSA, Volkswagen, Daimler, and BMW*). In the financial sector, economic indicators refer mostly to the 'green' investments associated with CE activities or with the promotion of renewable energy or resource efficiency solutions.

Most of the environmental KPIs which are employed are efficiency indicators, comparing a measure of polluting activities (for instance, carbon emissions) to the total production output. It must be highlighted that the usage of such indicators for measuring the success of CE practices is problematic. Figures could be manipulated to obtain better results, for example just by increasing production volumes (for instance, through productivity improvements), rather than by implementing practices which can promote a more efficient usage of resources.

Social impacts associated with CE practices are included only in 3 organisations and refer to the employment opportunities provided by the CSC. Just one company, the Italian Energy Utility provider *Enel*, develops a measurement system to assess the level of circularity of its solutions and products. Enel *X Circular Economy Score* is calculated by combining two values. The first represents five CE key dimensions, which are: the commitment by suppliers to CE principles; the presence of reusable elements which can increase the life-cycle of the product; the resource efficiency; the reuse of materials; and the support offered to suppliers. The second dimension evaluates the implementation of five circular business models (inter alia: product as a service; sharing platforms; product life cycle extension). The indicator is subject to third-party verification and then made available to supply chain stakeholders'

5. Developing an ideal composite CE indicator for supply chains

Decision-makers inside the supply chain have to make continuous trade-off decisions among different goals in order to design and operationalise profitable, efficient, circular and sustainable supply chains. Organisations in a CSC could recognise opportunities of increasing returns while reducing costs, minimising the environmental impact of their product and services and increasing the social well-being.

However, measuring the performance of circular networks might require to accommodate the perspective of multiple stakeholders. Those stakeholders are already enacting pressures, supporting their evolution of production and consumption systems towards more circular configurations. Consumers are calling for the

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commercialisation of sustainable products, which could last longer, being easier to repair and update. Also, governmental bodies see in the CE paradigm and in CSCs enablers for 'green' development and growth for regional economies.

For these reasons, and in line with the objective O1.1 of ReTraCE WP1 (i.e., establishing a decision support framework aimed at measuring the 'circularity quotient' of a supply chain), this final chapter of the report collects early attempts to design such a decision-making model. These early attempts are based on:

1) The review of existing indicators in the academic literature;
2) The review of CE practices implemented in the main industries in Europe;
3) The requirements for a CE indicator established in the subchapter 2.3.1.

This chapter aims to identify a restricted set of KPIs which could be used to keep track of the effectiveness of CE interventions in CSCs. Three alternative composite indicators are proposed, based on findings of the reviews presented in the previous sections. In addition, a summary of a possible method to capture social implications in the measurement of the performance of CSCs is presented.

5.1. Building composite indicators for CSC decision-making

A composite indicator is formed when individual indicators are compiled into a single index on the basis of an underlying model (Joint Research Center- European Commission (JRC-EC), 2008). Defining a composite CE indicator for a CSC would require us to:

1) Define an appropriate subset of indicators;
2) Focus on the trade-offs between the three dimensions of sustainability (i.e. economic, environment and social);
3) Account for benefits, impacts and preferences of different decision-makers and stakeholders.

An interesting approach to the construction of composite indicators is offered by multi-criteria decision-making (MCDM) methods, which can provide assistance with the process of weighting and aggregating more metrics into a composite indicator. The objective of MCDM methods is to combine performances offered by alternative solutions across different criteria, assisting decision-makers in selecting the best course of action according to their preferences. Such methods are particularly effective in contexts in which multiple stakeholders are involved.

Composite indicators are particularly suitable for measuring multidimensional concepts, whose complexity cannot be addressed by a single indicator (JRC-EC, 2008). Multiple applications have been established among practitioners thanks to their usability in different contexts. JRC-EC, 2008). A notable example includes the composite indicators used in the context of policy analysis.

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Their main advantage provided by composite indicators is the ability to summarise complex, multi-dimensional realities for supporting decision-makers. An overview of the advantages and the disadvantages over single indicators is summarised in Table 10 (JRC-EU, 2008).

Table 10 – Overview of the advantages and disadvantages of composite indicators over a battery of single indicators (adapted from JRC-EC, 2008)

Composite indicators	
Advantages	Disadvantages
• Can summarise complex and multi-dimensional realities • Easier interpretation • Facilitate communication with stakeholders and promote accountability • Enable users to compare complex dimensions effectively	• May send misleading messages if poorly constructed or misinterpreted • May invite simplistic conclusions • The selection of weights could be the subject of a dispute

Also, in SCM environments, composite indicators are rather common, both among researchers and practitioners. CSCs provide an ideal theoretical and practical context in which these methods could support decision-making. In this complex context, a wide range of stakeholders inside and outside the supply chain may be interested in evaluating the performance of the CSC using an established and standard model.

A composite CE indicator could be seen as a source of differentiation at a supply chain level. It is a fact that global competition has shifted from involving single organisations to the level supply chains (Hearnshaw & Wilson, 2013). A CE composite indicator could allow supply chains to showcase the circularity of their operations to a wide range of stakeholders, thus providing a source of competitive advantage. On the other side, such an instrument could be the basis of a certification that could directly support European policies and strategies to facilitate a transition to CE for the most critical supply chains.

In the next two subsections, MCDM methods are applied to define three distinct CE scores for a supply chain according to two models. The aim is to identify, on the basis of different criteria, a restricted set of KPIs which could be used to keep track of the effectiveness of CE interventions in CSCs.

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5.1.1. A literature-based CE composite indicator for supply chain

The first attempt to build a multi-objective composite indicator is based on the results of the literature review. This Literature-based CE index (L-CEI) aims to synthesise the models and tools already developed in the literature. The steps for the definition of this indicator are presented below:

- The weights of the three components representing the sustainability dimensions have been determined on the basis of their relative frequencies (as reported in Table 11). For instance, the weight of the economic dimension is 0.49 as this represents the normalised frequency of articles accounting for economic factors (with respect to a normalisation factor that is the sum of the percentage of articles reporting of each dimension).
- The subset of indicators considered for each dimension has been determined by considering the most popular metrics in the subset of papers selected in the review. The three most popular metrics have been selected for each dimension. Weights have been determined in a similar manner to what has been done for dimensions, considering normalised relative frequencies.
-

Table 11 – Calculation of the normalised weights for the dimensions

	Occurrences (%)	Normalised dimension weight
Economic	80%	0.49
Environmental	66%	0.40
Social	18%	0.11

Table 12 – Calculation of the normalised weights for the economic indicators

	% articles	Normalised indicator weight
CSC Cost	52%	0.31
CSC Profit	22%	0.13
Time Responsiveness	8%	0.05

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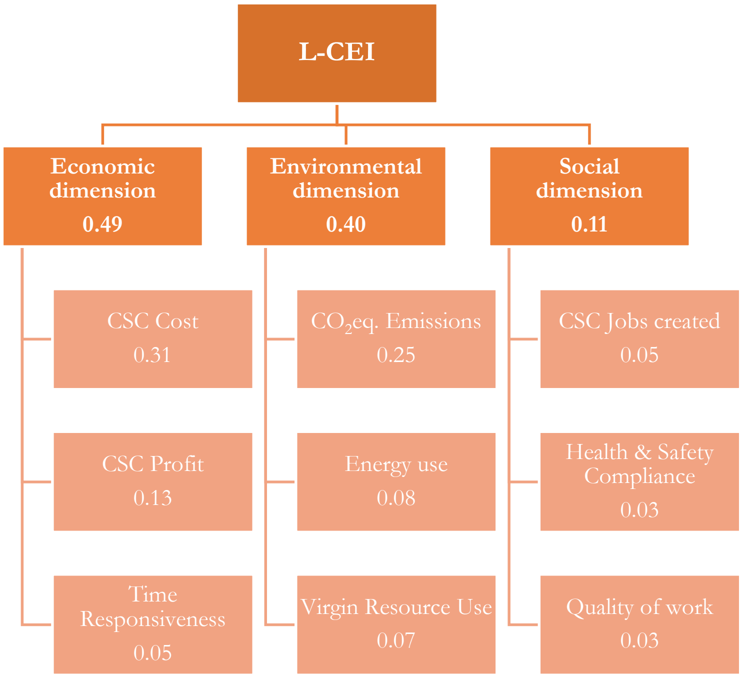

Figure 2.7 – A literature-based CE indicator

Figure 2.7 shows L-CEI and its components and the weights. The economic dimension dominates, and accounts for around half of the total weight. The metrics are mainly cost-based and -profit-based measures. A small portion (0.05) is given by a parameter representing the Time Responsiveness of the supply chain. Among the environmental metrics prominence is given to the CO_2-eq. emissions parameter. The 'Energy use' and 'Virgin Resource use' metrics have a similar and limited importance (0.08 and 0.07). The Social just accounts for 11% of the weight; within this dimension, selected metrics include the 'CSC Jobs created' (0.05), compliance to Health & Safety standards and 'Quality of work'.

It must be highlighted that the literature-based composite indicator seems to over-represent measures that depend on the economic cost and on the cumulative carbon emissions of the supply chain. Materials circularity indicators are not included at all. This seems to confirm the scarce level of adherence to the CE paradigm of the commonly employed metrics within the current CSCM literature.

5.1.2. An industry-based CE composite indicator for supply chain

The second attempt to build a composite indicator is based on the results of the previously presented review of the industrial practice. This Industry-based CE index (I-CEI) aims to synthesise the indicators employed in CS reporting. The steps for the definition of this indicator are presented below:

- The weights of the three components representing the sustainability dimensions have been determined on the basis of the relative frequencies, in analogy with the calculations shown for L-CEI.

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- The subset of indicators considered for each dimension has been determined by considering the most popular metrics in the sample of organisations. The three most popular metrics have been selected for each dimension.
- The relative weights inside each dimension have been chosen on the basis of the relative frequencies, in analogy with the calculations shown for L-CEI.

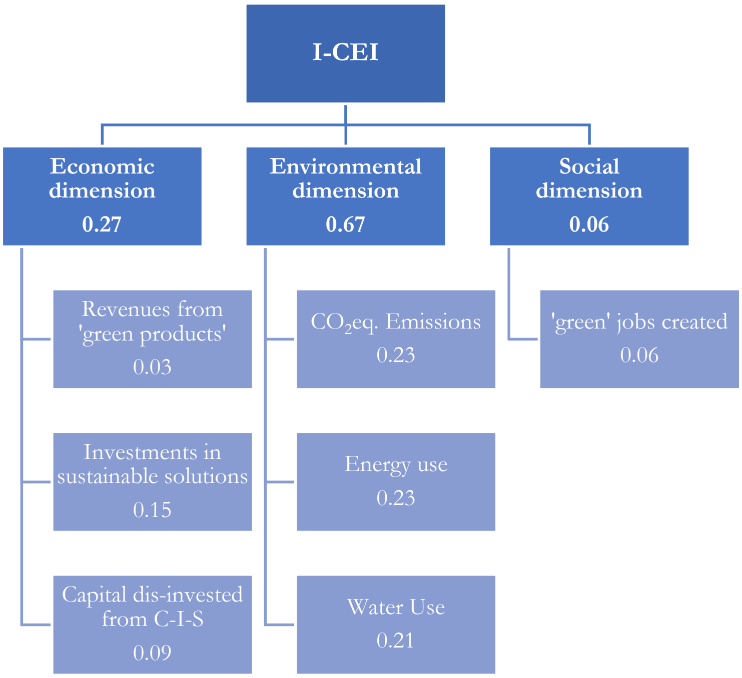

Figure 2.9 – An industry-based CE indicator

Figure 2.8 shows I-CEI and its components and the weights. The environmental dimension is dominant, and accounts for more than half of the total weight. The most important metrics are mainly carbon-based and energy-based measures. A large portion (0.21) is also given by a parameter representing the consumption of water. Among the economic indicators considerable importance is given to investments to support the transition towards a more CE, both through sustainable investments (0.15) and through disinvesting from polluting and carbon intensive solutions (C-I-S) (0.09). The Social dimension has a slightly lower weight than in the L-CEI (0.06) and includes a single indicator (the amount of 'green jobs' created).

Unlike L-CEI, the industry-based composite indicator places more emphasis on environmental measures that depend on the energy consumption of the supply chain, and on its dependence on carbon intensive sources. Economic measures are mainly representative of revenue flows related to 'circular' products. This can be explained as, at the moment Industrial Organisations are not adopting CE practices across the whole supply chain, but just in some niches. As such, the current indicators are not designed to measure the performance of a whole CSC, but just of some parts of it.

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Interestingly, also in this composite indicator, the issue of the circularity of material flows is scarcely addressed. As such, a more accurate selection of the subset of the representative indicators might represent a possible way to define an alternative CE- based indicator (CEI) for a supply chain.

5.1.3. An ideal CE composite indicator for supply chain

The third attempt to build a multi objective composite indicator is also based on literature and on industrial practitioners' perspectives. While current indicators seem mostly able to measure the negative environmental impacts of CSCs, they face some challenges in evaluating the economic and environmental potential behind the circulation of resources. Thus, the objective of CEI is to acknowledge alternative and less popular indicators, which has been already used both by researchers and by practitioners. Those indicators have been selected for their capability to measure the prominence of feedback loops of products and materials, the shift towards regenerative resources and the capacity to reduce and recover waste streams across the supply chain processes. Its structure is the same of the L-CEI (i.e., three dimensions with three indicators per dimension). The only difference is in the choice of the subset of indicators, and in the determination of the weights, both of which have followed different criteria.

The CE-based index for a supply chain (CEI) has been determined according to the following principles:

- Equal weight has been assigned to each of the three components representing the sustainability dimensions
- The subset of indicators considered for each dimension has been determined by considering only metrics that are directly related to the CE principles. Looking at tables 5, 6, 7 and 9, these indicators have been highlighted with a dark green font colour.
- The same weight has been assigned to each of the three indicators relative to each dimension.

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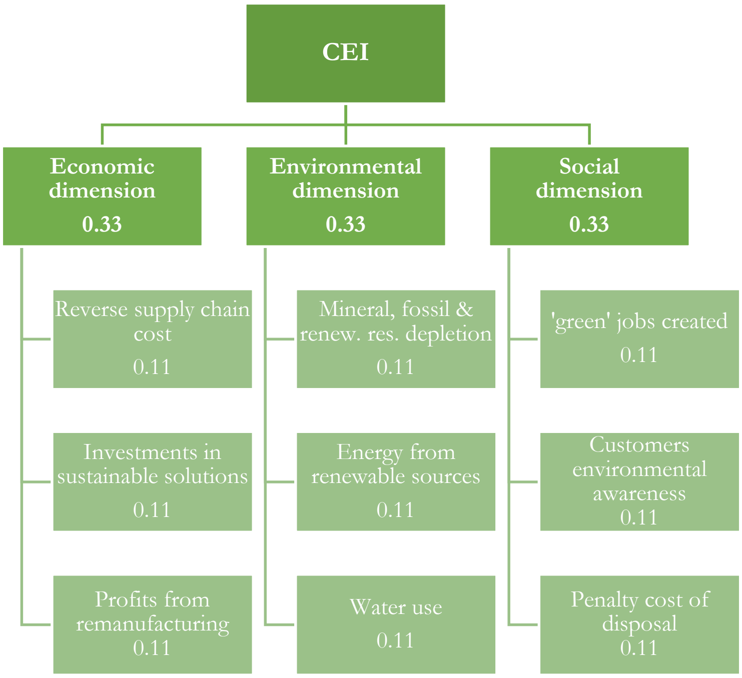

Figure 2.9 – A CE -based indicator

The result is a more balanced composite index (Figure 2.9) which includes three new indicators within the economic dimension, e.g. 'reverse supply chain cost', 'investments in sustainable solutions' and 'profits from remanufacturing'. 'Profits from remanufacturing' includes all the profits associated with the sale of remanufactured/refurbished and repaired products. The choice of this parameter has been influenced by a similar metric – 'Parts Collected and Remanufactured' – that has been adopted by industry practitioners.

The environmental dimension accounts to a greater extent of resource utilisation within the CSC, e.g. virgin resources (minerals, fossil fuels and renewable resources), water, and energy from renewable sources. The social components of the CE-based indicator focus on employment, on customers, as well as on society. 'Customers environmental awareness' describes the willingness of customers to engage actively in the CSC, for example in returning end of life products. 'Penalty cost of disposal' is a measure of the environmental penalties faced across supply chains.

While this composite indicator could provide a more balanced view of the transition towards a CSC, it could also be useful developing approaches which are based on the consideration of the full life cycle cost, including the environmental and social dimensions, which is a typical feature of the CE paradigm (Webster, 2017). This aspect is developed further in the next subchapter, thanks to the introduction of the eMergy accounting paradigm, which could represent a novelty in the supply chain management field of study.

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5.2. EMergy Accounting (EMA) for supply chains

Another gap, which characterise both the literature and the industrial practice, is represented by a simplified and superficial consideration of social implications in measuring the transition towards the CE in supply chains. The only cost that is generally considered by models in the academic literature is the economic cost (Andersen et al., 2007). Existing methods are unable to account for the full cost of products throughout their lifecycle, including the environmental cost of ecosystems degradation and the social cost related to human labour. This reflects the practice of a linear thinking in the use of natural resources as if they were commodities. Within the linear paradigm, resources are not provided with the time to regenerate, and the labour that Nature has employed to produce a resource in the biosphere and to generate a product or a service in the economy is not taken into account. However, the inefficient approach to the use of natural resources has resulted in the degradation of ecosystem and has impacted communities around the world. These disruptions call for methods and tools that are able to support decision-making, devoting a special attention to natural resources.

EMergy Accounting (EMA) is a method that could be able to describe the balanced interplay that exists between economic and environmental systems (Odum 1996), as it should be within a CE paradigm. The method considers the thermodynamic work done by nature and humans to produce resources and products, starting from phytoplankton sequestration and processing over millions of years, up to the age of industrial production and distribution.

All flows and stocks in a system are expressed in a standard unit, joule of equivalent solar energy (sej), also solar emjoule. Different types of energy can be assimilated to the standard unit thanks to the presence of established coefficients. EMergy (represented by Yield in Figure 2.9) is described as the total sum of aggregated inflows to a process or system, divided in locally (L) Renewable (R) and Non-Renewable (N) natural resources and Imported Resources (F).

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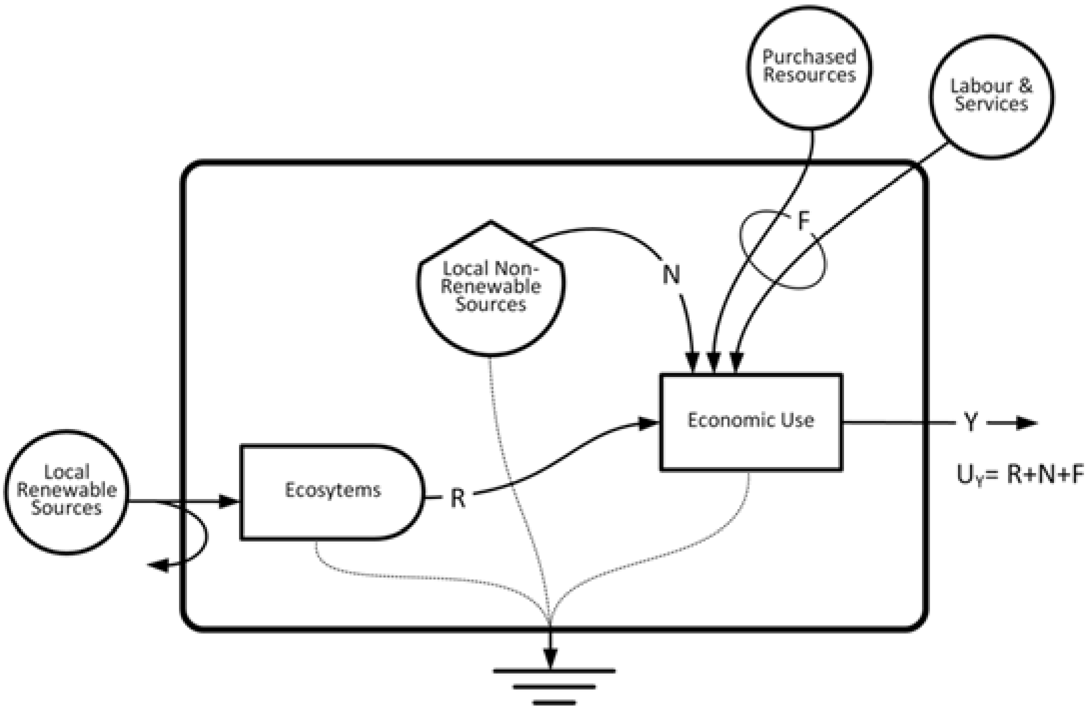

Figure 2.9 – General Energy Flow Diagram (Adapted from Brown, 2018).

The utilisation of such a method could integrate established approaches in the evaluation of the environmental and social implications of production and consumption systems. Emergy indicators could also become part of a composite indicator to measure the circularity quotient of a supply chain, being able to evaluate aspects that are not caught by the most popular indicators, both in the literature and in the industry.

5.3. Future directions

Further possibilities to improve the composite indicator include are represented by a more comprehensive and structured application of MCDM methods. For example, the involvement of stakeholders and experts from a variety of backgrounds (academia, industry, NGOs, national and local government) might support more rigorous choices of the subset of representative indicators and of the relative weights. The perspectives of the different actors should be taken into account, especially in the presence of discrepancies in how they perceive this phenomenon and the transition towards the CE in general.

Moreover, to avoid overloading end-users with overly complex and redundant information, other scientific methods could be used to identify a subset of indicators that are independent of one another. Previous studies have already tried to assess redundancies in environmental performance measures for supply chains (Genovese et al., 2017b). A possible contribution in this sense could be represented by the employment of Principal Component Analysis (PCA). PCA could help the development of a more robust and effective index, by determining its smallest set of independent indicators. Secondary datasets could be utilised for this

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purpose, such as Ecoinvent (2018)[3], a life cycle inventory database that associates detailed environmental impact indicators across all the phases of the life of a product; essentially, such database provides a big repository of Bill of Materials for specific products and processes, along with associated environmental impacts and estimates of resource consumptions.

6. Conclusions

The analysis illustrated in this report is an initial step towards the development of decision support tools for CSC implementation, contributing to deliverable D1.5 (which will develop a tool measure the 'circularity quotient' of a supply chain), which will also become part of a set of modelling tools with the objective to design and plan supply chain in a CE context (D1.6).

After having introduced the origins of CE discourse in supply chains and described how the largest European MNEs have implemented the CE concept, the report has focused on the current indicators in the context of CSCM literature as well as those found in company CS reports. Leveraging on the literature, three alternative synthetic indicators have been proposed.

The definition of the first two synthetic indicators of CE in a supply chain (e.g. L-CEI and I-CEI) has taken into account the academic literature focused on previous CSCs Decision-making problems and the industrial practice, and hinting out gaps of current approaches.

CSCs are an attempt to operationalise production methods that enable regenerative and restorative processes to re-use material flows and waste as a resource according to an Industrial Ecology view. However, while current indicators seem mostly able to measure the negative environmental impacts of CSCs, they face some challenges in evaluating the economic and environmental potential behind the circulation of resources. The objective of the third indicator (CEI) is to acknowledge alternative and less popular indicators, which, has been already used both by researchers and by practitioners. Those indicators have been selected for their capacity to measure the prominence of feedback loops of products and materials, the shift towards regenerative resources and the capacity to reduce and recover waste streams across the supply chain processes.

Another gap, which characterise both the literature and the industrial practice, is represented by a simplified and superficial consideration of social implications in measuring the transition towards the CE in supply chains. With the inclusion of EMA in the last chapter, authors want to highlight a possible avenue to be explored, to integrate a more comprehensive evaluation of the social consequences of circular production systems.

[3] Ecoinvent is one of the world's leading life cycle inventory database. Available at: https//www.ecoinvent.org/

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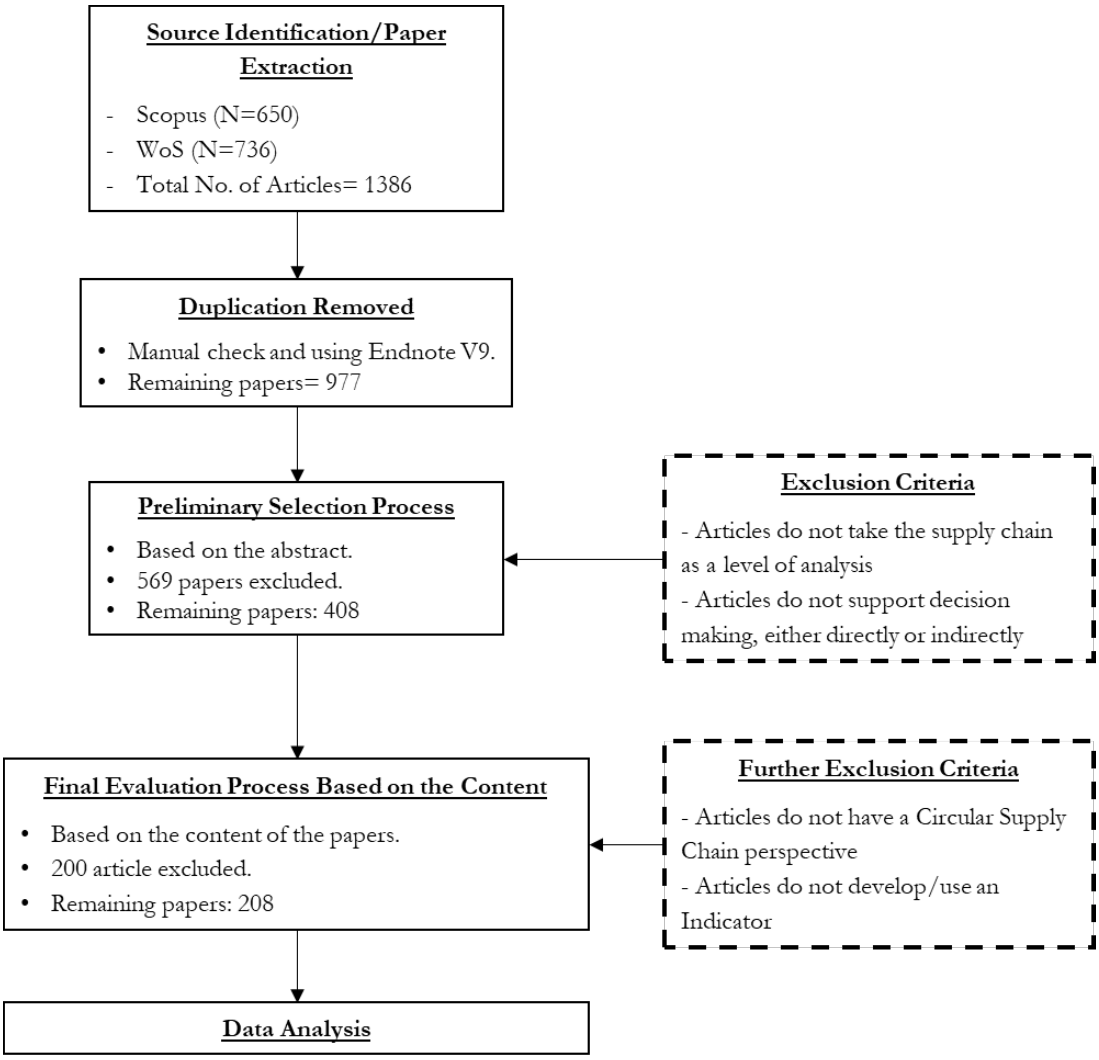
Appendix I: SLR Protocol

The first step in the systematic literature review was a keyword-based search using the SCOPUS and Web of Science databases. In order to maximise the number of available resources, the following generic keywords combination was used:

(('Circular Economy' OR 'Circular' OR 'Closed-loop' OR 'Reverse' OR 'Industrial Ecology' OR 'Industrial Symbiosis') AND 'Supply Chain*' AND ('indicator*' OR 'measur*' OR 'assess*' OR 'index*' OR 'metric*'))

Results were limited to articles and review document types. All the papers not in English have been excluded from the search. Papers published in 2020 have been excluded as well.



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