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Circular economy supply network management dynamics and its transition phases: a complex adaptive system

Gestão dinâmica da rede de suprimentos em economia circular e suas fases de transição: um sistema adaptativo complexo

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Gestão dinâmica da rede de suprimentos em economia circular e suas fases de transição: um sistema adaptativo complexo

Circular economy supply network management dynamics and its transition phases: a complex adaptive system

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*"Insanity is doing the same thing
over and over again and expecting
different results". Einstein, Albert*

*"Let's building a regenerative
and restorative economy through
a circular economy". MacArthur, Ellen*

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RESUMO

Braz, A. C. (2022). Gestão dinâmica da rede de suprimentos em economia circular e suas fases de transição: um sistema adaptativo complexo (Tese de Doutorado). Faculdade de Economia, Administração, Contabilidade e Atuária da Universidade de São Paulo, São Paulo.

Recentemente, a economia circular ganhou força nas agendas políticas e acadêmicas. No entanto, pouco se sabe da pratica gerencial sobre as configurações, dinâmicas e mecanismos de coordenação das redes de suprimentos em economia circular. Com o objetivo de preencher essa lacuna teórica e prática, este estudo emprega uma abordagem multimétodos envolvendo três artigos interrelacionados: uma revisão sistemática da literatura, estudo de caso de variância e processual (de sete cadeias de suprimentos circulares de diferentes setores industriais) e modelagem com dinâmica de sistemas. Como principais contribuições do artigo 1, apresentamos uma tipologia das cadeias de suprimentos relacionadas a economia circular, as principais estratégias de gestão das cadeias e suas táticas para implementá-las. O artigo 2 apresenta um modelo conceitual para gestão da rede de suprimentos em economia circular, com três elementos chave: mecanismos de gestão, ambiente interno e externo e propriedades emergentes, com três conjuntos de proposições. Outra contribuição é que uma gestão de rede multi-camadas com as partes interessadas externas à rede de suprimentos pode levá-la a uma configuração de rede de suprimentos de ciclo híbrido, combinando uma cadeia de suprimentos de ciclo fechado com uma de ciclo aberto, adaptando-se dinamicamente às mudanças do ambiente interno e externo. Também introduzimos dois tipos de pontos de alavancagem, em que os agentes com diferentes funções e posições na rede podem ser responsáveis por iniciar ou coordenar o fluxo reverso físico do subproduto ou produto pós-consumo. Finalmente, o artigo 3 traz um modelo de gestão das fases de transição da rede de suprimentos em economia circular ao longo do tempo, com os respectivos fatores circulares e desafios cooperativos e competitivos para a sua gestão, desde o seu pré-desenvolvimento até a sua auto renovação ou declínio. Também se discute uma ferramenta de estratégia para gerenciar a circularidade da rede de suprimentos para acadêmicos, formuladores de políticas e praticantes do mercado, modelada por dinâmica de sistemas simulando o impacto das variáveis-chave de gestão da rede de suprimentos (gestão da cadeia de suprimentos multi-camadas, gestão da liderança híbrida, mecanismos de coordenação e mecanismos de iniciação do fluxo de subprodutos e produtos pós-consumo circular) no desempenho da sua circularidade.

Palavras Chave: Economia circular. Gestão da cadeia de suprimentos. Sistema adaptativo complexo. Gestão de cadeia de suprimentos multi-camadas. Gestão da rede de suprimentos. Gestão das fases de transição.

ABSTRACT

Braz, A. C. (2022). Circular economy supply network management dynamics and its transition phases: A complex adaptive system. (Ph.D. Thesis) Faculdade de Economia, Administração, Contabilidade e Atuária da Universidade de São Paulo, São Paulo.

Recently circular economy is gaining momentum in the political and academic agendas. However, little is known from the managerial practice about the configurations, dynamics and coordination mechanisms of the circular economy supply networks. Aiming to fill this theoretical and practical gap, this study employs multimethod approach, developing three interrelated articles: a systematic literature review, a variance and process multiple case study (of seven circular supply chains of different industries), and system dynamics modelling. As main contributions we present in article 1 a supply chains' typology related to circular economy, a set of supply chains management strategies and tactics to implement circular economy. In article 2 we present a conceptual framework to circular economy supply network management, with three key elements: management mechanisms, internal and external environment, and emergent properties, with three sets of propositions. Explaining, that a multi-tier supply network management and external stakeholders may lead it to a hybrid loop configuration, a closed loop and open loop combined, dynamically adapting to internal and external environment changes. We also introduce two types of leverage points, related to agents' role and position in supply networks, one related on which agent initiates post consumption product or byproduct physical reverse flow and one related on which agent coordinates this activity. Finally, in article 3, we suggest an over time circular economy supply network transition phases management model, with the respective circular factors and cooperative and competitive challenges for managing it from its pre-development to self-renewal or decline. We also present a dynamic strategy tool to manage supply chain circularity for academics, policymakers and market practitioners, modeled by system dynamics, simulating the impact of supply network management key variables (multi-tier supply chain management, hybrid leadership, circular flows coordinating and initiating mechanisms) on its circularity performance.

Keywords: Circular economy. Supply chain management. Complex adaptive system. Multi-tier supply chain management. Supply network management. Transition phases management.

LIST OF PAPERS IN THIS PhD THESIS

Paper 1

Braz, A. C., & Mello, A. M. (2020). Supply chains types and strategies for circular economy transitions. Published in *9th International Workshop Advances in Cleaner Production Conference Proceedings, Melbourne, Australia. May 26th*, 2020 (Melbourne, Australia), 271. Manuscript also submitted for *Management Review Quarterly Journal. It is in R1 process.*

Paper 2

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Paper 3

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LIST OF SUPLEMENTARY PAPERS (NOT INCLUDED IN THIS PhD THESIS)

Paper 4

Braz, A. C., & Mello, A. M. (2022). Dynamics of circularity and sustainability in circular economy supply chain management. submitted for *Journal of Environment Planning and Management. It is under review.*

Paper 5

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Abbreviations

CAS	Complex Adaptive System
CE	Circular Economy
CESN	Circular Economy Supply Network
CI	Circularity Index
CLSC	Closed Loop Supply Chain
CLSN	Closed Loop Supply Network
DS	Descriptive Study
DRM	Design Research Methodology
HLSN	Hybrid Loop Supply Network
NRS	Natural Resource Scarcity
OEM	Original Equipment Manufacturer
OLSN	Open Loop Supply Network
ORQ	Overarching Research Question
OSCM	Operations and Supply Chain Management
PS	Prescriptive Study
PPB	Post-consumption Product and Byproduct
RC	Research Clarification
RQ	Research Question
RO	Research Outcome
RSC	Reverse Supply Chain
RS	Rede de Suprimentos
SC	Supply Chains
SCM	Supply Chain Management
SD	System Dynamics
SDG	Sustainable Development Goal
SLR	Systematic Literature Review
SME	Small Medium Enterprise
SN	Supply Networks
SSCM	Sustainable Supply Chain Management
WP	Work Package
WEEE	Waste from Electrical and Electronic Equipment

SUMMARY

1 INTRODUCTION

Circular economy (CE) research has grown significantly over the past few years, to the extent that it has become an applied field of knowledge driving research streams of strong influence on the modus operandi of a more sustainable world (Gandolfo & Lupi, 2021). Not surprisingly, in the mainstream operations and supply chain management (OSCM) literature, some studies use ‘circular economy’ as an umbrella term loosely applied to characterize the sustainability of production systems and related supply chains. The variety of CE perspectives contributes to contested claims about its theoretical underpinnings, which posit conceptual tensions and create a constellation of disparate ideas. Some of these are undoubtedly important to OSCM research, but many others still present inconclusive concepts. Some scholars have acknowledged that CE is directly related to sustainable production and operations, the integration of CE principles within sustainable supply chains and related operations can provide clear managerial and competitive advantages (Bressanelli et al., 2022). On the other hand, some scholars (Franco, 2017; Frei et al., 2020; Genovese et al., 2017) have acknowledged that the linkages between CE and sustainability are still problematic as the similarities and differences between both concepts remain ambiguous, with blurred conceptual contours that undermine the development of theory supporting sustainable OSCM. This scenario highlights the lack of a solid amalgamation between theory and practice (Alkhuzaim et al., 2021). From the perspective of knowledge generation, the CE concept has been discussed by scholars which is stimulating discussions and joint actions among academia, civil society, governments and companies from all over the world. It is noteworthy the rising interest by academia to comprehend and develop the CE field.

The number of publications in the Web of Science and Scopus using “Circular Economy” and “Supply chain management” has increased from 1 in 2006 to 140 in 2019. Circular Economy special issues emerged in the recent years in respected operations management journals, including the Production Planning and Control, International Journal of Production Research, International Journal of Production Economics and International Journal of Operations and Production Management, and sustainability operations such as Journal of Industrial Ecology, Resources, Conservation & Recycling, Journal of Cleaner Production and Sustainable Production and Consumption. Apart from the sustainability oriented journals taking also operations perspective, the concept is under discussion in the strategy (e.g. Business Strategy and the Environment), economics (e.g. Ecological Economics and Journal of Evolutionary Economics), innovation (e.g. Research Policy) and social sciences (e.g.

Technological Forecasting and Social Change) fields as well. The aggregation of different perspectives to ground the debate contribute to the development of CE as a promising research field to guide urgent discussions between the diverse macro-areas of knowledge and helping achieving sustainable development.

Therefore, the CE is grounded in knowledge from multiple fields. Several existing concepts must still be translated into this emerging field. For example, the intersection of operations and supply chain management and the circular economy demands clarification. This thesis contributes to the academy by clarifying the potential of supply chain management to understand and facilitate CE transitions. Discussing CE from the perspective of multi-stakeholders' complexities, stocks and flow structures, and the effects of feedback loops in internal and external environment boundaries change through multiple cases study approached by variance and process analysis combined with system dynamics modelling enrich to the debate. Besides, relying on complex adaptive system, multi-tier sustainable supply chain management and transition phases management theoretical lens allowed for a more comprehensive and grounded reasoning about the supply chain management fostering CE networks and transitions.

The Circular Economy concept has already an extensive practical application. Governments, business, consultancies and think tanks are discussing and applying the CE principles to foster a sustainable future in different regions and industries. Exemplary cases of application of CE strategies in businesses are widely reported including the cases in this research. Many tools for business model and product design are available. Besides, local, regional, and international policies continue to be globally discussed, designed, and implemented. However, for the time being, we are still far from reaching a sustainable consumption and production system and most companies are struggling to implement CE such as: Unilever (Unilever, 2021) and Globalpet (Globalpet, 2021) (have not yet find an efficient and effective tool or strategy to increase the quality and quantity of returned postconsumption products), Braskem (Braskem, 2022), besides this same challenge, it has not yet found a scalable solution to manage the integration of mechanical and chemical recycling operations flow. As well as, governments such as São Paulo city municipality (São Paulo, 2022), it has adhered to Ellen Macarthur Foundation program seeking solutions to become a circular city. In addition, industry entities, such as Federação das Indústrias do Estado de São Paulo (Fiesp, 2020), has promoted 2020 South American Circular Economy Forum as part of World Circular Economy Forum.

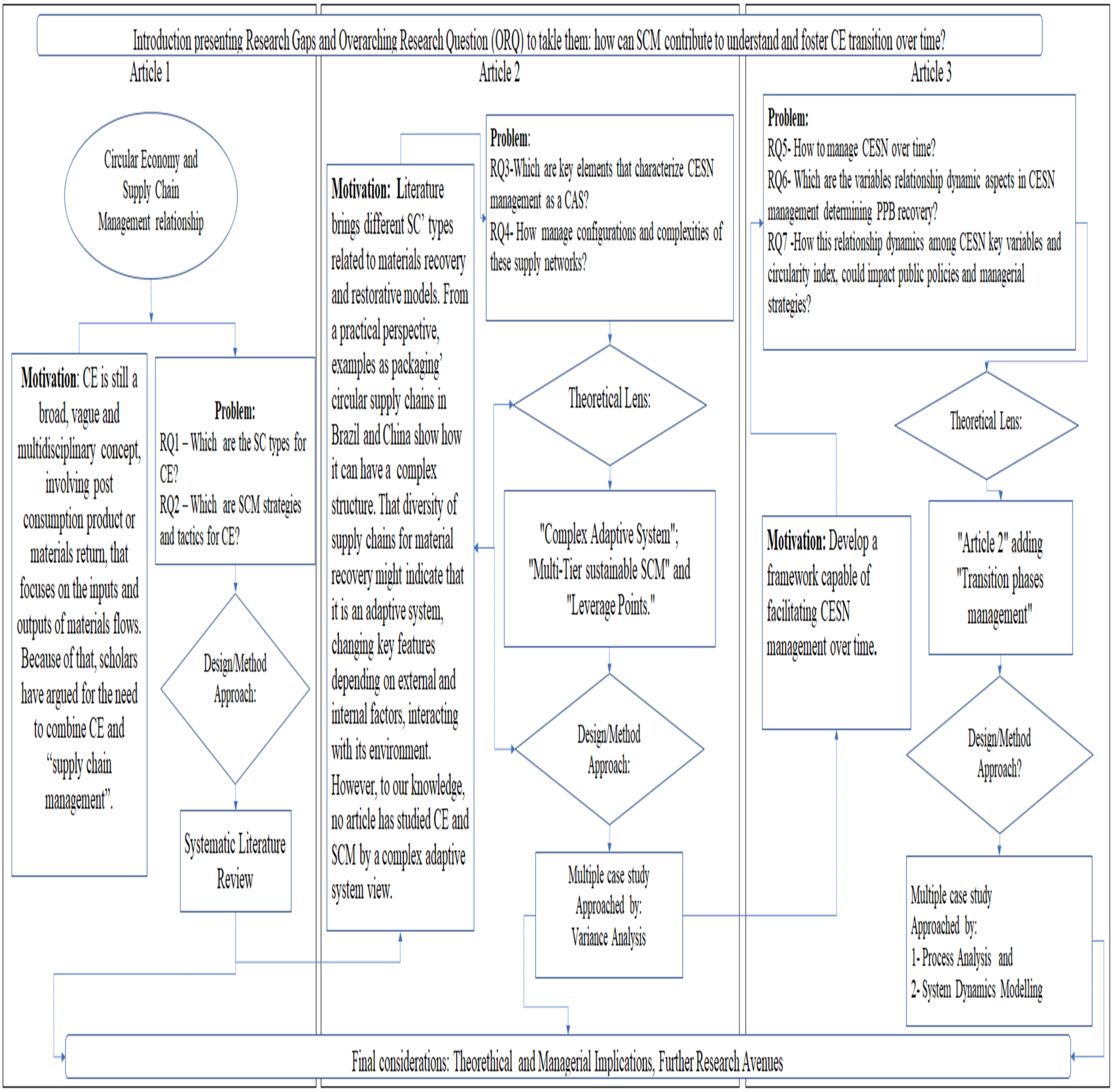
Therefore, to refine the concepts still in formation and disseminate validated knowledge, the academy must create tools to help business practitioners and policymakers to make the right decisions in CE transition. In this thesis, the choice to develop a tool was deliberate because it aims not only to understand further how SCM could foster CE transitions, but also to create ways to facilitate change. To do so, this thesis was designed as three article-based with additional background knowledge that links, integrates and discusses the articles. This section explains the theoretical foundation that leads to the definition of two research gaps. An overarching research question enables inquiring paths for resolving the identified gaps, supported by two additional research goals, a theoretical and a practical one, directs the research efforts to contribute to scholars and to managers. The research methodology details six work packages holding specific sets of objectives, questions, methods, and outcomes with scoping, descriptive and prescriptive aims. These six work packages lead to the research plan, three articles, and additional results contained in this thesis.

The main contributions for theory and practice are: (i) framework for supply chains types in circular economy, showing five supply chains types contributing to CE transitions and clarifying that they are increasing the level of broadness and complexity since they are applying different reverse supply chain process and materials recovery activities. The less complex and broad supply chain type is the sustainable supply chain that focus in address the three dimensions of sustainable development overall in linear supply chain. Thus, integrating CE principles would begin to expand sustainable supply chains boundaries by reducing the need of virgin materials which could increase the circulation of resources within supply chains systems Extending sustainable supply chain broadness through reverse supply chains that focus in the reverse flows of materials from the same or different players through activities such as: reuse, repair, refurbish, remanufacture or recycle. While closed loop supply chains increase the complexity adding to these activities the design, control and operation of the original equipment manufacturer, open loop supply chains add sustainability innovations from independent actors outside the control of the original equipment manufacturers; (ii) a circular economy supply network management framework, identifying and characterizing three key elements (internal and external environment, management mechanisms and emergent properties) that influence its configuration and dynamics; (iii) a circular economy supply network transition phases management dynamics, that are pre-development, learning, expansion, leadership, stabilization and self-renew or decline, identifying and explaining the coopetitive challenges and circular factors for each phase; (iv) CESN transactional, transformational and hybrid leaderships by each actors' role and position. Finally, the structure of the thesis prepares the reader for the next sections.

1.1 Thesis structure

The thesis structure shown in Figure 1, is following detailed, along with identifying the research outcomes contained in each section. Section 1, Introduction, contains the theoretical foundation sustaining the research gaps, goals and overarching question.

Figure. 1- Thesis structure



Source: elaborated by the author.

In addition, research design explaining the three articles' interconnections methodology and justification are detailed. The three articles are presented in sections 2, 3, and 4. Although article 2 presents knowledge that sustains much of the conceptual development of the SCM to foster CE, the studies presentation follow the order in which they occurred. The order of occurrence is maintained as it better portrays the research journey.

Thus, the order of the sections follows Table 1, which details the title of the three articles.

Table 1- The title and section of each article

Section	Articles' Title	Methodology
2	1-Supply chains types and strategies for circular economy transitions	Systematic literature review
3	2- Circular economy supply network management: a complex adaptive system	Multiple cases study by variance analysis
4	3- Circular economy supply network transition phases management dynamics	Multiple cases study by process analysis and system dynamics modelling

Source: elaborated by the author.

Finally, section 5 contains the final considerations for the thesis, highlighting contributions to academia and practice, alongside further avenues of investigation.

1.2 Theoretical background

Circular economy is still a broad, vague and multidisciplinary concept involving postconsumption products or materials return (Kirchherr et al., 2017) that focuses on the inputs and outputs of material flows. That is deeply related to activities such as reduction, reuse, repair, refurbish, remanufacturing and recycling (Braz et al., 2018; Kalmykova et al., 2018). Hence, scholars have argued for the need to combine CE and supply chain management (SCM) research (Frei et al., 2020). One of the challenges connecting CE with SCM is that CE research is handled across a various set of disciplines, ranging from "environmental economics" to "management science" (De Angelis et al., 2018). In addition, all literature review (LR) or systematic literature review (SLR) until 2019 on CE and SC (33 papers) have not a combined understanding of the SCM types, strategies and tactics to foster CE (see Table 8), and the high number (thirteen) of different SC types related to postconsumption products and materials recovery might hamper the development of this research field.

The most frequents SC connected to CE, showing that could have been an evolution related the complexity and broadness of scope of each SC type from more focused “sustainable supply chains” (SSC) to more comprehensive “circular supply chains” (CSC), their most popular definitions are:

-Sustainable supply chains management (SSCM), could be defined as: " the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements, looking at the overall supply chain or life-cycle of the product”. Besides, “when the focal company is pressured, it usually passes this pressure on to suppliers” (Seuring & Müller, 2008 p. 1700 and 1723);

-Reverse supply chains (RSCs), could be defined as: “the reverse flow of materials from the same agents or different independent agents in the SC through closed or open loops” (Guide & Van Wassenhove, 2009);

-Closed loop supply chains (CLSCs), could be defined as: “the management of the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time. The complex systems that involve reverse flow of postconsumption products from the final customers to the original manufacturer” (Guide & Van Wassenhove, 2009);

-Open loop supply chains (OLSCs), which are similar to RSC, but involve “independent actors developing new products/solutions outside of original manufacturer control” (Kalverkamp & Young, 2019);

- Circular supply chains (CSCs), which could be considered “an extension of closed loop supply chains and the embodiment of CE principles within SCM, through coordinated forward and reverse supply chains via purposeful business ecosystem integration for value creation from products/ services, by-products and useful waste flows through prolonged life cycles that improve the economic, social and environmental sustainability of organizations.” (Batista et al., 2018; De Angelis et al., 2018).

Therefore, the literature suggests different SC types related to material recovery and restorative models (Kalverkamp & Young, 2019). From a practical perspective, examples of packaging circular supply chains in Brazil and China show how such SC can have a complex structure (Batista et al., 2018). Circular economy supply chain could be conceptualized as a connected network of organizations involved in the design and management of value adding processes and the value recovery of a product, component, material, byproduct or waste.

The diversity of supply chains for material recovery might indicate that it is a complex adaptive system that changes key features depending on external and internal factors, that interacts with its environment (Choi et al., 2001; Nair & Reed-Tsochas, 2019).

Research gap 1: Circular economy supply chains have increasing complexity, face of internal and external environment changes, besides that is limited the understanding of these supply chains' sources of complexity and configurations.

In addition, empirical support for the theoretical discussion is limited, with the majority of empirical findings focused on downstream supply chains (Batista et al., 2018; Guide & Van Wassenhove, 2009). There is, also a call to study the CE and CLSCs with a more systemic approach (Coenen et al., 2018; Murray et al., 2017). Hence, we need, to better understand this circular economy supply chain management over time with its transition phases. (Chizaryfard et al., 2021).

Circular economy (CE) has feedback loops and could be considered an evolutionary system for industrial transformation over time. This is also the central core of system dynamics, that could be used to better understand circular economy supply chain management variables dynamic relationship and their over time transition phases (Alkhuzaim et al., 2021). However, still is scant in the literature circular economy supply chain management system dynamics modelling studies explaining variables relationships dynamics over time connected to quantitative circularity performance measures with the number and types of parameters to be measured (Kravchenko et al., 2020; Rebs et al., 2019). As well as, the empirically grounded, theoretical explanation of the buyer-supplier and supplier-buyer relationship dynamics between the firms in extreme upstream and downstream supply chains positions, to implement circularity of postconsumption products and byproducts, still there were not discussed (Batista et al., 2018). Besides that, most researches studying circular economy and supply chain management (SCM), have data collection from just one company in a micro level unit of analysis (Braz & Mello, 2020).

Acknowledging the high complexity of real SCs, this research uses networks rather than chains following Carter et al. (2015) and Choi et al. (2001) suggesting as circular economy supply network (CESN). Thus, the high complexity of supply chains and the scant information on practical aspects of how to introduce the circular economy into supply chains (SC) in a real-world context over time could be the cause of this slow implementation (De Angelis et al., 2018; Frei et al., 2020).

Research gap 2: Available tools and frameworks insufficiently address the experimenting needs of theoretical explanation of the buyer-supplier and supplier-buyer relationship management dynamics between the firms in extreme upstream and downstream positions in supply networks to implement and manage circular economy supply networks over time.

The theoretical foundations and research gaps presented in this section pave the path for the research questions addressed in this research and used methodologies.

1.3 Statement of the Purpose and Overarching Research Question

A general research question and two complimentary goals were defined to tackle the two research gaps identified when taking the perspective of systems thinking and case study for investigating circular economy supply network transitions. The general research question is following outlined:

Overarching research question (ORQ): How can supply chain management contribute to understand and foster CE transition over time?

The ORQ embraces the CE and SCM fields perspective, which are under rapid development in theory and practice, thus, the primary beneficiaries of the contributions in this thesis. Two complementary research goals are derived from the overarching research question. They constitute a theoretical goal and a practical goal, aiming to direct the thesis to contribute to academia and practice, as follows:

Theoretical goal (TG): Understand transition phases management towards CE over time, through SCM perspective;

Practical goal (PG): Generate tools to help SCM decision-makers to foster CE over time.

To accomplish these overarching research question and the two complementary goals, this research has the efforts following described.

1.4 Thesis design

This thesis develops three separates but highly interrelated articles to address the fundamental research question of the present research, what is how can supply chain management contribute to understand and foster CE transition over time?

The first article uses the systematic literature review (SLR) to provide clear definitions supporting supply chains related to CE. The second article apply complex adaptive system

(CAS) (Choi et al., 2001; Nair & Reed-Tsochas, 2019), leverage points (Meadows, 1999), and multi-tier sustainable supply chain management (Jia et al., 2019; Tachizawa & Wong, 2014) as the theoretical lens to study multiple cases by variance approach (Gehman et al., 2018) characterizing circular supply network management as complex adaptive system and investigate how to manage this circular supply chain. The third article uses also these theoretical lens plus transition phases management lens (Bressanelli et al., 2022; Kanger & Schot, 2016; Kivimaa et al., 2019) to study multiple cases by process approach (Gehman et al., 2018) to investigate how to implement circular supply chain management over time combined to system dynamics modelling to offer a management simulation dynamic tool to understand variables relationship impact on circularity performance, as following described.

Research design is presented following the design research methodology (DRM) (Blessing & Chakrabarti, 2009). Work packages (WPs) positioned in the DRM are presented in table 2, to facilitate the understanding of the results of this research. Addressing overarching research question, theoretical and practical goals, articles' specific research questions, methods and outcomes are following detailed for each WP (Blessing & Chakrabarti, 2009).

Table 2- Work packages structure followed in this research

Research Stage	Research objectives	Work Packages (WP)
Research Clarification (RC)	Setting research scope. Understanding how SC are related to CE.	WP1-Systematic literature review to set research scope and clarification (Article 1).
Descriptive Study I (DS-I)	Increasing our understand of the phenomenon, identifying and clarifying which SC types, strategies and tactics could foster CE.	WP2- Developing research foundation (Article 1).
	Develop the foundation for a CESN management drawing in CAS that enables experimenting and discussing how to foster CE.	WP3- CESN management framework characterized as CAS (Article 2).
Prescriptive Study (PS)	To use the understanding obtained in previous stages to determine the most suitable factors to be addressed in PS (key factors) in order to improve the existing situation. Develop practical support, generating a framework capable of facilitating decision-making in CESN management over time.	WP4-CESN transition phases management framework (Article 3).
Descriptive Study II (DS-II)	Generate a tool capable of facilitating decision-making in CESN management. Investigate effects of support use, discussing scenarios of dynamic aspects in circular economy supply network management variables relationship.	WP5-CESN management SD simulation tool (Article 3).
Iterative Process	Theoretical goal: Understand CE transitions through SCM perspective over time; Practical goal: Generate tools to help SCM decision-makers to foster CE over time.	WP6 - Cross articles contributions and outcomes analysis.

Source: elaborated by the author.

The first stage research clarification (RC) approached by WP1 is detailed in Table 3, aims to identify the specific research goals we must accomplish to achieve theoretical and practical research goals, developing and providing foundation and focus to descriptive study one (DS-I) stage finding factors or elements that contribute to find or hind specific answering research questions and help prescriptive study (PS) stage on developing support to address these factors or elements over time. Moreover, to provide a focus to descriptive study two (DS-II) stage evaluating their effects by simulating several scenarios over time.

Table 3- WP1(Article 1) - Description of research questions and research outcomes

Research Stage	Research Objectives	Research Questions (RQs)	Method	Research Outcomes (ROs)
RC	Understanding how SC are related to CE.	RQ1: Which supply chains types are related to circular economy?	Systematic Literature Review	RO1: There are more than ten SCs types for CE and they are increasing the level of broadness and complexity.

Source: elaborated by the author.

Second stage descriptive study one (DS-I) approached by WP2 and WP3 is detailed in Table 4, aims to obtain a better understanding of the existing situation by identifying and clarifying in more detail the elements that influence the preliminary understanding and the way in which these elements/categories influence it, complete conceptual framework and propositions including the variables, suggesting possible key elements categories that might be suitable to address in the PS and DS-II stages, as these are likely to lead to an improvement of the existing situation.

Table 4- WP2 and WP3 (Articles 1 and 2) - Description of research questions and research outcomes

Research Stage	Research Objectives	Research Questions (RQs)	Method	Research Outcomes (ROs)
DS-I	Identifying and clarifying which SC types, strategies and tactics could foster CE.	RQ2: Which SCM strategies and tactics could foster circular economy?	Systematic Literature Review	RO2: SC management strategies and tactics could foster CE by different SC types, countries and industries.
	Develop the foundation for a CESN management as CAS that enables experimenting and discussing how to foster CE.	RQ3: Which are the key elements that characterize CESN management as complex adaptive systems?	Case Study	RO3: Conceptual model with key elements, its variables and characteristics.

	Generate a framework capable of facilitating decision-making in CESN Management.	RQ4: How firms can manage the configurations and complexity of these supply networks?	Variance Approach	RO4: CESN framework and propositions.

Source: elaborated by the author.

Third stage prescriptive study approached by WP4 is detailed in Table 5, aims to use the initial understanding obtained in DS-I to refine it, and determine the most suitable categories to be addressed in PS (the key categories) in order to improve the existing situation, developing an impact model, based on the reference modes and initial impact model, describing the desired, improved situation that is expected as a consequence of addressing the selected key categories, selecting part of the impact model to address and to determine the related success elements and measurable success criteria, developing the intended support, that addresses the key categories and subcategories relationship in a dynamic and systematic way, and to realize this to such a level of detail that an evaluation of its effects can take place against the measurable success criteria.

Table 5- WP4 (Article 3) - Description of research questions and research outcomes

R. Stage	Research Objectives	Research Questions (RQs)	Method	Research Outcomes (ROs)
PS	Develop practical support, generating a framework capable of facilitating decision-making in CESN management over time.	RQ5: How to manage circular economy supply network over time?	Case Study Process Approach	RO5: CESN transition phases management over time framework.

Source: elaborated by the author.

Last stage descriptive study two (DS-II) approached by WP5 is detailed in Table 6, aims to evaluate the actual support with respect to its in-built functionality, consistency, etc., the support evaluation, in order to proceed from PS to DS-II to evaluate the effects of the support and developing an outline evaluation plan to be used as a starting point for the scenario's evaluation in DS II. In addition, identify whether the support can be used for the task for which it is intended and has the expected effect on the key categories (application and evaluation), evaluating whether the support indeed contributes to success (success evaluation), i.e., whether the expected impact, as represented in the base case impact model, has been realized, identifying necessary improvements to the concept, elaboration, realization, context, structure and behavior of the support.

Table 6- WP5 (Article 3) - Description of research questions and research outcomes

R. Stage	Research Objectives	Research Questions (RQs)	Method	Research Outcomes (ROs)
DS II	Generate a tool capable of facilitating decision-making in CESN management.	RQ6: Which is the variables relationship dynamic aspects in CESN management determining postconsumption products and byproducts recovery?	Case Study System Dynamic Modelling	RO6: Discussing dynamic causal loop connections among CESN management key variables: internal and external environment, management mechanisms, and emergent properties.
DS II	Investigate effects of support use, through scenarios of dynamic aspects in CESN management variables relationship.	RQ7: How this relationship dynamics among circular economy supply network key variables and circularity index, could impact public policies and managerial strategies?		RO7: Presenting quantitatively how CESN management dynamic behavior influence internal and external stakeholders to adopt circularity, through multi-tier SC management, hybrid leadership and initiating mechanisms bringing new agents to CESN.

Source: elaborated by the author.

Finally, as an iterative process, final work package, WP6, consists of cross analysis of previous research outcomes addressing the overarching research question based on the research foundation contained in this thesis. Table 7 summarizes the work package 6, containing the overarching research question: How can SCM contribute to understand and foster CE transition over time? The knowledge accumulated with the development and application of the frameworks and tools in the three research articles allowed development of guidelines for experimenting with CESN management using SD, which are made available in the section 5 of this thesis.

Table 7- WP6 - Description of research questions and research outcomes

R. Stage	Research Objectives	Overarching Research Question	Method	Overarching Research Outcomes
Iterative Process	Theoretical goal: Understand CE transitions through SCM perspective over time. Practical goal: Generate tools to help SCM decision-makers to foster CE over time.	ORQ: How can SCM contribute to understand and foster CE transition over time?	Cross articles contributions and outcomes analysis	ORO:SC types framework for CE, CESN management framework with propositions and system dynamics modelling; CESN transition phases management' circular factors and events framework, CESN contextual, structural and behavioral definition.

Source: elaborated by the author.

2 SUPPLY CHAINS TYPES AND STRATEGIES FOR CIRCULAR ECONOMY TRANSITIONS

Circular economy (CE) is considered a new economic paradigm. Its great comprehensiveness and complexity stem from different disciplines, requiring studies and efforts at different levels and disciplines for effective and efficient implementation. Thus, it arguably remains a broad concept. Numerous definitions involve the post consumption product return, which is clearly connected to supply chain management (SCM). However, the relation between CE and SCM still has received limited attention, in literature. Aiming to fill this theoretical gap, we present the body of academic literature on the main supply chains (SC) types, strategies and tactics that could foster CE, by means a systematic literature review combining bibliometric and content analysis of studies published in the Scopus and Web of Science databases. Our results show that SC types most connected to CE are closed-loop, open-loop, reverse, circular and sustainable SC. We also find that, SCM strategies related to CE are: collaboration management, competitive advantage management and systemic effectiveness management. Furthermore, nonlinear SCM seems to have a more sophisticated management incorporating more agents and levels (multi-tier supply chains) with management of competitive advantage through some tactics as an antecedent to foster CE transitions. Finally, we suggest a set of tactics by industry, SC type and country. This research contributes to both literature and practice by broadening the understanding of the challenges involved in CE transitions and how it is related.

Keywords: Circular economy. Supply chain management.

2.1 Introduction

Only recently, has the discussion of the CE paradigm appeared on the political and academic agenda. In particular, in Europe (European Commission, 2014) and China (Principles et al., 2009) CE is hoped to promote economic development by creating new sustainable businesses and jobs and reducing raw material price volatility, natural resource scarcity and costs, and environmental tensions and impacts (Kalmykova et al., 2018). Despite this growing importance, CE, arguably remains a broad and vague concept. Most of CE definitions involve post consumption product return, material and products flows, by activities such as reducing, reusing, remanufacturing and recycling (Braz et al., 2018; Kazemi et al., 2018).

One of the challenges connecting CE with SCM is that CE research is handled across a various set of disciplines, ranging from "environmental economics" to "management science" (De Angelis et al., 2018). Moreover, all literature review (LR) or systematic literature review (SLR) to date on CE and SC (33 papers) have not a combined understanding of the SCM strategies, tactics and types to foster CE (see Table 8). This study aims to contribute to this debate by exploring how SCM can foster CE, addressing the following questions:

RQ1- What supply chains types are related to circular economy?

RQ2- Which supply chain management strategies and tactics could foster circular economy paradigm?

To answer these research questions, we conduct a systematic literature review combining bibliometric and content analysis of studies published in Scopus and Web of Science databases.

Our findings show that the high number (thirteen) of different SC types related to post consumption product recovery might hamper the development of this research field. Therefore, to organize this diversity and improve this research field we suggest SC types framework, defining and sorting the most frequents SC types connected to CE, showing that could there be an evolution related the complexity and broadness of scope of each SC type from more focused "sustainable supply chains management" (SSCM) to more comprehensive "circular supply chains" (CSC).

We also propose a set of SCM strategies to foster CE: collaboration management, competitive advantage management and systemic effectiveness management. Once, nonlinear

SCM seems to have a more sophisticated management incorporating more agents and levels (multi-tier supply chain management (Mena et al., 2013)) by the management of competitive advantage through some tactics as an antecedent to achieve CE implementation as shown in our framework.

Regarding practical aspects, we present a list of forty-three tactics by industry, SC type and country that could be used by managers to implement CE, as well as, policy makers to provide more focused regulations for each industry and country. Moreover, combining CE and SCM could help to achieve United Nations (UN) "sustainable development goal number twelve" (SDG- 12) regarding "responsible consumption and production" (George et al., 2016). Finally, we suggest a future research agenda.

2.2 Prior Literature Review

Previous literature review studying circular economy and supply chain detailed in Table 8, show that no paper to date (Dec 2019) has reviewed the SCM strategies, tactics and types towards CE implementation, by country and industry. Therefore, our study is advancing for building theory in this field, and may be the first (to our knowledge) to explore how SCM strategies, tactics and types could foster CE.

Table 8- Literature review to date (Dec 2019) on SC and CE

Article objective	Article	Method
They review the literature (TRL) on CE initiatives.	(Ghisellini et al., 2016)	LR
TRL on CE definitions.	(Kirchherr et al., 2017)	LR
TRL on CE concepts.	(Murray et al., 2017)	LR
TRL on CE by different fields.	(Homrich et al., 2018)	SLR
TRL on drivers, barriers ad enablers of photovoltaic SC on CE.	(Salim et al., 019)	SLR
TRL on sustainable SC to understand the CSC and which forms of CSC enables regenerative process.	(Batista et al.,2018)	SLR
TRL on links between SCM, sustainable SCM and CE.	(De Angelis et al., 2018)	SLR
TRL on GSCM and CE to clarify linkages between these concepts.	(J. Liu et al., 2018)	SLR
TRL on the drivers, barriers and practices that influence the implementation of the CE in SC context.	(Govindan & Hasanagic, 2018)	SLR
TRL on the customer experience of CE product service systems	(Schallehn et al., 2019)	SLR
TRL on SC practices and conditions towards CE.	(Masi et al., 2017)	SLR
TRL on industrial symbiosis, CE in discrete parts product manufacturing industry.	(Halstenberg et al., 2017)	SLR
TRL on Reverse SC financial performance including in CE.	(Larsen et al., 2018)	SLR
TRL on bullwhip effect on closed loop SC.	(Braz et al., 2018)	SLR
TRL on CE, to identify research gaps and to provide potential future research directions.	(Merli et al., 2018)	SLR
TRL on CE and SC to propose a CSCM definition	(Farooque et al., 2019)	SLR
TRL on sustainability, sustainable development, CE and SC.	(Muñoz-Torres et al., 2018)	SLR
TRL on the RL and closed loop SC literature in WEEE.	(Islam & Huda, 2018)	SLR
TRL on the integration of energy efficiency in SCM and design including in CE.	(Marchi & Zanoni, 2017)	SLR
TRL of a Special Issue on CE and CSC.	(Batista et al., 2018)	LR
TRL on GSCM including in CE.	(Kazancoglu et al., 2018)	LR
TRL on CE strategies including in SC.	(Kalmykova et al., 2018)	LR
TRL on sustainable SCM by system dynamics view.	(Rebs et al., 2019)	LR
TRL on back casting, eco-design and CE.	(Mendoza et al., 2017)	LR
TRL in food security challenges SC in CE.	(Irani & Sharif, 2018)	LR
TRL of phosphorus use in CE.	(Mew et al., 2018)	LR
TRL on industrial symbiosis and CE.	(Mulrow et al., 2017)	LR
TRL on closing the loop in plastic packaging.	(Hahladakis & Iacovidou, 2018)	LR
TRL on sustainable SC network in CE.	(Winkler, 2011)	LR
TRL on sustainable SC network in CE.	(Winkler & Kaluza, 2006)	LR
TRL on critically material case studies analysis in CE	(Gaustad et al., 2018)	LR
TRL sustainable packaging for CE	(Meherishi et al., 2019)	LR
TRL on CE in industrial symbiosis	(Herczeg et al., 2018)	LR

Source: elaborated by the author.

2.3 Theoretical background

2.3.1 Circular economy and supply chain management

For this research, CE could be defined as “an industrial system that is restorative or regenerative by intention and design, aiming to maximize the circulation of resources between the points of use and production, where products, components and materials are maintained in the market at their highest utility and value in the long term, that replaces the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus as a tool to organize social and natural resources to create environmental quality, economic prosperity and, equity and social well been, to the benefit of current and future generations” (Ghisellini et al., 2016; Kirchherr et al., 2017). CE is also considered a new economic paradigm. Its great comprehensiveness and complexity stem from different disciplines. Perhaps for this reason CE has received so many different definitions (Merli et al., 2018; Vlajic et al., 2018). SCM is one of these disciplines. CE concept is deeply related to material and products flows, by activities such as reducing, reusing, remanufacturing and recycling (Braz et al., 2018; Genovese et al., 2017).

Prior literature in product recovery options was conceptualized as “an integrated supply chain where service, product recovery, and waste management activities are included. Returned products and components can be resold directly, recovered, or disposed {incinerated or land- filled). The five product recovery options are: repair, refurbishing, remanufacturing, cannibalization, and recycling. The options are listed in order of the required degree of disassembly (teardown). All options are suitable for both products and components (Thierry et al., 1995, p. 117).”

Therefore, SCM is also related to CE, because might involve efforts at different levels, from such micro (at the firm) and macro (at the governments of cities, states and countries) levels. In order to connect those levels, it also involves decisions on supply and value chains, or meso level (Masi et al., 2017). Therefore, in supply and value chain level, CE depends on multidimensional changes and management strategies to link different agents in a SC such as: transaction costs, information, knowledge, products, material flows and exchanges, responsibilities, foreseen and sharing advantages (Jain et al., 2018; Leising et al., 2018). Hence, combinations of multiple SCM strategies and/or types are required.

2.3.2 Circular economy and related supply chain types

CE concept could be synthetized as a system for maintaining the value and utility of materials and products in the long term, hence, it is important to understand which SC types are related to post consumption products and byproducts' value recovery. The literature introduces the concepts of the reverse supply chains and closed loop supply chains, which are associated with restorative models that include several processes and activities to recover postconsumption products and parts (Braz et al., 2018; Guide & Van Wassenhove, 2009; Kalverkamp & Young, 2019).

CLSC are complex systems that involve reverse flows of post consumption products, from final customers to the original manufacturer that can be reused, reprocessed, refurbished, remanufactured or recycled, recovering their value. On the other hand, RSC focus on the reversal flow of materials from different and independent players in the SC through closed or open loops (Guide & Van Wassenhove, 2002; Kalverkamp, 2018).

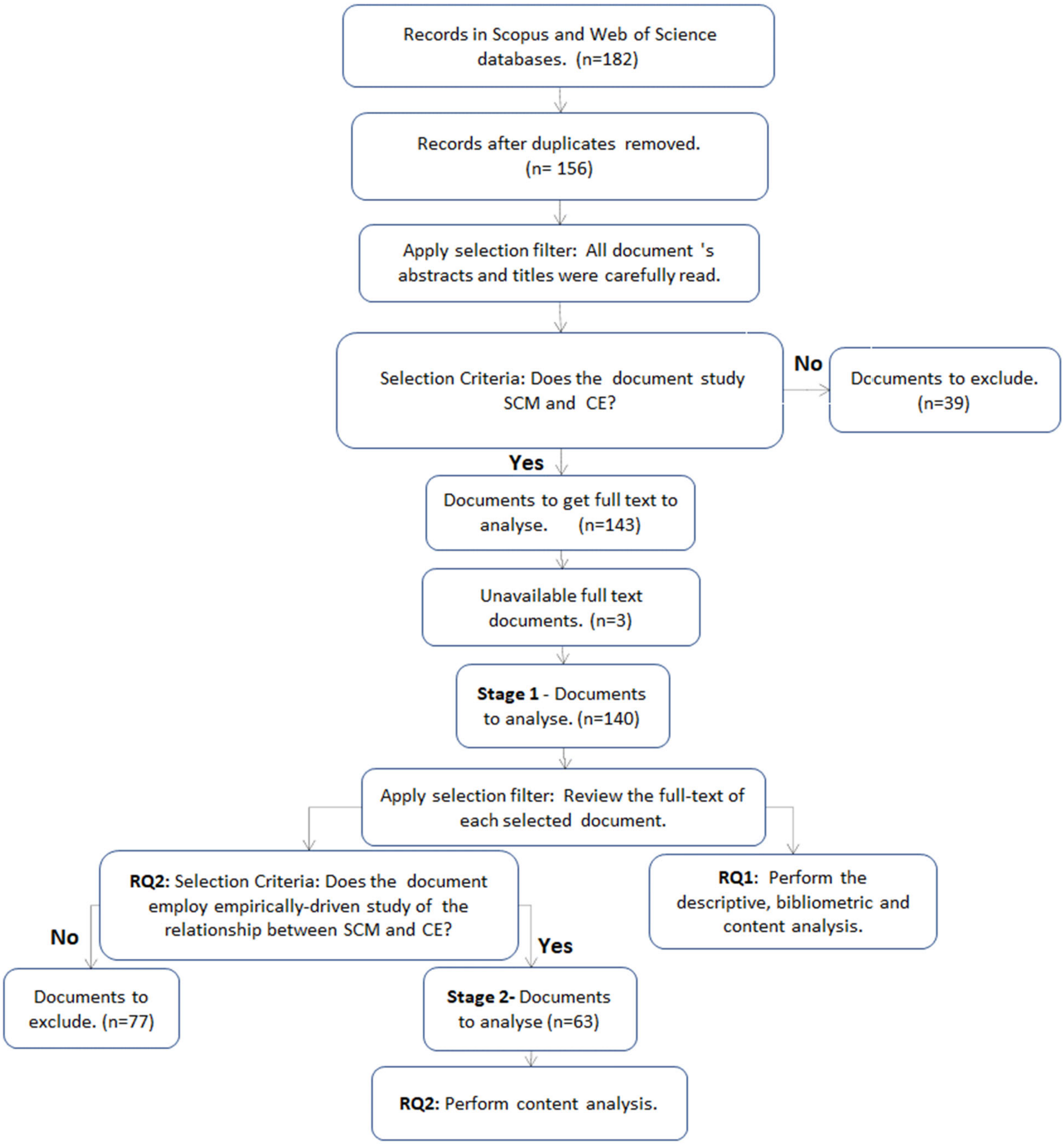
More recently, researchers have presented an additional type, circular supply chain which aims to be an intrinsic part of the CE on the micro (firm) level and meso (SC) level. A CSC can be conceptualized as a "connected network of organizations involved in the design and management of value adding processes and value recovery of a product, component or material" (Vlajic et al., 2018) that focuses on end-of-life product management for reuse, repair, reassembly, remanufacture, recycling and waste disposal (Jain et al., 2018). "It also represents an expansion of the closed loop supply chain narrative of a sustainable SC in terms of the scope and focus of the value chain systems they consider" (Batista et al., 2018). "Open-loop supply chains" is another type of SC related to CE. It aims to facilitate the sustainable performance of CLSC through independent actors that create loops and innovative solutions in the SC outside of original equipment manufacturing (OEM) control (Kalverkamp & Young, 2019).

2.4 Research design

To identify how the literature on the CE and SCM has developed, we explore the available body of knowledge. A mixed-methods approach is applied: a SLR (Tranfield et al., 2003) that combines a quantitative bibliometric analysis and qualitative content analysis.

Besides that, to answer our research questions (RQ1 and RQ2) the SLR was divided in two stages (see Figure. 2).

Figure 2- Systematic literature review workflow



Source: elaborated by the author.

2.4.1 Sampling process

The first step consists of the search and string selection approach used to survey the existing literature in two “scientific databases, Web of Science (WoS) and Scopus”. These platforms were chosen because they include articles from other databases, such as ScienceDirect, ProQuest, Springer and Wiley. Therefore, they provide robust and reliable metadata for the bibliometric and content analyses,

After several simulations, the search strings used to perform this research were defined (detailed in Appendix 1). Two different string sets are used “circular economy” AND “supply chain management” to search within titles, abstracts and keywords. All articles in English recorded in these databases up to December 2019 were considered in the initial group.

Then we proceed of screening of the initial total sample of n= 182 documents (Fig. 2), removing duplicates documents in Scopus and WoS remaining n= 156 documents. Then we carefully read title, abstract and keywords, applying selection filter and criteria to each document: does the document study SCM and CE? We get a final sample of remaining n= 143 minus 3 unavailable full text documents n= 140 documents for stage 1, to review the full-text of each selected document to answer RQ1.

Then we applied the selection criteria: does the document employs empirically-driven study of the relationship between CE and SCM? Resulting a final sample of n=63 documents for stage 2, to answer RQ2 (Fig.2).

2.4.2 Data analysis

To answer RQ1, bibliometric, network and content analyses on the final sample n=140 were conducted. Bibliometric studies are gaining relevance due to the high number of scientific publications and the ability to use techniques to quantify and identify the relevance of research clusters in the field through search engines in scientific databases” (Bartolini et al., 2019). NVIVO 12 Plus and MS Excel were used to handle the data. Core relationships of the CE and SCM are presented through a keyword network analysis (Fig. 6) to provide an overview of the relationships between constructs and to identify main themes. The software used to illustrate the keyword network is “VOSviewer version 1.6.5” (Van Eck & Waltman, 2010).

Insights from the bibliometric analysis were the starting point for defining the codes and keyword networks. Further in the content analysis, new codes emerged from the answers to the research question RQ1. Adding a feedback loop for the content analysis that might be needed for the whole iterative process. To support the content analysis and the coding process, MS Excel, MS Word and NVivo 12 Plus were used.

Content analysis, is a class of methods at the junction of the quantitative and qualitative traditions, is auspicious for rigorous exploration of many important but difficult-to-study issues of interest to management researchers (Duriau et al., 2007).

The final codes selected to perform the content analysis, further findings and an overview of the researched samples, and statistical analysis, with the frequency in the literature and all references, are shown in Appendix 2. Content analysis, followed Mayring (2014) main steps: “review idea (research questions, search strategy and coding), operationalization (frequency counts and cross-tabulations), and the results and main conclusions (interpretation)”.

Coding process followed the Webber protocol (Duriau et al., 2007): “(a) definition of the recording units”: words and text segments; “(b) definition of the coding categories”: the main themes related to CE and SCM that answer our research questions; “(c) identification of the codes related to CE and SCM themes and categories”; “(d) test of coding on a sample of text”: we use the codes to tag text for retrieval and measurement, assigning values to text such as the frequency, amount or presence/absence of information, to start codebook creation; “(e) assessment of the accuracy and reliability of the sample coding”: comparing the code database and the research database; “(f) revision of the coding rules”: checking whether the codes retrieve the core of the texts related to the CE and SCM”; “(g) coding of all the text: finishing the codebook (Appendix2); and “(h) assessment of the achieved reliability or accuracy”: comparing the complete research database with the completed codebook using multiple coders to check the validity of our data source, i.e., journals indexed in Scopus or WoS.

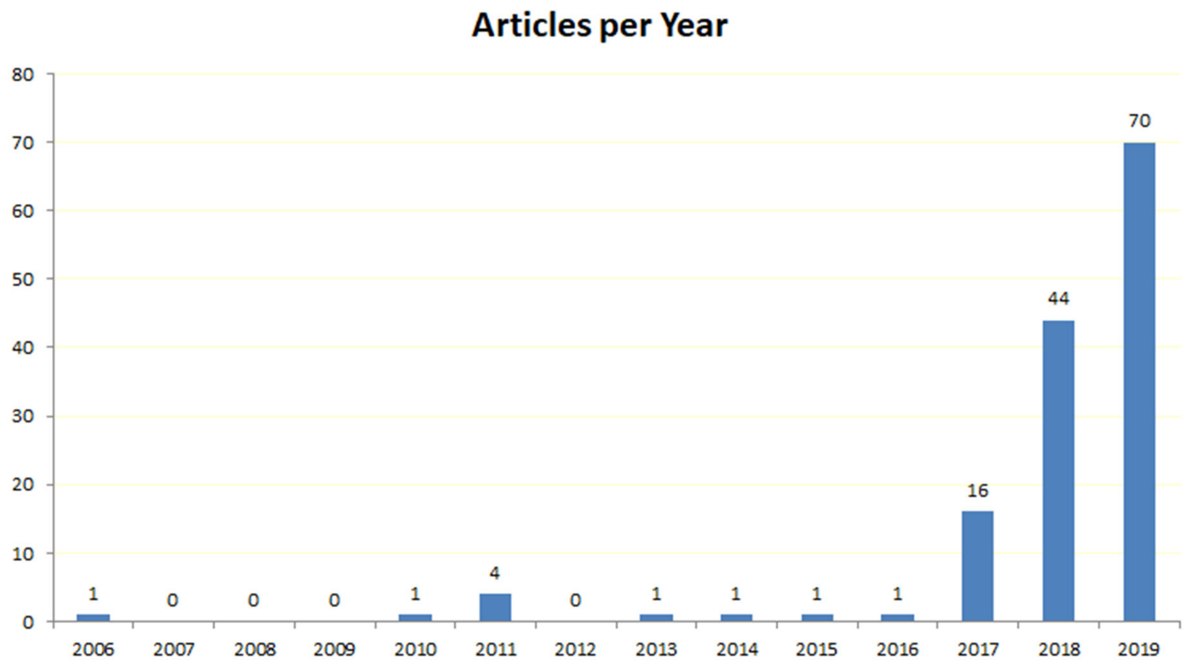
To answer RQ2, content analysis on the final sample of n= 63 was conducted.

2.5. Results

2.5.1 Bibliometric analysis

In response of RQ1 with our final sample of n=140, Fig. 3 provides an overview of publications over the years. To consider the time span, journals, research areas, etc., no filters were applied. The only filters applied were the document type (articles and reviews) and the language (English).

Figure 3- Evolution of publications by year across the period of analysis (2006-2019)

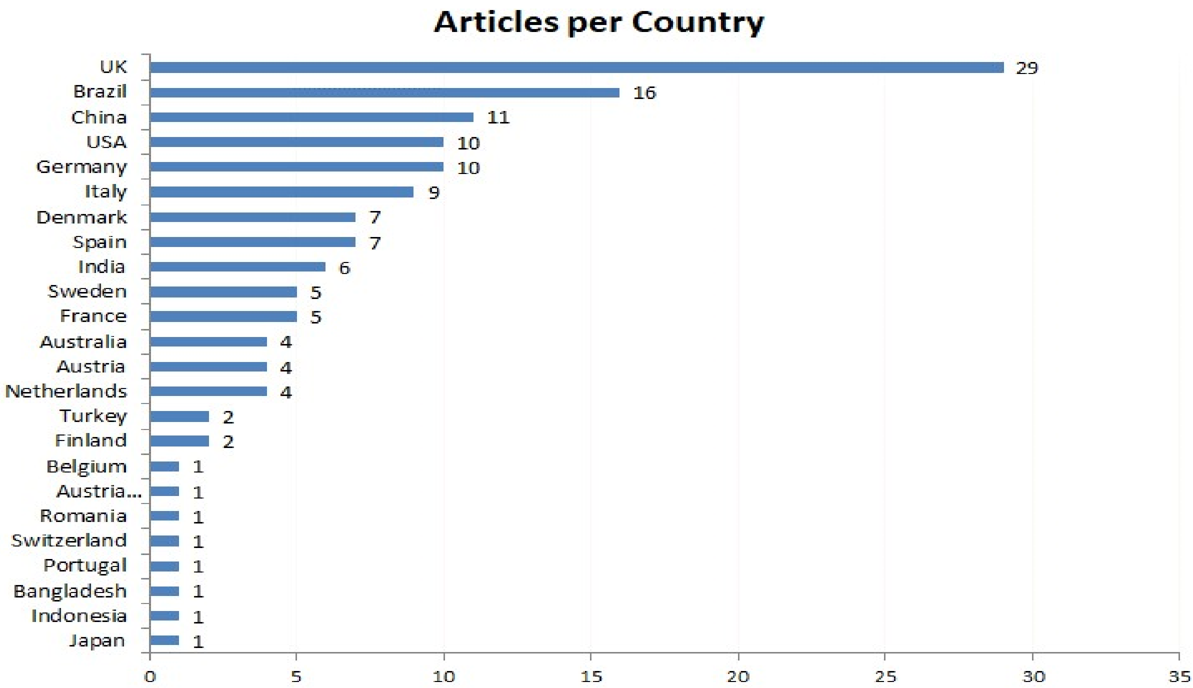


Source: elaborated by the author.

Remarkably, the amount of research published on the CE and SCM became relevant as of 2017 (Figure 3), reaching a peak in 2019 with 70 papers. The evolution of publications by year reveals that the first document studying the combined topics of the CE and SCM was published in 2006 and that such publications are gaining traction in academia since 93% of the total articles were published in the last three years, which shows a strong growth trend.

One possible explanation for this trend is that the European Union has adopted CE in its political agenda, the British government in association with the Ellen MacArthur Foundation (EMF) has called for research since 2013, and the Chinese CE promotion law was passed in 2009 (Masi et al., 2018).

Figure 4- Publications by country



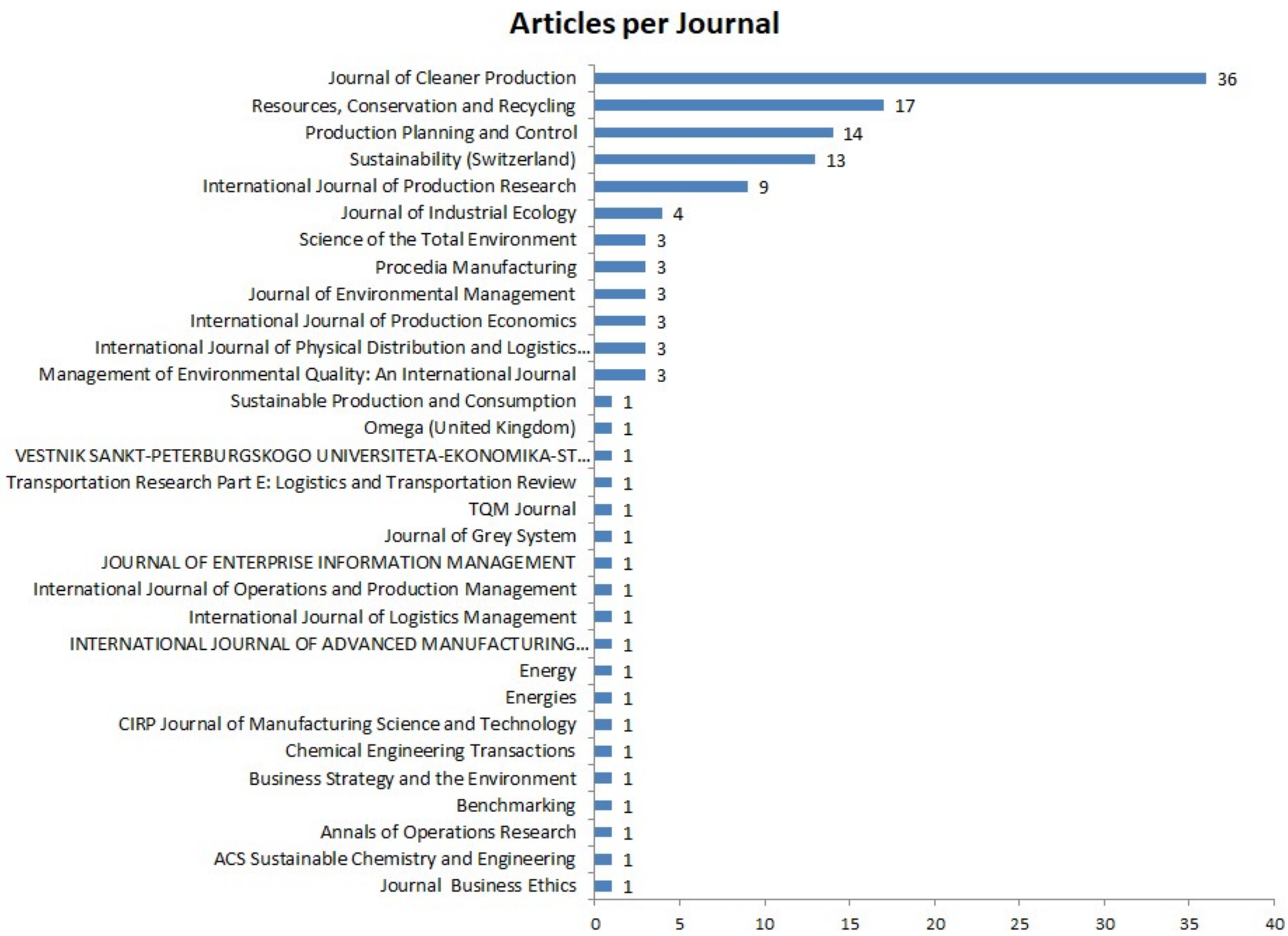
Source: elaborated by the author.

Based on the first author's institution, Fig. 4 shows that United Kingdom (UK) is the country with the highest number of publications, which can be explained by the political agenda of the European Union and the influence of the EMF on the British government (29). The UK is followed by Brazil (16) even without government incentives, China (11), which can be explained by China's CE promotion law. The United States of America (USA) (10), Germany (10), Italy (9), Denmark (7), Spain (7) and India (6) follow. Although research connecting CE and SCM is concentrated in Europe (89), the issue is becoming global; the top five countries, including Brazil (16), China (11) and the USA (10) are evidence that scholars worldwide are studying CE and SCM.

The 140 documents were published in 41 different journals, but 67 documents representing 62% of the total were concentrated in only six journals: the "Journal of Cleaner

Production" (36), "Resources Conservation and Recycling" (17), "Production Planning and Control" (14), "Sustainability" (13), "International Journal of Production Research" (9) and "Journal of Industrial Ecology" (4) as shown in Fig. 5. The subject areas of these journals based on the "SCImago Journal and Country Rank are mainly business management and accounting, environmental science, engineering and operations research". Furthermore, most of the documents were published in interdisciplinary sources, which are evidence that the CE and SCM are interdisciplinary concepts with broad research areas, resulting in strong complexity and great opportunities for future research.

Figure 5- Publications by journal



Source: elaborated by the author.

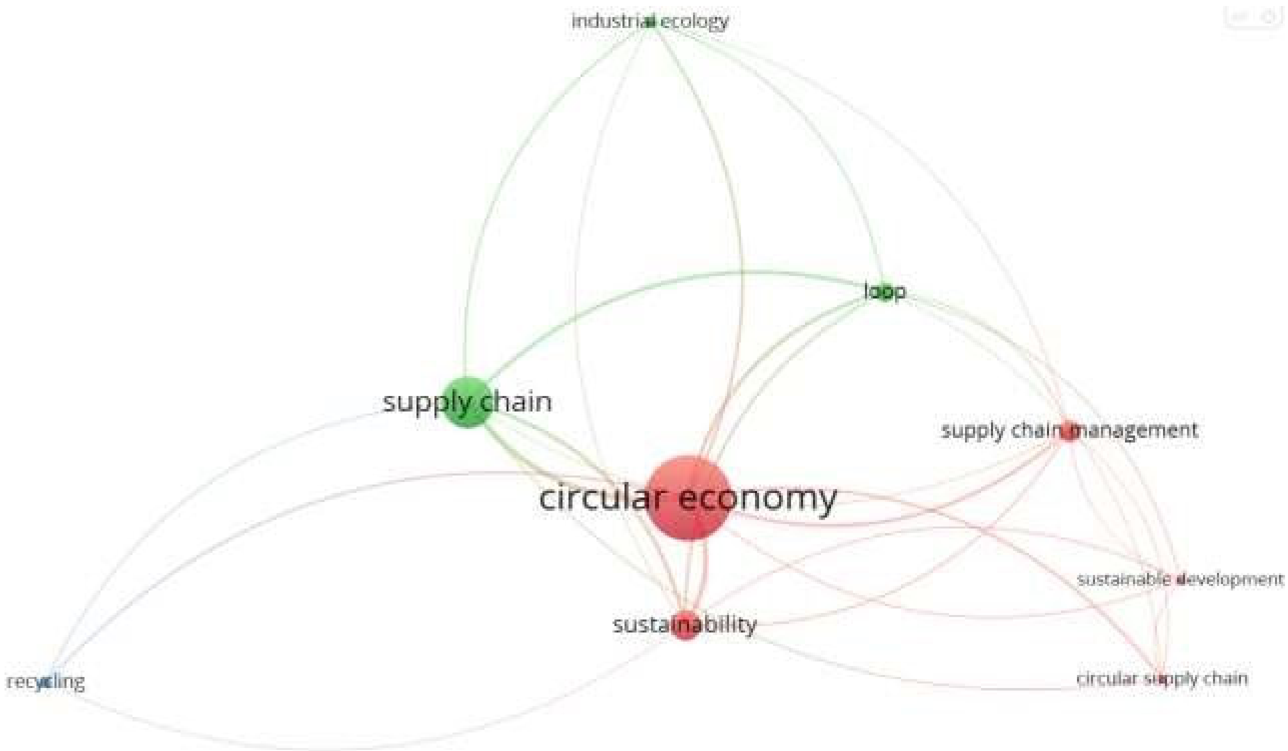
2.5.2 Content analysis and Discussion

In response also of RQ1 with our final sample of n=140, the SC type was selected based on criteria regarding the particular characteristics in each SC, such as the type and level of SC integration, the type of process, (Lejeune & Yakova, 2005) the type of issues faced (Vonderembse et al., 2006) and structure (de Kok et al., 2018).

Some characteristics were drawn from the keyword network in Fig. 6, but most of them were from the codebook, which is shown in Appendix 2.

Fig. 7 shows how CE is connected to SCM through a keyword network. This network strength map has the keywords with the most occurrences. These keywords form a set consisting of three different clusters: The first set of keywords (in red), which are those most related to the CE, consists of supply chain management, sustainability, sustainable development and circular supply chain. The second set of keywords (in green) consists of supply chain, loop and industrial ecology. Finally, the third set of keywords (in light blue) consists of recycling.

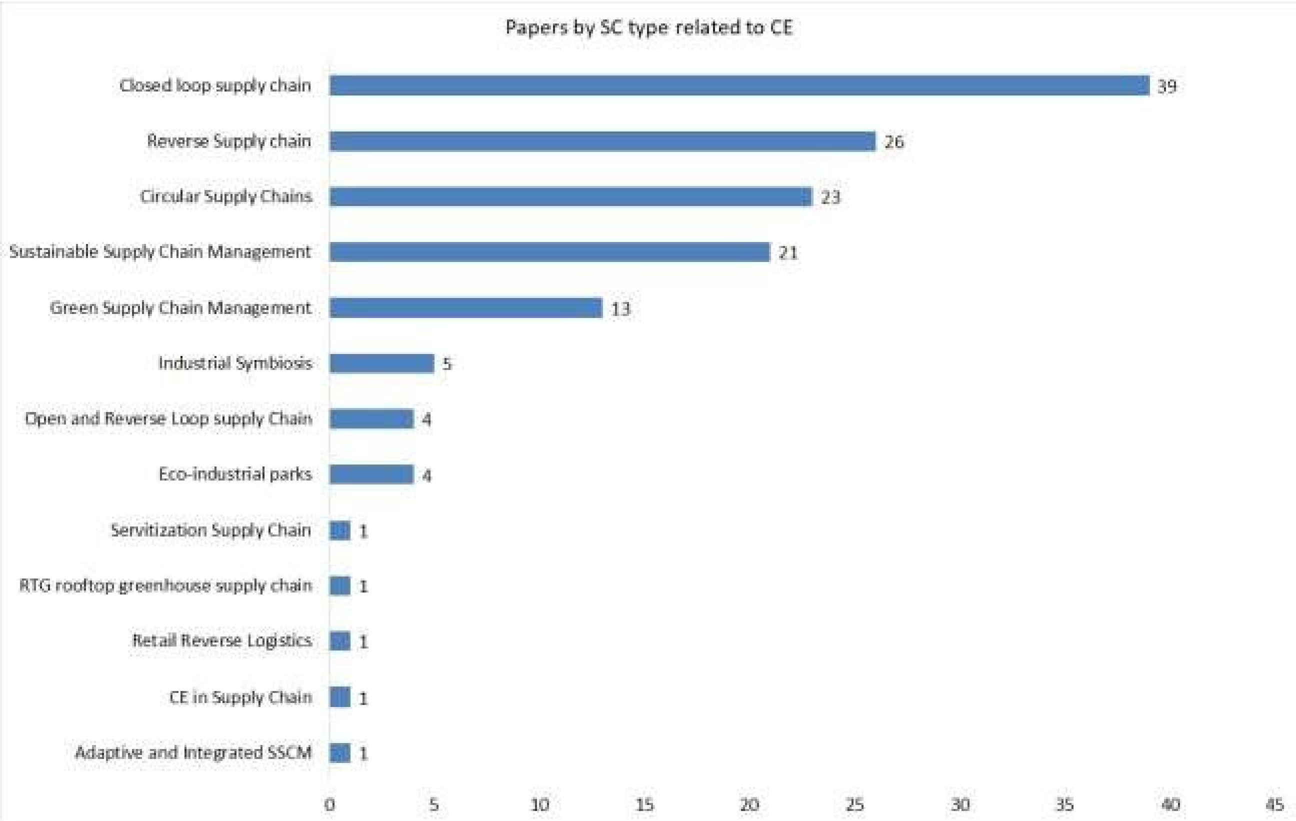
Figure 6- Keyword network



Source: elaborated by the author.

The distribution of the occurrences of SC types in the n= 140 documents is shown in Fig. 7: CLSC (with 39 occurrences) and RSC (26) are the most frequently mentioned, followed by CSC (with 23) and SSCM (21). These 4 types represent almost 80% of the final sample, while the remaining, which includes 31 documents, represents 20%. There are nine different SC types in the remaining 20%: green supply chains, industrial symbiosis, eco-industrial parks, servitization SCs, rooftop greenhouse SCs, retail reverse logistics, integrated OLSC, RSCs and CLSC, CE in SCs and adaptive and integrated SSCM.

Figure 7- Publications by SC type related to the CE



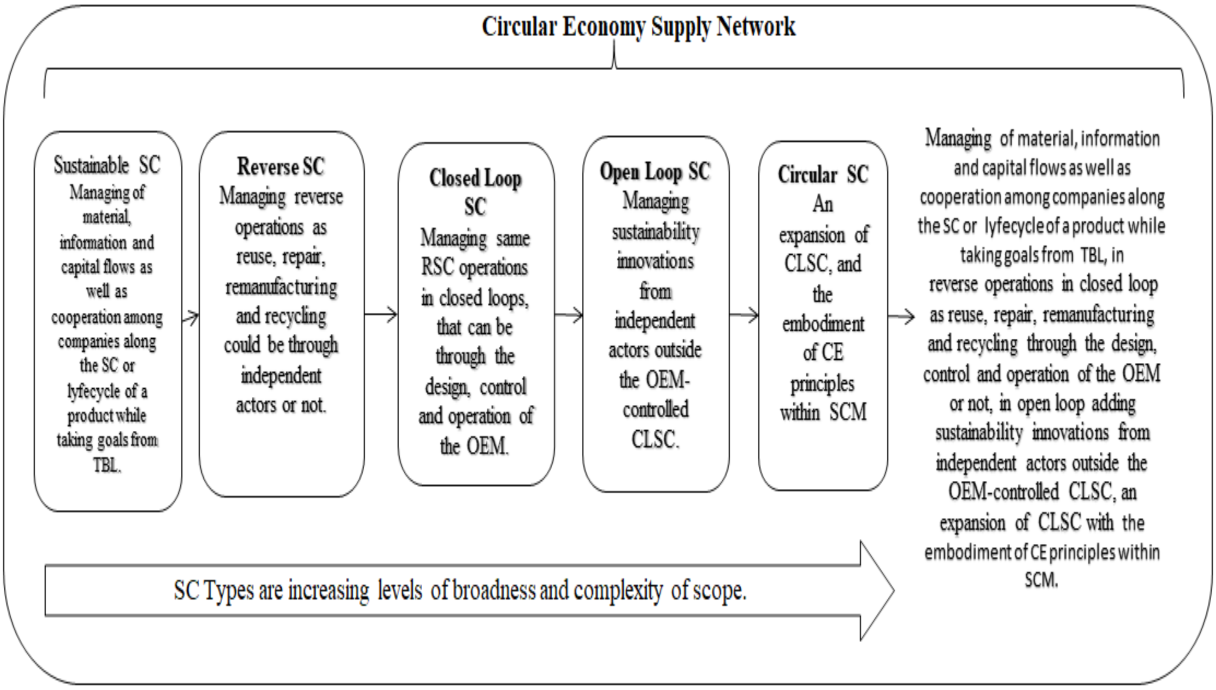
Source: elaborated by the author.

We found more than ten different SC types, that could generate more confusion and hamper the development of this research field and policies establishment by governments and managers of companies to foster CE.

Closed-loop (Guide & Van Wassenhove, 2009) reverse (Kalverkamp & Young, 2019) circular (Batista et al. 2018) and sustainable (Seuring & Müller, 2008) supply chains are the most frequently mentioned SC concepts and types for understanding how SCs can contribute to foster CE.

Therefore, we propose a SCM types' framework for the CE, as shown in Fig. 8. This framework is composed of four most frequently types, plus the most recent, OLSC, which is related to the CLSC and RSC. We analyzed similarities, differences and connections among diverse SC types found in our final sample, based on their most popular and recent definitions, then we identified the commonalities related to CE.

Figure 8- SC types framework for CE



Source: elaborated by the author.

Sustainable SCM is " the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements. Besides, when the focal company is pressured, it usually passes this pressure on to suppliers. Looking at the overall supply chain or life-cycle of the product” (Seuring & Müller, 2008 p. 1700 and 1723).

RSC focuses on the reverse flow of materials from different and independent players in the SC through activities such as: reuse, repair, refurbish, remanufacture or recycle (Guide & Van Wassenhove, 2002; Kalverkamp, 2018).

CLSC are complex systems that involve reverse flows of post consumption products from final customers to the OEM that can be reused, reprocessed, refurbished, remanufactured or recycled, recovering their value, by the design, control and operation of the OEM (Braz et al., 2018; Guide & Van Wassenhove, 2009).

OLSC aim to facilitate the sustainable amelioration of CLSC allowing innovations from independent SC actors outside of OEM control (Kalverkamp & Young, 2019).

A CSC considered an expansion of CLSC and the embodiment of CE principles within SCM ,through coordinated forward and reverse supply chains via purposeful business ecosystem integration for value creation from products/ services, by-products and useful waste flows through prolonged life cycles that improve the economic, social and environmental sustainability of organizations (Batista et al., 2018; De Angelis et al., 2018).

We argue that SC types framework shows an evolution related the complexity and broadness of scope of each SC type from more focused SSCM to more comprehensive a circular economy supply network (CESN), that include managing of material, information and capital flows as well as cooperation among companies along the SC or life-cycle of a product while taking goals from triple bottom line (TBL), in reverse operations in closed loop as reuse, repair, remanufacturing and recycling through the design, control and operation of the OEM or not, in open loop adding sustainability innovations from independent actors outside the OEM-controlled CLSC, an expansion of CLSC with the embodiment of CE principles within SCM. Thus, circular economy supply chain can be conceptualized as a connected network of organizations involved in the design and management of value adding processes and the value recovery of a product, component or material.

In response of RQ2 with our final sample of n=63, documents employing empirically-driven studies of the relationship between CE and SCM. We set the SC dimensions and subcategories as shown in Table 9.

Table 9- Supply Chains dimensions used in the analysis.

Dimension	Subcategories
Sustainability (Sust.)	Economic (E)
	Environmental (E)
	Social (S)
Process	Reuse
	Refurbish
	Remanufacturing
	Recycling
	Recovery
	Repurposing
	Disassembly
Level of Analysis (LoA)	Micro (firm)
	Meso (a dyad relationship)
	Macro (supply chain with 3 or more firms)
Tactics	The method used to achieve something
Strategy	A planned series of actions to achieve something

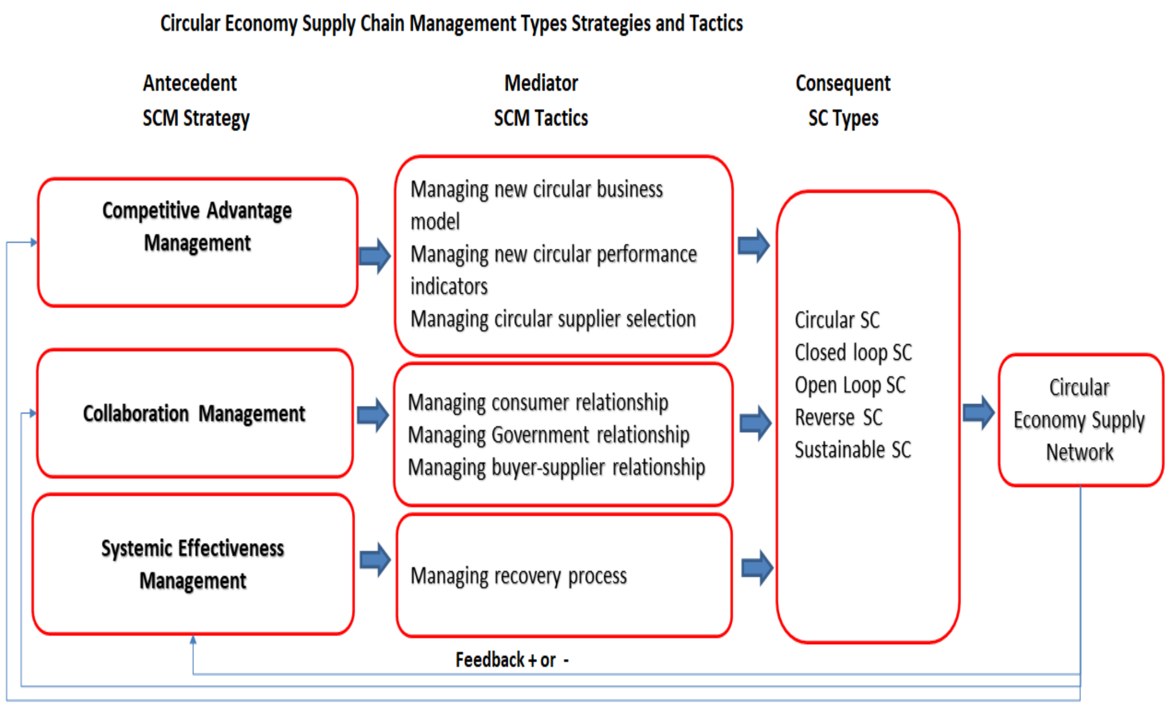
Source: elaborated by the author.

Since, most popular SCM definition is “the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole” (Mentzer et al., 2001 p.18).We should understand which tactics and strategies related to each SC type are involved in CE transitions.

Aiming fill this gap, we use examples from our sample to understand which specific tactics these companies have adopted. We found forty-three tactics, across the most frequent SC’ types and dimensions for different industries and countries, then we synthetized these tactics and linked to the different supply chain management strategies (collaboration management, competitive advantage management and system effectiveness management), as shown in Table 10.

Expanding Mentzer et al. (2001) linear SCM definition for nonlinear circular SCM, we have identified key strategies that could be supply chain orientation antecedents, with tactics mediating these supply chain strategies and types to foster CE as consequence, as shown in Figure 9. The linear SC is bounded by the visible horizon of the focal company (Carter et al., 2015) the nonlinear SC could not be, due to the consequents SC’ types that emerge (Fig.9).

Figure 9- SCM strategical and tactical level framework for CE



Source: elaborated by the author.

Mentzer et al., (2001), consider competitive advantage as a SCM consequence. However, they posit that it is a motivator for SCM's strategic arrangement. We argue that the competitive advantage management is an antecedent, precisely because it motivates companies', to use tactics such as management of new business models, new performance indicators and supplier selection. Consequently, developing circular economy supply networks, through positive (reinforcing) or negative (balancing) feedback loops to antecedents.

Managing new circular performance integrating economic, environmental and social indicators, it is in most cases a fundamental tactic, some cases detail what and how to measure qualitatively, however, most of cases agree (Table 11 and Appendix 4) that there is still a huge gap on how to integrate these indicators to clearly and transparently assess their cross-effects and to define them in a quantitative way understanding how to measure and the weight among them, whether it will be 33.33% for each one or some will have a greater weight in relation to the others (Husgafvel et al., 2017). Ecological Network Analysis (ENA) was the only one suggested as an alternative model to be used to measure circularity in supply chains that integrates the life cycle assessment (LCA) concept through equations that connect different indicators (Piezer et al., 2019).

Managing new circular business models, such as leasing products and not selling (van Loon et al., 2018), integrating circular product design (Husgafvel et al., 2017) and closed cycles (Braz et al., 2018) are tactics widely used to carry out the competitive advantage management strategy.

Managing circular suppliers' selection to add new partners with a new role for SC (Perey et al., 2018) reduce dependence on imported materials (Geissdoerfer et al., 2018) and reduce the scarcity of natural resources by replacing raw material virgin by recycled (Kalaitzi et al., 2018) are also one of the most used tactics to carry out the competitive advantage management strategy.

Collaboration strategic management could be carried out by managing consumers' relationship to increase their participation in collection process with donations (Vlajic et al., 2018) or prioritize the new circular products design (Veleva & Bodkin, 2018). It can be done by government relationship management to spread out responsibilities among members to provide incentives or reduce barriers. Finally, it can be carried out by buyer-supplier relationship management, through cooperation between organizations' R&D, sharing ideas to improve product's recovery and developing new sustainable materials (Schraven et al., 2019). Systemic effectiveness strategic management could be performed through product recovery process management by aligning product portfolio with reverse logistics (Bernon et al., 2018) implementing a web based traceability creating and supporting connections between suppliers and buyers (Batista et al., 2018).

All of these strategies through these tactics could result in types of supply chains integrated in a “circular economy supply network”. Reverse operations management in closed loops through the design, control and operation of the OEM or not, in open loops, adding sustainability innovations from independent actors outside the OEM-controlled’ CLSC, been an expansion of it, to promote CE.

Moreover, empirical research has been developed by process and activity perspective, as well as, on environmental and economic dimensions of sustainability. Although they study SC, most of them have as unity of analysis only one firm (micro level of analysis) in a downstream flow and position.

Table 10- Supply chain management strategies and tactics for CE across industries, countries, SC types and dimensions.

Strategies	Tactics main idea	Level of Analysis	Process	Sust.	Industry	Country	SC type	Freq.
Collaboration Management	buyer supplier relationship management	Micro	Recycling, Reuse and Recovery	E, E.	Cross Industry, Textile, Automotive and Aluminum	Europe, UK and USA	CSC, CLSC and RSC	7
	consumer relationship management	Micro and Macro	Reuse, remanufacturing and recycling	E, E, S	Automotive, Furniture and Food	Brazil, China, Germany, Indonesia and UK	CLSC	5
	government relationship management	Meso	Recovery	E, E.	Construction	Netherlands	CLSC	2
Competitive Advantage Management	new business models	Micro	Reuse, Refurbish, Remanufacture and Recycle.	E, E.	Air, OEM baby stroller, Automotive, Cross Industry and Retail	China, Europe and UK	CLSC	5
	new performance indicators	Micro	Recovery	E, E, S	Biorefinery and Urban Agriculture	Finland and Spain	CLSC	2
	supplier' selection	Micro, Meso and Macro	Reuse, Refurbish, Disassembly, Remanufacture and Recycle.	E, E, S	Automotive, Aluminum, Construction, Cross Industry, IT, Electronics,Web based	Australia,Brazil, Chile, China, Japan, Europe, UK and USA	CSC, CLSC, OLSC and RSC	12
System Effectiveness Management	recovery process	Micro, Meso and Macro	Reuse, remanufacturing, reverse logistics and recovery	E, E, S	Urban Furniture, Gypsum, Automotive,Retail, Healthcare,Fashion, Cross Industry and Food packaging	Brazil, China and Europe	CSC, CLSC and RSC	12

Source: elaborated by the author. All detailed 43 tactics and references are in Appendix 3.

Table 11- Supply chain management measurements across industries, countries, SC types and dimensions.

Measurement main idea	Strategies	Tactics	Level of Analysis	Process	Sust.	Industry	Country	SC type	Freq.
Lack of, added value indicators	Collaboration and Competitive Adv. Mag.	government relationship and new business models management	Micro; Meso	Reuse, remanufacturing and recovery	E.and E.	Construction; Retail	Netherlands; UK	CLSC	2
Lack of non-standardized data and LCA method	Competitive Adv. Mag.	supplier' selection and new performance indicators management	Micro	Recycling; Recovery	E and E.	Textile and construction; Urban Agriculture	UK; Spain	CSC	2
Lack of data and indicators to measure the impacts.	Collaboration and System Effectiveness Management	buyer supplier relationship and recovery process management	Micro; Meso	Reuse; waste reporpusing; remanufacture; retail reverse logistics	E. and E.	Cross Industry; Fashion; Automotive; EIP; Retail	China;USA; UK; Italy	RSC, CLSC	6
Lack of NRS measures	Collaboration Management	buyer supplier- relationship management	Micro	Recycling	E and E.	Automotive and Aluminum	UK	RSC	1
Lack of measures to reintroduced material in SC	System Effectiveness	recovery process management	Micro	Recycling	E and E.	Automotive; Healthcare	Brazil; Germany	CSC; RSC	2
Lack of, standardized, quantitative, clear measurement and objectives for assessing the performance of circular sustainable	Collaboration and Competitive Adv. Mag.	Not informed	Micro	Recovery	E, E and S.	Cross Industry; Biorefinery	Across the world and Finland	RSC, CLSC	3
The economic indicators preponderance and/or lack of decision making could be a barrier.	Collaboration and Competitive Adv. Mag.	manage buyer supplier- relationship; manage new business model	Micro	Recovery; Refurbish	E. and E.	Cross Industry; OERM baby stroller	Europe	RSC, CLSC	3

Source: elaborated by the author. All references are in Appendix 4.

2.6. Conclusions and implications

2.6.1 Implications for theory

First, we found more than ten different SC types (Fig. 7), related to post consumption product recovery, strong evidence of CE and SC themes' connection. On the other hand, this diversity of concepts might hamper the development of this research field, generating more confusion and delaying the development of policies by governments and managers of companies to foster CE. Therefore, to organize this diversity and improve this research field, we suggest a SC' types framework (Fig. 8), defining and sorting the most frequent SC connected to CE explaining that could there be an evolution related the complexity and broadness of scope of each SC type from more focused "sustainable supply chains management" to more comprehensive "circular supply chains". Our framework shows an evolution in the understanding of the concept that has become more sophisticated and incorporated other ways of implementing circular economy than just closing the chain.

Second, although circular economy could be a more tangible way to implement sustainability through supply chain management level, most of the empirically-driven papers (Table 10 and Appendix 3) have a micro level (firm) approach to study SC, what clearly will not reflect the dynamic relationship between members through a systemic view, that could be fundamental to study SC and CE. Therefore, our SCM strategies and tactics, across different industries and countries (Fig.9) could lead for SC types more fitted to implement CE, resulting in a circular economy supply network (CESN).

Moreover, these empirical works are also focused in the downstream flow, it seems that it is more related to brand owners, retail, consumers and buyers not a buyer-supplier or supplier-buyer or supplier's-supplier relationship in an upstream flow. Following linear (traditional) supply chain management literature (Chen & Paulraj, 2004), which was also focused on micro relations and downstream flows, that has competitive advantage as a consequence of SCM. However nonlinear SCM seems to have a more sophisticated management incorporating more agents and levels (multi-tier supply chain) (Mena et al., 2013) in an upstream flow with competitive advantage management through some tactics as an antecedent to foster CE as shown in our framework in Fig. 9.

Finally, competitive advantage strategy management as a nonlinear SCM' antecedent instead of a consequent as a linear SCM, also could be a key trigger to manage new performance indicators integrating economic, environmental and social indicators, to clearly and transparently assess their cross-effects in a quantitative way, for instance, defining the weight between them, whether it would be 33.33% for each one of them or one would have a greater weight in relation to the others for instance the economic dimension (15%) as a tool to run environmental dimension (42%) and social dimension (43%) resources to achieve the social well been and environmental protection (Kravchenko et al. 2020).

2.6.2 Implications for practice

Managers of different industries and countries can use our strategies and tactics (Table 10 and Appendix 3) as a guide to implement CE in their firms and SC. Once that, they could use collaboration management strategy to implement buyer-supplier, consumer and government relationship' management tactics, getting value creation and/or competitive advantage management to implement new business models, supplier selection, new performance indicators' tactics and effectiveness systemic management to implement recovery process' management tactic to value creation and capture.

In general terms this research provides two useful frameworks that can assist policy makers to assess SCM strategies and consequent SC types to foster CE (Figures 8, 9 and Appendix 3).

Policy makers could also use the empirical findings for better understanding and managing, the challenges of SCM to implement CE. They can develop regulations to incentive the set of tactics to implement each SCM strategy for each industry type and country.

Zero waste programme for Europe (European Commission, 2014) and sustainable development goals (SDG) of the United Nations (George et al., 2016), in particular SDG 12 could be mitigated by the adoption of our framework in Fig. 8 understanding the evolution of the concept that has become more sophisticated and incorporated other ways of implementing circular economy than just closing the chain, and our framework in Fig. 9 choosing the SCM strategies and tactics, across different industries and countries could result in a circular economy supply network (CESN), improving responsible consumption and production.

2.6.3 Future research opportunities

Considering that, most of the documents were published in interdisciplinary sources, in more than twenty countries (Figures 4 and 5), which are evidence that CE and SCM are interdisciplinary concepts with broad research areas. Besides that, there are more than ten different SC types linked to CE, resulting in strong complexity and great opportunities for future research using complexity theories.

We can see in Tables 10 and 11, that more real-world studies on integration of environmental, social and economic indicators are needed, to understand how sustainable circular SC are and to assess whether going circular makes a SC more sustainable or not, this is a huge gap to foster CE in real world context.

Besides that, social dimension of CE still is neglected in the literature, for instance the moral obligation of waste places, the social impact to move from a linear to a circular economy, assessing created job quality, as well as, is needed more studies on SC collaboration considering transition theory.

Empirical studies should focus in meso (the relationship between two or more firms) level (Tables 10 and 11), small and medium companies' role in the SC, as well as, on value creation and capture mechanisms, modelling real cases, through simulation, for instance using system dynamics modelling to understand how feedback loops could enhance or reduce circularity.

Developing management frameworks on meso and macro levels focusing upstream SC flows on CE solutions and innovations.

2.7 Acknowledgements

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3 CIRCULAR ECONOMY SUPPLY NETWORK MANAGEMENT: A COMPLEX ADAPTIVE SYSTEM

Abstract

The circular economy is gaining momentum in political and academic agendas. However, little is empirically known about circular economy supply network configurations, dynamics and coordination mechanisms. In aiming to fill this theoretical and practical gap, this study employs a multiple case study of seven circular supply chains from different industries using coding, within and cross-case analysis. As the study's main theoretical contribution, an innovative framework is proposed, characterizing circular economy supply network management as a complex adaptive system leading to three different configurations: a closed loop supply network, an open loop supply network and a combination of both, adding new industries' supply chains and nonlinear connections and resulting in a hybrid loop supply network. This framework is composed of three key elements, management mechanisms, the internal and external environment, and emergent properties, and three sets of propositions, which relate each of these key elements to different circular economy supply network management configurations that dynamically adapt to internal and external environment changes. The framework also introduces two types of leverage points, one upstream and another downstream, in that agents with different roles and positions might be responsible for coordinating or initiating the postconsumption product or byproduct physical reverse flow, merging sourcing and customer strategy. Managers and policy-makers could benefit from this framework, as it could help them make decisions on how to foster circular economy implementation, even amid lacking government incentives and regulation complexity.

Keywords: Circular economy. Supply network. Complex adaptive system. Closed loop supply chain. Multi-tier sustainable supply chain.

3.1 Introduction

The circular economy (CE) concept is not new, as Pearce and Turner used it in 1990 (Irani and Sharif, 2018). However, only recently has the discussion of CE appeared on political and academic agendas. An overview of current CE strategies worldwide reveals that the European Union, the United States, China, and Japan have developed their own CE plans (Bernon et al., 2018). The CE promises to promote sustainable development and reduce environmental pressures and impacts by creating new sustainable businesses and jobs and reducing raw material price volatility, natural resource scarcity (NRS) and costs (Kalmykova et al., 2018). Thus, this study contributes to the achievement of the sustainable development goal of 12-responsible production and consumption established by the United Nations (George et al., 2016).

Despite its growing importance, CE is still a broad, vague and multidisciplinary concept involving postconsumption product or material returns (Kirchherr et al., 2017) that focuses on the inputs and outputs of material flows. Therefore, scholars have argued for the need to combine CE and “supply chain management” (SCM) research (Frei et al., 2020). Moreover, the CE concept is deeply related to activities such as reduction, reuse, remanufacturing and recycling (Braz et al., 2018; Kalmykova et al., 2018).

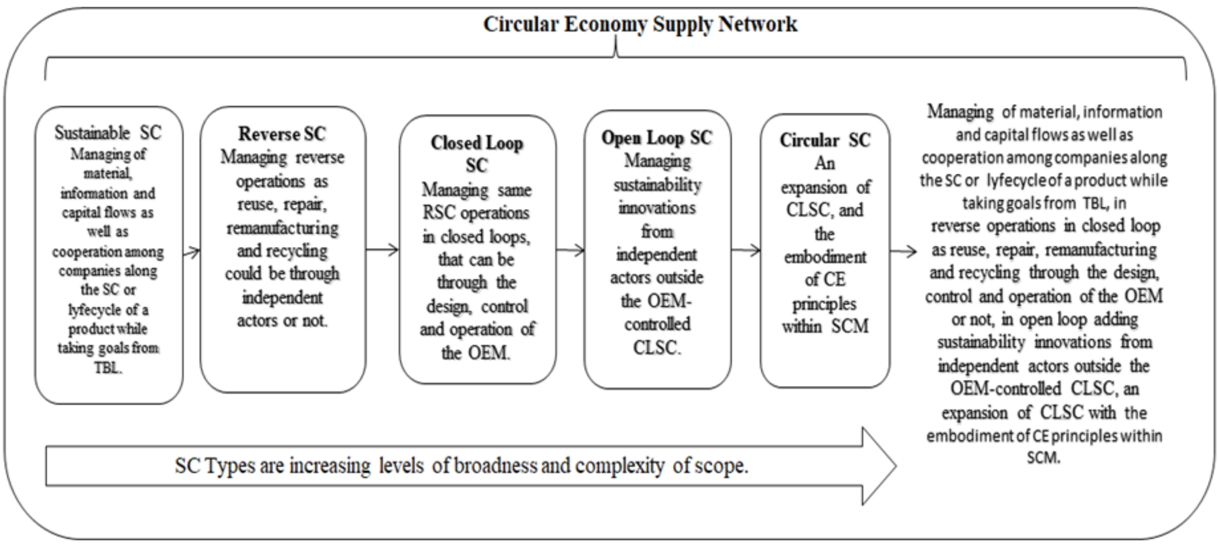
The literature discusses different types of supply chains (SCs) related to material recovery, such as the following:

- Sustainable SCM is " the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements. Besides, when the focal company is pressured, it usually passes this pressure on to suppliers. Looking at the overall supply chain or life-cycle of the product” (Seuring & Müller, 2008 p. 1700 and 1723).
- Reverse supply chains (RSCs), defined as the reverse flow of materials from the same or different independent agents in the SCs through closed or open loops (Guide et al., 2002);
- Closed loop supply chains (CLSCs), defined as complex systems that “involve reverse flow of postconsumption products from the final customers to the original manufacturer” (Guide & Van Wassenhove, 2009);

- Open loop supply chains (OLSCs), which are similar to RSCs, but with independent actors developing new products/solutions outside of original manufacturer control (Kalverkamp & Young, 2019).
- Circular supply chains (CSCs), which could be considered “an extension of closed loop supply chains and the embodiment of CE principles within SCM” (Batista et al., 2018; De Angelis et al., 2018).

Figure 10 shows the main SC types related to the CE based on a systematic literature review of 140 papers (Braz & Mello, 2020) studying the CE and SCs. SC are classified by criteria regarding particular characteristics of each SCs group, such as the type and level of integration, the type of process involved (Lejeune & Yakova, 2005), the types of issues faced (Vonderembse et al., 2006) and structures involved (de Kok et al., 2018) to analyze similarities, differences and connections of these SC types based on their most popular and recent definitions. SC types related to the CE are broader and more complex in scope. Therefore, the literature examines different SC types related to material recovery and restorative models (Kalverkamp & Young, 2019). From a practical perspective, examples of packaging circular supply chains in Brazil and China show how such SCs can have a complex structure (Batista et al., 2018) The diversity of supply chains for material recovery might indicate an adaptive system that changes key features depending on external and internal factors and that interacts with its environment (Choi et al., 2001; Nair & Reed-Tsochas, 2019). However, to our knowledge, no article has studied the CE and SCM from a complex adaptive system perspective.

Figure 10- SC types related to the CE that increase the broadness and complexity of the scope



Source: adapted from Braz & Mello, 2020.

First, empirical support for the theoretical discussion is limited, with the majority of empirical findings focused on downstream supply chains (Batista et al., 2018; Guide & Van Wassenhove, 2009). Second, the great complexity of real SCs and the scant information on practical aspects of how to introduce the CE into SCs in a real-world context could be the cause of this slow implementation (De Angelis et al., 2018; Frei et al., 2020) Third, there is no empirically grounded, theoretical explanation of buyer-supplier and supplier-buyer relationship dynamics between firms in extreme upstream and extreme downstream SCs for implementing the circularity of postconsumption products and byproducts (Batista et al., 2018; Guide & Van Wassenhove, 2009; Kalaitzi et al., 2018; Sgarbossa & Russo, 2017). Fourth, there is a call to study the CE and CLSCs with a more systemic approach (Coenen et al., 2018; Murray et al., 2017).

Taken together these issues, the intended contribution of this paper is twofold. First, we seek to understand and identify the key elements that characterize circular economy supply network management as a complex adaptive system and, second, we explore how firms can manage the configurations and complexities of these supply networks.

To achieve this objective, this research adopts a case study design (Ketokivi & Choi, 2014) that explores multiple case studies and draws on the integration of a “complex adaptive system” (CAS) that focuses on the interaction between a system and its environment. In the SC context, a system includes agents’ networks involved in a buyer-supplier relationship. Once agents adapt and can overcome a complex environment through innumerable interactions and relationships (Choi et al., 2001; Nair & Reed-Tsochas, 2019) “multi-tier sustainable supply chain management” focused on governance mechanisms and SC structures (Jia et al., 2019; Tachizawa & Wong, 2014) and “leverage points” that focus on identifying places in which to intervene within a complex system where a small shift in one facet can generate major changes in everything else (Meadows, 1999) Moreover, in acknowledging the high complexity of real SCs, this research uses networks rather than chains following Carter et al. (2015) and Choi et al. (2001).

The paper is organized as follows. Section 3.2 presents a theoretical background on circular economy supply networks as CASs requiring governance and coordination mechanisms in a multi-tiered SSCM. Section 3.3 describes the method adopted in this study. Section 3.4 presents a case analysis of the seven circular SCs examined and discusses the results of the coding and cross-case analysis. Section 3.5 discusses theoretical, managerial and policy implications. Section 3.6 presents conclusions and further researches perspectives.

3.2 Theoretical background

The CAS is part of complexity theory that suggests that firms operate in a system that includes both order and disorder, where interactions of the involved parties will determine the performance outcomes of the system. Scholars discussing complexity theory in organizations have pointed out some key elements: agents with schemata, self-organizing networks and system coevolution whereby agents adapt to their environment to increase gains over time because each individual's gain depends on the decisions of other agents. In a complex system, changes from inputs to outputs occur in a nonlinear manner because their components interact with one another via a network of feedback loops (Anderson, 1999).

Choi et al. (2001) developed the CAS framework for supply networks renewed by Nair & Reed-Tsochas (2019). The CAS framework covers three key concepts:

- Internal mechanisms with agents that share interpretive and behavioral rules, attributes at different levels of scale, and degrees of freedom represent the rules or schemas that socially embedded agents use to make decisions, creating patterns through this collective behavior of multiple agents resulting in self-organization and emergence;
- The interpreted and enacted environment shows constant and interdependent changes whereby decision-making agents respond within the boundaries of the CAS and across the external environment outside the boundaries of the CAS;
- The boundaries between each environment are dynamic; the interactions between agents and the environment lead to emergent system properties, which could, in turn, influence the agents and the environment.

These key CAS concepts could characterize circular economy supply networks. To the best of our knowledge, no article has studied the CE and SCM from a complex adaptive system perspective. For example, Batista et al. (2018) showed that packaging circular supply chains in Brazil and China have a complex structure in that buyer-supplier relationships cannot be limited to a dyad but to triads or more, requiring understanding of the governance and coordination mechanisms involved in a "multi-tier SSCM" that might be conceptualized by the influence of governance mechanisms, SC leadership, the power of the focal company over the SC structure and interdependence in a buyer-supplier's-supplier relationship (Jia et al., 2019; Mena et al., 2013; Sarkis et al., 2019; Tachizawa & Wong, 2014). Furthermore, in sourcing decisions, the increasing levels of complexity and uncertainty involved in supplier selection should be considered to manage several suppliers' performance, contextual and relationship factors, including quality, cost, financial, process capability, product complexity, sourcing maturity and regulation issues (Sarkis & Talluri, 2002; Schleper et al., 2019).

Coordination mechanisms are used to manage interdependencies between activities performed to achieve a goal for value creation through relations whereby key actors create, maintain, and potentially transform network activities (Gosling et al., 2016; Simatupang et al., 2002). "The SC leader is characterized as the organization that demonstrates higher levels of the four elements of leadership in relation to other member organizations (the organization capable of greater influence, readily identifiable by its behaviors, creator of the vision, and that establishes a relationship with other SC' organizations)" (Defee et al., 2010). Therefore, the SC leader could perform "transactional leadership, demonstrating contingent reward, which indicates that followers will be rewarded on their expected performance and be punished if a target is not achieved, and management-by-exception (asserts that leaders point out followers' mistakes and take actions when needed), or could play transformational leadership exhibiting inspiration (as a mission and vision of a desirable future and the definition of the path to achieve the vision), intellectual stimulation (indicates leaders calling on followers to be more innovative and creative to provide better solutions to problems), and individualized consideration (leader's ability to recognize each individual follower's unique skills and development needs), more frequently, focusing on developing long-term relationships and do not seek to control followers' behavior through the use of contingent rewards but manage in a more holistic way" (Jia et al., 2019).

Therefore, in nonlinear systems such as a CESN, major changes in input may lead to minor changes in outcomes, and minor changes in input may lead to major changes in outcomes (Choi et al., 2001). Hence, a small shift in one feature can generate major changes in everything else, which leads us to add the concept of leverage points to the CESN, i.e., specific points in the network where an intervention could generate a change from linear to circular supply networks (Meadows, 1999).

3.3 Research Method

Research on the CE, drawing on the CAS and multi-tier sustainable SCM views of postconsumption product and byproduct return management, is still emerging, and in this setting, there have been calls for exploratory research providing an in-depth understanding of the relationships between key elements of the circular economy supply network and of how firms can manage their configurations and complexities to foster the CE. This research adopts a multiple-case study method merging theory generation and elaboration (Gong et al., 2018; Ketokivi & Choi, 2014). The case studies are guided by open research questions and not by a priori propositions.

3.3.1 Case selection

Case selection was driven by our research objective. The present research followed a theoretical sampling approach with the number of cases set to between four and ten (Eisenhardt, 1989). The following criteria were applied in selecting CESNs:

- Companies and their SNs actively involved in a CESN were selected (Batista et al., 2018);
- SNs needed to operate RSCs in loops (Kalverkamp & Young, 2019);
- Most supply networks have intensive upstream flows positioned close to the last-tier supplier, as most innovations occur upstream of the supply network (Sarkis et al., 2011).

We attended industry business conferences in Brazil (FIEE for the electronics industry, Fenibat for the lead acid battery industry, and Movimat for-packaging industry) where we interacted with sales and product managers to obtain the appropriate managerial contacts responsible for the RSC management of each involved company. In addition, we obtained some contacts from the professional network of one of the researchers. Then, we contacted responsible managers and asked them to participate in an interview explaining the purpose of our study and asking them to sign a confidentiality agreement. During the visits and interviews, we asked the participants about their byproducts and postconsumption product operations, suppliers and customers. The final results and details of this search, with the number of cases (seven) and profiles of interviewees from the firms (25 firms and 35 interviews in total), are summarized in Table 13.

3.3.2 Data collection

Our three sources of data were interview transcripts, site visit notes and documentation. The primary data were collected mainly during plant visits held between July 2016 and December 2019 (between 2016 and 2017 for batteries and electronics and between 2018 and 2019 for printers, precious metals, plastic packaging, cardboard box and bioproducts) from semi structured interviews and observations. Most of the interviews were recorded, and all were transcribed within 24 hours. The interview protocol (detailed in Appendix 5) was divided into four parts: we obtained information from the respondents about the studied companies, products and markets; obtained recovered operations information; and finally obtained policy and management systems information and data on RSC operations value added.

Site visits were conducted at the facilities of the manufacturers and recyclers involved. These visits allowed the researchers to understand involved products, parts, services and information flows; to obtain data about interorganizational processes and transactions and to triangulate data about buyer-supplier relationships. If during the visits information that was new or contradictory to our earlier findings was found, we asked for clarification. Visits lasted between 2.5 hours and more than a day depending on the operation's location, size and complexity.

Secondary data were collected from companies, governments, associations and business conferences. Documents regarding CESN relationships were collected, such as documents on recycling, recovery and recommerce products, services and information flows, suppliers' selection and development processes, new components and systems development, supply network mapping, sustainability policies and reports, and regulations and markets. We did not ask for contracts due to their confidential nature, and buyer-supplier relationships were identified from quotations, supplier assessments, and transactions executed by fiscal documents and purchase orders. These multiple data collection sources made it possible to perform data analysis triangulation.

3.3.3 Data analysis

We employ an embedded design with several units of analysis, including a CESN and the buyer-supplier/supplier-buyer relationship, to explore and understand the perceptions and implications of configurations, dynamics and governance mechanisms of a CESN. This analysis was conducted over four stages as recommended by Miles et al. (2014) in a dynamic and iterative manner.

In the first stage (first cycle codes), the coding process started with the descriptive coding of interviews, observations and documents to create an inventory of code labels.

In the second stage (the transition from first to second cycle codes), we executed code mapping, recoding, merging and the overlapping of some codes. We clustered data to deductively obtain subcategories from our theoretical background (Skjott Linneberg & Korsgaard, 2019). For instance, CAS were coded by Choi et al. (2001), Nair & Reed-Tsochas, (2019) and Anderson (1999) and multi-tier sustainable SCM and SC leadership was coded by Jia et al. (2019) and Mena et al. (2013). Then, we proceeded with axial coding to explore the relationships between subcategories to obtain categories. Finally, theoretical coding was used to integrate and refine categories into high-level concepts (Saldaña, 2013). To organize the coding process, we used Open Code 4.03 (University of Umea -ICT Services and System Development and Division of Epidemiology and Global, 2013) and MS Excel. Both stages and related coding processes are detailed in Appendixes 6 and 7.

In the third stage, a within-case analysis was performed by mapping specific postconsumption product and/or byproduct flows and indicators as described by members of each organization based on peculiar characteristics of relationships among the members of each CESN that support subcategories and categories obtained in the previous stage. Our familiarity with each case accelerated the cross-case analysis (Eisenhardt, 1989; Miles et al., 2014).

The fourth and last stage involved cross-case analysis, where we identified similarities and differences across the seven CESNs, highlighting categories reflected in propositions and research frameworks (Eisenhardt, 1989; Miles et al., 2014). Finally, the study results were validated according to Miles et al.'s (2014) standards for quality, as shown in Table 12.

Table 12- Standards for the quality of conclusions.

Standards	Description
Reliability	• Uses a case study protocol to guide field research and analysis. • Development of a case study database including transcripts recorded within 24 hours, sustainability reports, internal documents, news coverage and some field photos. • Iterative discussion with uninvolved senior academics.
Internal Validity	• Structured data coding and analysis. • Triangulation of complementary data sources.
External Validity	• Theoretical sampling approach. • Thick descriptive data use. • Plant visits to various suppliers. • Findings are connected to prior theory.
Construct Validity	• Use of multiple sources of evidence including semi structured interviews, various forms of secondary data and observations. • A chain of evidence: multiple informants, supply chains and companies.

Source: elaborated by the author.

Table 13- Profiles of companies across cases.

Case Number	Case name and industry	Company pseudonyms	Company's role	Number of employees (approximately)	Interviewees/Key informants
Case 1	Battery	Batrec	Brazilian recycler	180	Product, quality and lab. managers, founder and CEO
		Batman	American multinational manufacturer	3500	SA strategic purchasing manager and lead specialist
		Batdis	Brazilian distributor	21	Operations manager and owner
Case 2	Printers	Prbrand	American multinational brand owner	1500	Supply chain security manager
		Prman	Singaporean multinational manufacturer	1500	Supply chain and Innovation directors
		Prrec	Singaporean and Brazilian recycler	190	Reverse logistics manager
		Prcoop	Brazilian waste picker cooperative	40	President and cofounder
Case 3	Electronics	Elereco	Brazilian recommerce	48	Operations director and owner
		Eleret	Brazilian retailer	26000	Logistics and operations director
		Eledist	American multinational components distributor	320	Country manager
Case 4	Precious Metals	PMrec	Belgian multinational recycler	480	Recycled products manager
		PMcomp	American multinational LED producer	4000	Latin America sales director
		PMman	American multinational manufacturer	450	New program supply supervisor
		PMcoop	Brazilian waste picker cooperative	40	President and cofounder
		PMrevlog	Brazilian reverse logistics provider	38	Operations manager
Case 5	Plastic Packaging	Packbrand	Brazilian multinational brand owner	7000	Environmental and sustainable growth and purchasing managers
		Packman	Brazilian manufacturer	250	Account manager
		Packrec	Brazilian recycler	120	Commercial director/owner
		Packcoop	Brazilian waste picker cooperative	36	Operations director and cofounder
Case 6	Bioproducts	Biogasman	Brazilian bioenergy multinational manufacturer	30000	Operations director
		Biogasol	Brazilian solutions provider of organic byproducts	40	Operations director/owner and process engineer
Case 7	Cardboard Boxes	Cardbrand	Brazilian multinational brand owner	7000	Environmental and sustainable growth and purchasing managers
		Cardppman	Brazilian plastic packaging manufacturer	250	Account manager
		Cardman	Brazilian corrugated and cardboard box manufacturer	2500	Operations director
		Cardcoop	Brazilian waste picker cooperative	40	President and cofounder

Source: elaborated by the author.

3.4 Empirical Findings

3.4.1 Findings of within cases

Case1 Battery Network.

This CESN was created many years ago due to primary lead mining economic unviability in Brazil, with Batman forming a multi-tier CESN management relationship with Batrec, creating new opportunities through a management strategy of shifting from primary raw material to recycled material. For instance, Batman indirectly coordinates a plastic recycler through Batrec. In addition, Batman provides hybrid leadership by managing Batdis collection process through contingent rewards in a “trade-in” operation and through greater influence and the establishment of relationships with other organizations such as acid recyclers (see the network structure in Appendix 8).

Case2 Printers Network.

This CESN formed as a result of Brazilian solid waste management policy requirements and when Prbrand discovered an economic disadvantage due to clandestine companies that, without its approval, refilled used and discarded ink cartridges manufactured by Prman. Since these competitors did not incur the costs of design and developing the product or legalizing their own operations, they were able to sell both the refilled cartridges and recharging services (for customers who supplied used cartridges) at prices not feasible for Prbrand. Prman created Prrec to recycle cartridges from Prbrand, which has a multi-tiered CESN management relationship with Prrec through Prman, and provided transformational leadership to build a long-term relationship with greater influence. For instance, Prbrand and Prman coordinate with Prrec waste picker cooperatives’ selection and development in addition to support Prcoop to increase the scale of returns (see the network structure in Appendix 9).

Case3 Electronics Network.

This CESN started mainly due to Brazilian waste management policy requirements, which led some entrepreneurs to start Elereco, which caused the supplier’s selection process to encourage Eledist to obtain obsolete electronic components from electronic component manufacturers and electronic product manufacturers supplying them to Elereco repair used products for resale. Eledist has a multi-tier CESN management relationship with brand owners of electronics products such as smartphones and tablets to buy obsolete electronics components from electronics products manufacturers. Elereco, Eledist and Eleret have developed coordination mechanisms to increase the use of recovered materials. Eleret also has a supplier-buyer/buyer-supplier relationship with final consumers. For instance, the final consumer buys a new smartphone with a used smartphone in a “trade-in” operation (see the network structure in Appendix 10).

Case4 Precious Metals Network.

This CESN was started by PMrec, a traditional mining firm, but due to natural resource extraction economic unviability and several mining civil conflicts in Africa, PMrec became an urban mining firm starting jewelry recycling operations and more recently electronics postconsumption product and byproduct recycling operations, besides mining and chemical firm’s byproducts recycling. Moreover, the network has nonrandom future characteristics, which means that common patterns of behavior are observable. For instance, PMcomp started to buy from PMrec, adding to its supplier selection processes smelter refinement issues according to obligations of regulated companies in the United States to report their use of tin, tantalum, tungsten, and gold (“conflict minerals”) extracted in the Democratic Republic of Congo and adjoining countries (“DRC region”) (see network structure in Appendix 11).

Case5 Plastic Packaging Network.

This CESN started two decades ago by two production engineering students from a public university in Sao Paulo inspired by a sustainability campaign to reduce plastic waste. The students created Packrec, a plastic packaging recycler playing hybrid leadership, inspiring and influencing Packcoop, and managing the Packman relationship by exception and contingent rewards. On the other hand, Packbrand provides transformational leadership to start and sustain circular flows, in turn influencing and inspiring Packcoop, distributors and consumers. Moreover, the network adopts an innovative management mechanism that merges supplier and buyer selection strategies, as the same agent can be both a supplier of postconsumption products and a buyer of waste management services. For instance, Packcoop, to increase postconsumption product and materials recovery rate and competitiveness, have merged supplier/buyer selection processes in its relationships with final consumers, including condominiums, restaurants and firms. Packcoop is a supplier of waste management services and also a buyer of recyclable waste, e.g., plastic, paper, glass, metals, and electronics (see the network structure in Appendix 12).

Case6 Bioproducts Network.

This CESN started when Biogasol developed mass production technology to produce biogas and biofertilizers using a high quantity of sugar cane harvesting and ethanol production byproducts. Biogasman, one of the largest sugar cane biofuel producers in Brazil, developed a project with Biogasol in one of its ethanol plants to produce electric energy on a large scale from biogases and biofertilizer to use in sugar cane farms, interacting with each other via feedback loops in a nonlinear way. Moreover, Biogasol plays transformational leadership, creating new possibilities through inspiration and intellectual stimuli. The same agent is both a buyer (buy byproducts) and a supplier (supply biogas and biofertilizer), representing another example of a merged supplier-buyer selection process (see the network structure in Appendix 13).

Case7 Cardboard Box Network.

This CESN started with multiple actions by Cardman combining the use of byproducts from its operations and reforestation with postconsumption products from Cardcoop, Cardppman and Cardbrand to produce corrugated and cardboard boxes. For instance, the cardboard box used by Cardppman to supply plastic packaging to Cardbrand returns in the same empty truck to supply more plastic packages seven times on average. Moreover, Cardman employs multi-tiered sustainable network management developing individual cardboard waste pickers to Cardcoop and scrap dealers. Cardman also employs hybrid leadership based on inspiration, intellectual stimuli and contingent rewards with Cardcoop and individual waste pickers (see the network structure in Appendix 14).

3.4.2 Findings of cross-cases

As mentioned in Section 3.3.3, Open Code 4.03 and MS Excel facilitated the coding process, resulting in 60 codes, 16 subcategories and 3 categories (detailed in Appendixes 6 and 7) shown in Table 14 and following discussed. The codes reflect key elements and their variables that emerged from the interview transcripts, observations and documents analysis in terms of the network's configurations and dynamics toward a CESN.

We synthesize the influences and relationships of CESN elements and their presence among the seven cases in the cross-case matrix shown in Appendix 15.

Table 14- Elements that influence CESN configuration and dynamics.

Key elements	Variables	Characteristics
Management Mechanisms	Agents	Most agents in the same CESN have different roles and positions. On the other hand, most agents in different SNs have similar roles, positions and reverse schemata.
	Coordination mechanisms	Agents interact in the CESN to overcome a lack of government incentives and develop new capabilities to increase value creation and capture.
	Supplier selection	Agents in the CESN adopt a systemic supplier selection process approach, and agents responsible for initiating physical reverse flow use merged sourcing and customer strategies.
	Transactional leadership	Agents closer to CESN downstream positions in role as distributors or retailers play transactional leadership.
	Transformational leadership	Agents in the CESN medium position between extreme upstream and extreme downstream positions in role of brand owners, plays transformational leadership.
	Hybrid leadership	Agents in the CESN extreme upstream position as mining, oil, reforestation and primary resource extraction' companies, and agents in extreme downstream position as waste picker cooperatives play hybrid leadership.
	Multi-tier SC management	Agents in the CESN extreme upstream positions as mining, oil, reforestation and primary raw material extraction companies, plays multi-tiered SC management in triad or larger relationships with waste picker cooperatives, reverse logistics providers and scrap dealers.
Internal and External Environment	Regulation	Regulation impacts the CESN positively by incentivizing brand owner involvement or negatively by increasing costs through high tax complexity.
	NRS	Natural resource scarcity or extraction economic unviability is a restriction that can initiate CESN.
	External stakeholders	People, governments, nongovernmental organizations, competitors, universities and companies outside of a CESN that can influence relationships and flows of products, materials, by-products, information, knowledge and finance among CESN agents.
	Internal stakeholders	Major agents in the CESN that can influence postconsumption product or byproduct quality and quantity variability, preferred suppliers and new agents in performing new roles in the CESN.
Emergent Properties	Nonlinear change	Small emergent agents as cooperatives can cause major changes in the CESN by increasing postconsumption product and byproduct competitiveness, brand owner and final consumer involvement, integrating others SC.
	SN hybrid loop	The CESN flows of recovered products and byproducts can be governed by the same or new agents "with (in a closed loop) or without (in an open loop) brand owner direct" involvement. Moreover, the CESN expands to others SNs even in other industries.
	Nonrandom future	Future CESN trends show common patterns of behavior such as cooperative business models and business spin-offs, and through self-organization a lack of government incentives and companies' corporate strategies can be overcome to explore sustainable development.

Source: elaborated by the author.

3.4.2.1 Management mechanisms

According to the previous CAS literature, agents are key elements influencing internal mechanisms (Choi et al., 2001) and internal and external environments (Nair and Reed-Tsochas, 2019). These agents, through coordination mechanisms, create, maintain, and potentially transform network activities, managing interdependencies between activities performed to achieve value creation (Simatupang et al., 2002). The most popular definition of "closed loop supply chain" is grounded mainly in the remanufacturing process and has not provided details about coordination mechanisms related to the agent's role and position in an SN (Guide and Van Wassenhove, 2009). In addition, recent literature has suggested that a "circular supply chain" act as an extension of "closed loop supply chain" (Batista et al., 2018).

This research shows that coordination mechanisms might generate two types of inflection points that act as leverage points (Meadows, 1999) in the CESN, with one related to which agent initiates postconsumption product or byproduct physical reverse flow and with the other related to which agent coordinates this activity. For instance, in case 2 (printers), Prrec recycler is responsible for coordinating the reverse flow, but it is not responsible for initiating the physical reverse flow, which is initiated, in this case, by Prcoop waste picker cooperative and the product distributor (Fig. 12). Additionally, in case 4 (precious metals), PMrec recycler is responsible for coordination, and PMcoop waste picker cooperative and PMrevlog reverse logistics provider are responsible for initiating reverse physical flow (Fig. 14). As well as, in case 5 (plastic packaging), Packrec recycler is responsible for coordination and Packcoop waste picker cooperative and scrap dealers reverse logistics provider are responsible for initiating physical reverse flow (as shown in Fig. 14). Therefore, agents in the same SN with different roles and positions might be responsible for initiating or coordinating the postconsumption product or byproduct physical reverse flow. On the other hand, agents in different SNs have similar roles, positions and reverse schemata.

CESN leadership is also related to agents' roles and positions. Agents closer to a CESN downstream position, in a role of distribution or retail, could play a transactional leadership role based on contingent rewards and management by exception. On the other hand, agents in midstream position, between upstream and downstream positions of a CESN as brand owners could provide transformational leadership based on inspiration, intellectual stimulation, greater influence and individualized consideration, establishing long-term relationships (Jia et al., 2019). Our interviews show that CESNs have developed another leadership style named hybrid leadership that combines SN transactional and transformational leaderships. Agents in upstream positions, such as mining, oil, reforestation and primary raw material extraction, and in downstream positions, such as waste picker cooperatives, could plays CESN hybrid leadership by combining elements from transactional and transformational roles.

Therefore, an agent's role and position can determine the respective leadership type employed. For instance, in cases 4, 5, 6 and 7, agents as mining, oil, reforestation and primary raw material extraction companies and recyclers and in cases 1 and 2 agents as manufacturing companies provide CESN hybrid leadership for agents such as scrap dealers, waste picker cooperatives and recyclers, establishing long-term relationships, rewarding expected performance and sanctioning unmet targets (the blue color in Figure 11). While in most cases, the focal company (brand owner) does not actively participate, in cases 2, 5 and 7, focal companies play a transformational leadership role (the green color in Figure 11). On the other hand, the agent role and position related to retail and distribution plays transactional leadership, as shown in cases 1, 2, 3, 5, 6 and 7 (the yellow color in Figure 11). Therefore, in line with recent literature on the positive influence of leadership on RSCs (Mokhtar et al., 2019), agents could play different types of leadership in initiating or coordinating a CESN. We therefore propose the following:

- **P1.** CESN has inflection points in that agents with different roles and positions might be responsible for initiating or coordinating postconsumption product or byproduct physical reverse flow.
- **P1a.** CESN agents' role and position might also indicate the types of supply network leadership they should play, agents in extreme upstream or downstream position could play hybrid leadership, combining transformational and transactional leadership types.

Agents acting in CESN adopt a systemic supplier selection process approach, and the agent responsible for initiating physical reverse flow adopts a merged sourcing and customer strategy. Supplier selection is one of the most important decision-making processes involved in a buyer-supplier relationship, and it is also one of the key factors related to management mechanisms influenced by internal and external environments. This is in line with the literature explaining the increased levels of complexity involved in considering various suppliers' performance and relationship factors, such as quality, process capability, cost, financial, product complexity, sourcing maturity and regulation issues (Sarkis and Talluri, 2002; Schleper et al., 2019).

Figure 11- Types of SN leadership and SN across all cases.

SN Types	Closed loop SN	Open loop SN	Hybrid loop SN =	Closed loop + Open loop supply network + Others industries supply chains			
Supply network cases	Case 2	Case 3	Case 1	Case 4	Case 5	Case 6	Case 7
Interviewed SC Agents	4	3	3	5	4	2	4
Agent's role and position				Extreme Upstream			
Mining, oil, reforestation and primary raw material extraction company	Mining and Oil	Mining and Oil	Mining and Oil	PMrec	Mining and Oil	Biogasman	Cardman
Raw material producer and or recycler	Prrec	Raw Material Producer	Batrec	PMrec	Packrec	Biogasol	Cardman
Raw material producer and or recycler	N	N	Plastic Recycler	N	Raw Material Producer	N	N
Raw material producer and or recycler	N	N	Acid Recycler	N	N	N	N
Other supply chains	N	N	Sinker Fish industry	Jewelry Industry	N	Cities	Chemical Industry
Other supply chains	N	N	Bullet industry	Chemichal Industry	N	Food industry	Construction Industry
Other supply chains	N	N	Battery Industry US	Mining Industry	Food industry	N	Food Industry
Part or component or packaging producer	Component Producer	Components Producers	Components Producers	PMcomp	Packman	N	Cardppman
Manufacturing	Prman	Products Manufacturers	Batman	PMman	N	N	N
Focal company (brand owner)	Prbrand	Mobiles,Tablets, PC Brand	Automotive OEM	Mobiles,Tablet, TV, Appliance, Machinery Brand Owners	Packbrand	N	Cardbrand
Part or component distribution		Eledist	N	Component Distributor	N	N	N
Product distribution	Distributor	Product Distributor	Batdis	Distributor	Distributor	Distributor	Distributor
Retailer or other services		Eleret	Resales	N	N	Gas Station	N
Recommerce		Elereco	N	N	N	N	N
Scrap dealers or reverse logistics provider		N	N	Pmrevlog	Scrap dealer	N	Scrap dealer
Waste picker cooperative	Prcoop	N	N	PMCoop	Packcoop	N	Cardcoop
Consumer individuals or condominiums	Consumers	Consumers	Consumers	Consumers	Consumers	Consumers	Consumers
Government collectors service; volunteer delivery points; individual waste collectors	GCS or VDP or IWC	GCS or VDP or IWC	GCS or VDP or IWC	GCS or VDP or IWC	GCS or VDP or IWC	GCS or VDP or IWC	GCS or VDP or IWC
Supply Network Leadership Type				Extreme Downstream			

Supply Network Leadership Type	
Transactional	Demonstrates contingent reward and management-by-exception.
Transformational	Based on inspiration, intellectual stimulation, greater influence and individualized consideration, establishing long term relationships.
Hybrid	Transformational and transactional combined, they demonstrate contingent reward and are capable of greater influence, creator of the vision and establishes a long term relationship with other supply network organizations.

Source: elaborated by the author.

The interviews show that supplier self-assessment must be done considering these factors and guided by a sourcing strategy, extending the literature and supporting the importance of agents responsible for initiating reverse physical flow. These agents should develop a merged sourcing and customer strategy because they must be able to manage agent relationships as suppliers and customers at the same time in buyer-supplier and supplier-buyer relationships.

The supplier selection process is part of the sourcing strategy used in managerial practice to deal with suppliers, and customer selection is part of the customer strategy used in a linear/traditional SC. However, our results show that in a CESN, to deal with the lack of quality and supply of recovered products and byproducts, agents in downstream positions, such as waste picker cooperatives, have developed a new supplier selection process with which they can control the quality and quantity of postconsumption products and byproducts, approaching suppliers as customers of their waste management services and merging a sourcing and customer strategy with the same agent, ensuring economic viability for this operation. For instance, in cases 2, 4, 5 and 7, Prcoop, PMcoop, Packcoop and Cardcoop, which are responsible for providing postconsumption products directly and/or indirectly to agents upstream in the SN, merge sourcing and customer strategies to increase the competitiveness of products by reducing costs and increasing quality and quantity. The firms approach their suppliers, such as condominiums, restaurants, schools and companies, and offer waste management services, with which they obtain revenue providing services and obtain supplies at no cost. In other words, the firms have created a strategy that integrates the entire supplier and customer management process whereby the same agent is a both customer of waste management services and a supplier of postconsumption products. In addition, in Case 1, Batdis manages relationships with consumers as a buyer of a new battery or by recharging it and as a supplier of used/postconsumption batteries. We therefore propose the following:

P1b. New supplier selection process merging sourcing and customer strategies is influenced by a lack of quality and supply due to high variability in the quantity of postconsumption products and byproducts.

Agents in extreme upstream positions of CESNs, such as mining, oil, reforestation and primary raw material extraction firms, start multi-tier CESN relationship management in triad or larger relationships with waste picker cooperatives, reverse logistics providers and scrap dealers. According to Gong et al. (2018) and Jia et al. (2019), in a multi-tiered SSCM, focal companies can adopt four approaches to their lower tier suppliers: “direct”, “indirect” (via tier

1 suppliers), "via third parties", "none" and "combined and dynamic". A focal company's multi-tiered SSCM learning involves three stages: setup, operation and sustainability. We extend this to a CESN in that focal companies' brand owners have the same role. For instance, in case 2, Prbrand adopts multi-tier CESN relationship management with Prrec and Prcoop (waste picker cooperative), in turn helping them achieve operations quality and environment management standards, and in case 5, Packbrand has a similar relationship with Packrec and Packcoop.

Moreover, we extend this literature beyond the focal company (downstream focused) multi-tiered SSCM to last-tier suppliers in upstream positions, such as mining, oil, reforestation and primary raw material extraction companies.

For instance, in case 7, Cardman, a primary raw material harvesting, reforestation and recycling company, started a multi-tiered CESN relationship with government collector services, individual waste pickers and volunteer delivery points to increase the postconsumption product recovery rate of Cardcoop. Cardman maintains the same relationship with Cardbrand (focal company brand owner) to approve recycled raw material to supply to Cardppman (cardboard box producer). The multi-tiered CESN learning relationship between Cardman and Cardcoop has also evolved to a fourth stage from the sustaining phase to a direct loop phase to overcome the challenge of maintaining momentum and reduce the risk of failure (Jia et al., 2019), then increasing the postconsumption product return rate. We therefore propose:

P1c. Agents in extreme upstream or downstream positions of CESN might apply a multi-tiered CESN management strategy to increase the postconsumption product return rate.

3.4.2.2 Internal and External Environment

Major CESN agents are internal stakeholders that can influence the quality and quantity variability of recovered products or byproducts by, for instance, developing new agents to play a new role in the SN or adding them to the preferred supplier list. On the other hand, external CESN stakeholders such as communities, governments, competitors, universities and companies outside of the SN can influence the relationships and flows of products, materials, information, knowledge, and finance between SN agents. Regulation can impact CESNs positively such as by incentivizing brand owner involvement or negatively such as by increasing costs through rising taxes or due to complexities of the taxation process.

For instance, in Case 5, the Packbrand brand owner recognizes the incentives of recent Brazilian policy regarding waste management even though there are many opportunities to increase community and government involvement to improve SN circularity. Packbrand has a greater influence on the CESN in developing renewable raw material suppliers, sharing its vision with Packrec. In Case 1 batteries, Batrec helped the Batdis distributor and some small resellers understand battery return regulations to avoid duplicate tax payments. These entities interacted in the SN to overcome a lack of government incentives, developing new capabilities to increase value creation and capture.

Therefore, the boundary between the internal and external environment is constantly changing in a dynamic way, extending the studies of Choi et al. (2001) and Nair and Reed-Tsochas (2019) to CESN.

P2. CESN configuration - agents, stakeholders and their relationships - dynamically adapts to internal and external environmental changes.

P2a. Internal and external stakeholders influence or are influenced by regulations and taxes.

Natural resource scarcity is a restriction that can form CESNs, as companies should know how to respond to growing competition considering factors such as the price and quantity of natural resources and the availability of alternative suppliers (Kalaitzi et al., 2018). For instance, case 1 (batteries) started many years ago due to primary lead scarcity in Brazil, and in case 4 (precious metals), PMrec, which was a traditional mining company, started a CESN because of NRS and several civil conflicts occurring in mining locations in Africa. Based on this, we propose the following:

P2b. Natural resource scarcity may initiate CESN formation.

3.4.2.3 Combined effects of management mechanisms and internal and external environments on emergent properties.

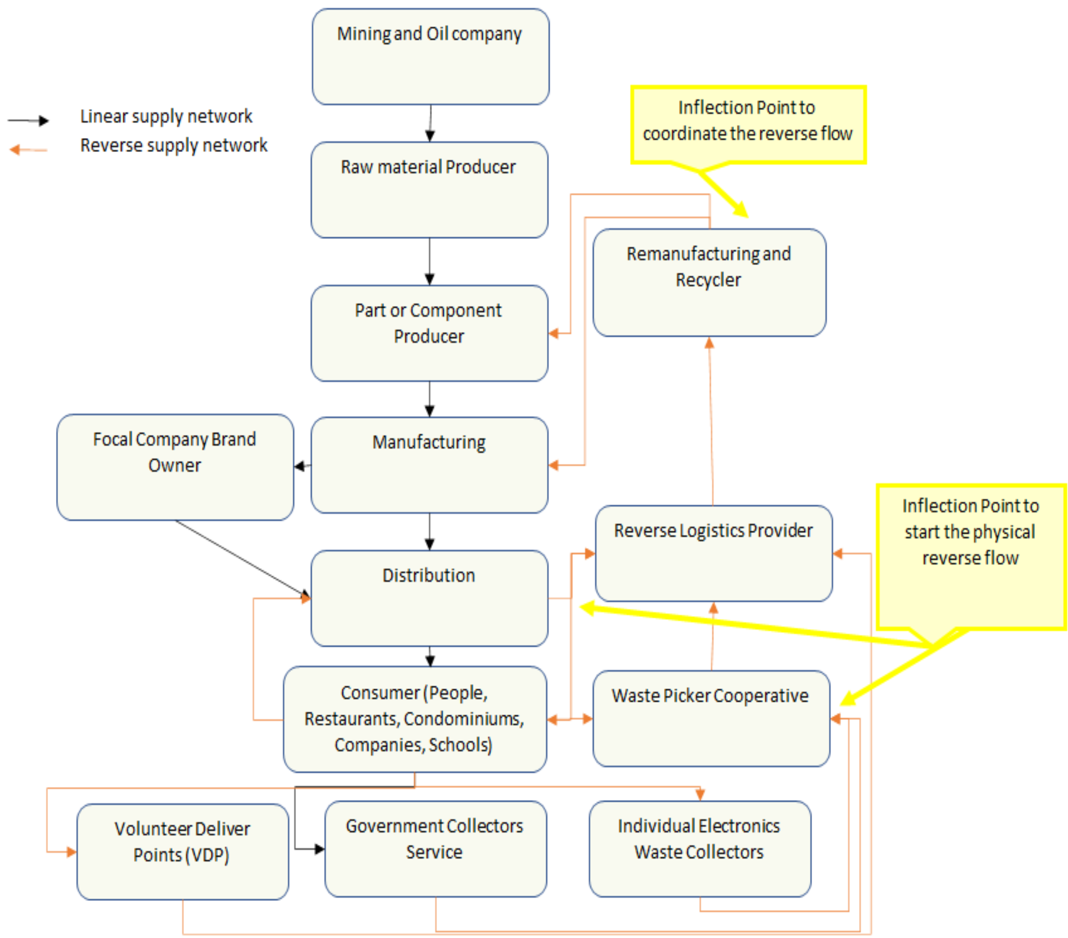
The CESN configuration in each case is related to emergent properties and can be influenced by the agent's multi-tiered CESN management. Thus, we propose synthetizing the seven cases into three SN configurations in which agents have similar roles and positions to create and improve the postconsumption product and byproduct recovery. For instance, we have a closed loop supply network (CLSN) configuration (Fig. 12, represented by case 2 printers) in which postconsumption products and byproducts circulate in the same SN with the direct involvement of the focal companies. An open loop supply network (OLSN) configuration (Fig. 13, represented by case 3 electronics), in which the flow of recovered products and byproducts is governed by a new agent "without brand owner direct" involvement, agent Elereco, which performs recommerce in retailer Eleret's position, circulating the recovered product between them and the consumer. Elereco also buys spare parts and components to repair or refurbish postconsumption products from Elecomp electronic component distributor without any participation or control from the focal company. This configuration is in line with recent literature defining an open loop SN wherein the component or product is still "looped" back to an independent remanufacturer for resale (Kalverkamp & Young, 2019). Moreover, we found an SN emergent configuration a hybrid loop supply network combining CLSN and OLSN features (Fig. 14, represented by case 4 precious metals) in cases 1, 4, 5, 6 and 7. Therefore we propose this as CESN configuration integrating closed loop, open loop and others industries SC as in Figure 15. The postconsumption products and byproducts circulate in the same SN with the same and new agents, and byproducts and recycled materials circulate to other SNs even in other industries. Examples include sinker fishing and ammunition industries in case 1; jewelry, mining and chemical industries in case 4 and chemicals, construction, and food industries in case 7, and food industry in case 5. Therefore, we propose the following:

P3. Multi-tiered CESN management and external stakeholders may lead to a CESN hybrid loop configuration with a combined open and closed loop.

P3a. The lack of competitivity and an agent to recover post consumption products and byproducts may lead to emerging small agents generating major outcomes.

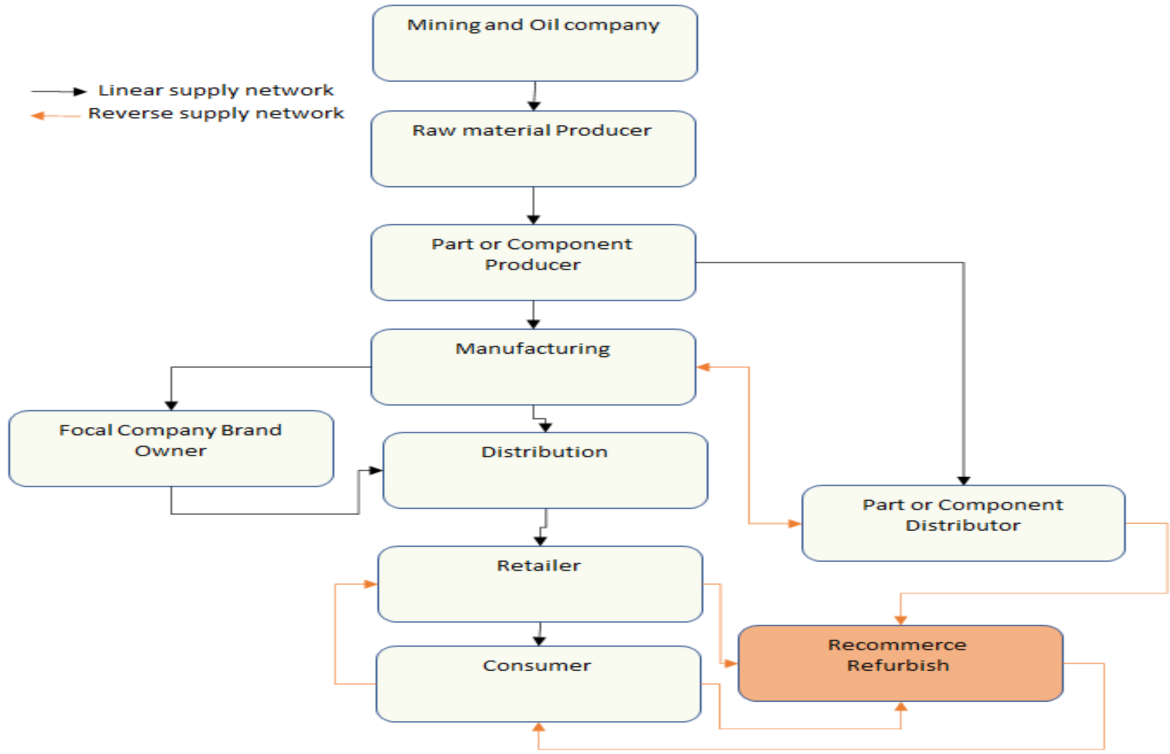
The emerging properties of these interactions between agents in these SN configurations can be a result of self-organization in the CESN once the agents show common patterns of behavior following a nonlinear change, integrating different SC, such as in terms of cooperative business models. These small agents' actions are responsible for initiating physical reverse flow in a circular economy, which is a major change. Examples are illustrated by Cases 2 Printers- PrCoop, (Fig. 12 and Appendix 9), 4 Precious Metals- PMCoop (Fig. 14 and Appendix 11) and 5 plastic Packaging- Packcoop (Appendix 12). Moreover, business spinoffs also have common patterns of behavior; through self-organization, they can also overcome a lack of government incentives and sustainable corporate strategies to explore sustainable development. For instance, in case 1 batteries, two agents, Batrec (a recycler and spin-off of an automotive battery manufacturer) and Batman (a battery manufacturer), are responsible for coordinating the reverse network, and one agent, Batdis (a battery distributor), is responsible for initiating reverse physical flow. On the other hand, in case 5 plastic packaging, Packrec, a plastic packaging recycler, is responsible for coordinating the reverse network, and two agents, Packcoop and scrap dealers, are responsible for initiating physical reverse flow.

Figure 12- Closed loop supply network configuration



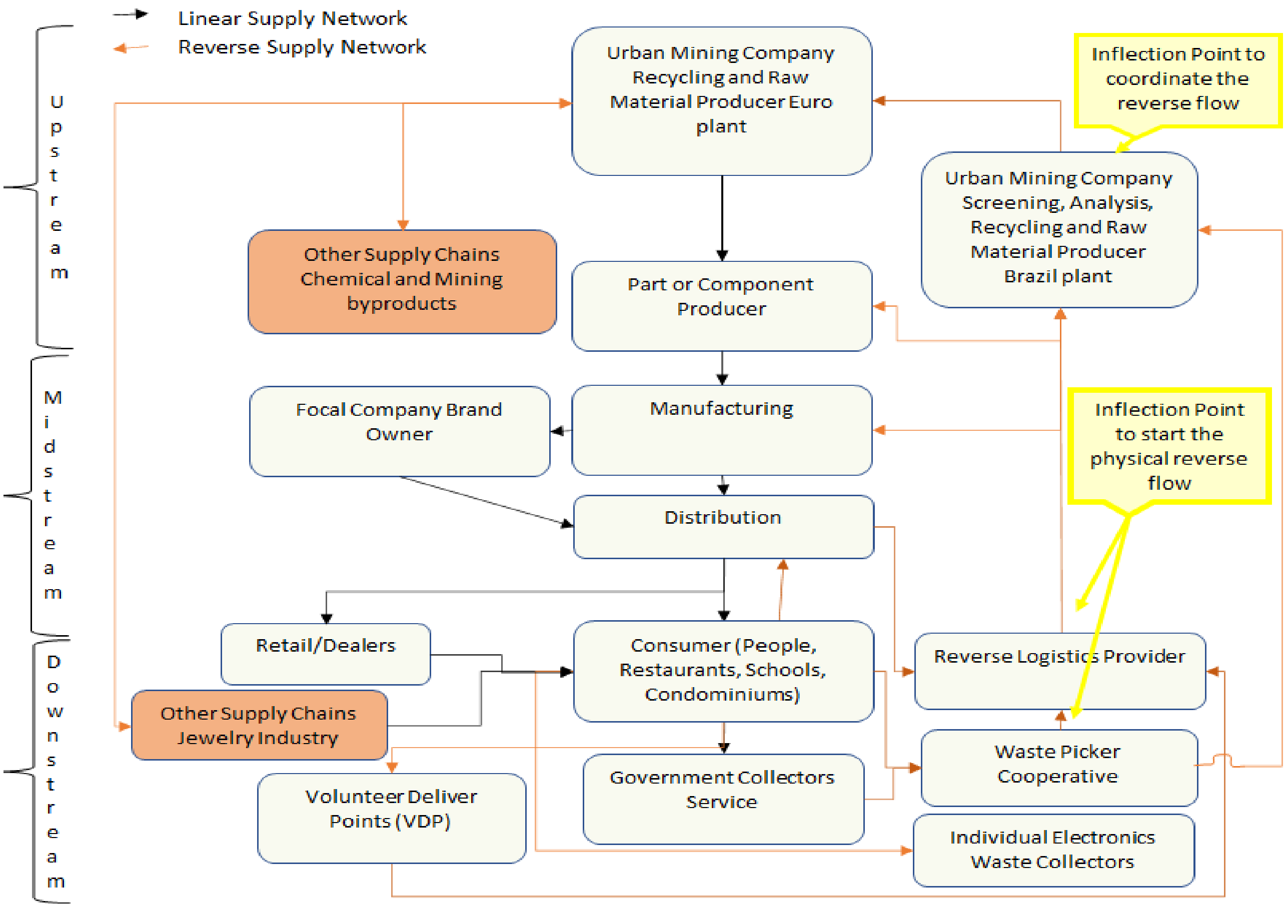
Source: elaborated by the author.

Figure 13- Open loop supply network configuration



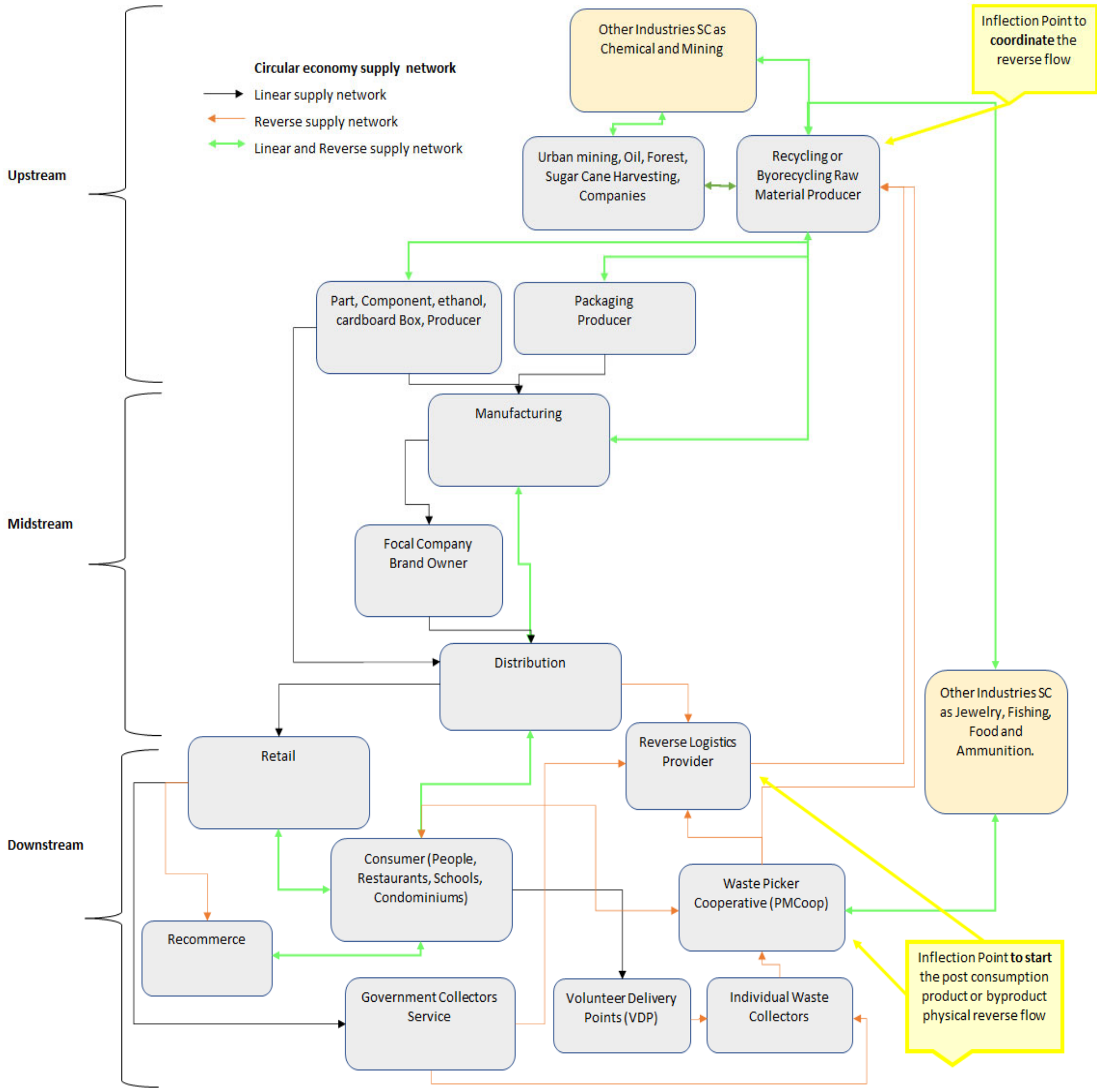
Source: elaborated by the author.

Figure 14- Hybrid loop supply network configuration



Source: elaborated by the author.

Figure 15- Circular economy supply network configuration



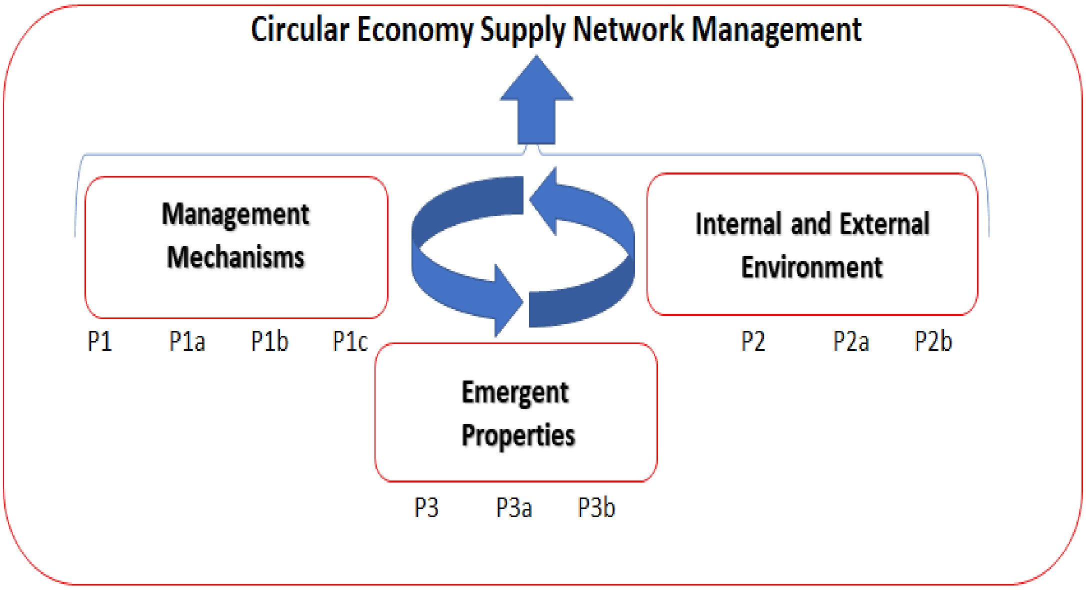
Source: elaborated by the author.

Emergent properties such as self-organization show nonrandom future behavior mainly at the meso level (supply network level), and they could be sources and outcomes of interactions between management mechanisms and internal and external environments. Choi et al. (2001) studied an SN as a CAS and propose self-organization as internal mechanism, and Nair & Reed-Tsochas (2019) recently proposed in a renewed framework, self-organization acts as an emergent property at a macro level and as the outcome of interactions between agents and the environment. Therefore, we propose the following:

P3b. Properties that emerge in different CESNs at a meso level may show common patterns of behavior once agents follow similar reverse schemas in SN self-organization.

Figure 16 illustrates the key relationships of CESNs findings and how the propositions interact in loops. Appendix 16 illustrates the causality of propositions developed for the association between the key elements and representative quotations.

Figure 16- CESN management conceptual framework and propositions



Source: elaborated by the author.

3.5 Discussion

3.5.1 Theoretical implications

Our analysis of seven different circular supply networks offers findings that contribute to theory in two different ways: we discuss the key elements that characterize circular economy supply network management in complex adaptive systems and how firms can manage the configurations and complexities of these supply networks.

In addressing the above research objectives, we employed the CAS theoretical approach with the aim of gaining an in-depth understanding of theoretical generation and elaboration in studying the CE and SCM. Then, we presented a pioneering conceptual framework (Fig. 16) presenting a set of propositions on CESN management with three key elements: management mechanisms, internal and external environments, and emergent properties, to recover postconsumption products and/or byproducts, thus extending beyond the traditional focus of

CLSCs and product recovery frameworks on activities and processes (e.g., reuse, repair, refurbishing, remanufacturing and recycling) (Braz et al., 2018).

We also extend existing research on the CLSC and CE by discussing how firms could manage CESN configurations and complexity by combining the agent's role and position; coordination mechanisms; supplier selection; SN transactional, transformational and hybrid leaderships; multi-tiered SN management; internal and external environments; regulation; natural resource scarcity; SN external stakeholders; SN internal stakeholders; nonlinear change; nonrandom future conditions; and SN hybrid loop configurations, closing the loop in the raw material's extreme upstream SN position and not in the product's midstream SN position (Guide and Van Wassenhove, 2009).

We may be the first to investigate how CESN management in a multi-tiered SN adopts leverage points to change from a linear to a circular network, which are points at which postconsumption product and byproduct physical reverse flows are coordinated and initiated (Batista et al., 2018; Kalverkamp & Young, 2019). These inflection points involve different agents and positions of an SN (Figs. 12 and 14).

Moreover, our results show that a CESN can have three different configurations: a closed loop SN, an open loop SN and a combination of both, adding new industry supply chains and nonlinear connections to form a hybrid loop SN (Figs. 12, 13 and 14). This is evidence that a CESN could be seen as a complex and adaptive system, as defined by Nair & Reed-Tsochas (2019). By noting these different SN configurations, we advance the definition of a circular supply chain as an extension of a CLSC, as discussed by Batista et al. (2018) proposing a CESN configuration (Fig. 15).

Our results also extend the literature on supplier selection and highlight the importance of the agent's role and position in initiating postconsumption product and byproduct physical reverse flow in CESNs. These agents should develop a merged sourcing and customer strategy once they should be able to manage an agent relationship between suppliers and customers at the same time in buyer-supplier and supplier-buyer relationships (Schleper et al., 2019). Moreover, this research offers work on SN hybrid leadership a combination of SN transactional and transformational leadership types used by key CESN agents (Defee et al., 2010; Jia et al., 2019).

3.5.2 Managerial and policy implications

In addition to its theoretical implications, this research has practical implications by offering a systemic approach based on framework key elements and propositions and thus helping managers determine how to foster CE implementation in their companies, even amid a lack of government incentives and regulation complexity.

Supplier selection can be managed as part of a combined sourcing and customer strategy to deal with a lack of quality and supply due to high variability in the quantity of post consumption products and byproducts. Agents' managers in downstream SN positions as waste picker cooperatives have developed a combined supplier and customer selection and management process whereby they must approach the same agent as a supplier to buy postconsumption products and byproducts and as also a customer of waste management services, merging sourcing and customer strategy (Schleper et al., 2019) and ensuring the economic viability of this circular operation.

In addition, companies in upstream SN positions, such as mining, oil, reforestation and primary raw material extraction firms, as well as companies in the SN midstream position, such as focal companies (brand owners), could coordinate operations for agents in downstream SN positions in multi-tier supply network management (subsection 3.4.2.1). Focal companies could also apply CESN transformational leadership by influencing and creating visions for suppliers related to benefits of recovering postconsumption products and byproducts, stimulating sustainable entrepreneurship, supporting cooperative business models creation (cases 2, 4, 5 and 7) (Mokhtar et al., 2019). Hence, such actors can promote the sustainable entrepreneurship of small and medium-sized enterprises, which can enter the CESN as coordinators of postconsumption product and byproduct flows or as firms responsible for initiating physical reverse flows as cooperatives or solution providers (cases 2, 4, 5, 6 and 7).

Managers can use the SN configuration and leadership frameworks (Figs. 11, 12, 13, 14 and 15) to identify which roles and positions they occupy in the current SN to make decisions on what they should do in terms of leadership and coordination mechanism types and which agent should be responsible for coordinating or initiating postconsumption products and byproduct reverse physical flows (Gosling et al., 2016).

Companies in upstream SN positions, such as mining, oil, reforestation and primary raw material extraction firms, can also use presented the results to enter the CESN and become more sustainable and reduce risks related to operations such as environmental and social disasters, and natural resource scarcity, as they can reduce or stop primary raw material extraction by initiating urban mining operations by using the presented cases as guidance and the management mechanisms (cases 1, 4, 5 and 7). Managers could use our results on industry CESNs to transform their SNs and promote local sourcing and reduce supply disruption risks (all cases) (Nair and Reed-Tsochas, 2019).

Regarding policy implications, policy-makers could use the results shown in Figures 11, 12, 13, 14 and 15 to create regulations aimed at agents based on the role and position of each agent in a given supply network, such as to incentivize companies in upstream SN positions, such as mining, oil, reforestation and primary raw material extraction firms, to assume recycling activities such as the coordination of postconsumption products and byproduct recovery for small agents' downstream SN positions. This kind of policy is innovative, as most regulations focus on downstream flow, mainly in focal companies (brand owners) (Jia et al., 2019).

Finally, our empirical findings can help policy-makers and managers achieve several sustainable development goals outlined by the United Nations (George et al., 2016), such as those related to "sustainable cities and communities", "the elimination of poverty" and "good jobs and economic growth", by organizing waste picker individuals in cooperatives who participate in a CESN to enhance their wage, reducing waste generation, as in cases 2, 4, 5 and 7. "Innovation and infrastructure" and "drinking water and sanitation" goals can be met by organizing more sustainability campaigns that reduce plastic waste use in public or private universities and inspire students to engage in innovative entrepreneurship, as in case 5. "Renewable energy" and "climate action" can be pursued by taking CESNs as means to use high sugar cane harvesting and biofuel production byproduct quantities to produce biogas and biofertilizers, as in case 6. "Responsible production and consumption" can be pursued by incentivizing more SN extreme upstream companies to implement multi-tiered sustainable network management developing individual waste picker in waste picker cooperatives or scrap dealers in addition to showing focal companies how to improve the use of cardboard boxes, as in case 7.

3.6 Conclusions and Further Researches

The starting point of this research was to discuss how supply chain management theories could contribute to circular economy development. With this main objective in mind, this study significantly contributes to theory in recognizing the diversity of supply network configurations and how their dynamics and management mechanisms foster the circular economy. The literature that connects the CE to SCM, such as Batista et al. (2018), Kalverkamp and Young (2019), De Angelis et al. (2018), Frei et al. (2020), Farooque et al. (2019) and Bernon et al. (2018), presents several types of circular supply chain configurations of increasing complexity and scope. As our main contribution, we show that this diversity occurs because CESNs are complex and adaptive systems in applying theoretical CAS frameworks given in Choi et al., 2001 and Nair & Reed-Tsochas, 2019 to CESNs. To demonstrate this pattern, we examined seven circular supply networks in different industries by drawing on complex adaptive systems and multi-tiered SSCM theories integrating leverage points, SC learning and leadership.

In addition to make this contribution, we aimed to remedy the paucity of empirically grounded work on the CESN dynamics of upstream actors such as reforestation, mining, and raw material producers, which were studied here employing a multiple case study of 25 companies. While this allows identification of the key elements of CAS and is an advantage, it is also a source of limitation, as most of the selected cases are from the same region (Brazil) to ensure comparability of the SN management context. Thus, our results may be biased; for instance, in Europe, Asia and North America, SN management may occur differently.

It is not our intention to provide exhaustive results on all types of SN, and the generalization of the findings is limited by the context. Moreover, all of the studied cases reflect the creation and capture of value in the CESN, which promotes sustainable development and may help render linear SNs circular.

Only the CESN initiatives of each case were studied in this project. Although we studied how different industries' supply networks foster the CE and provide an in-depth relationship dynamics perspective, this did not cover all types of SN or all agents' relationships. More research on different industries and supply networks could expand our findings.

This research opens several opportunities for future investigation. Studies could explore relationship modelling of our framework' key elements and variables (Fig. 16 and Table 14). As mentioned above regarding the limitations of the case study method, further studies should be conducted to test the propositions derived from this research and expand the generalizability of the findings by exploring framework circularity performance and dynamics over time within a base case supply network configuration to foster CE transitions through system dynamics modeling. Studies could also explore why some focal companies adopt transformational CESN leadership while others do not and how brand owner's firms could work closer with mining, oil, reforestation and primary raw material extraction companies that use hybrid CESN leadership to increase circularity through leadership.

3.7 Acknowledgments

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4 CIRCULAR ECONOMY SUPPLY NETWORK TRANSITION PHASES MANAGEMENT DYNAMICS

Abstract

This paper discusses transitions towards circular economy, developing a circular economy supply network management dynamics framework. We studied seven circular supply networks in Brazil through process analysis and system dynamics modelling. Primary data were collected through 35 manager's interviews and companies' plant visits and their suppliers. We suggest these transition phases are pre-development, learning, expansion, leadership, stabilization and self-renew with cooperative and competitive management challenges, characterized by specific circular factors over time. The simulation and transition phases models provide strategic tools to make decision on which circular factor project team should focus applying multi-tier supply chain management and hybrid leadership to stimulate internal and integrate external stakeholders to adopt circularity, unveiling challenges and average time to achieve each phase. We also enrich circular economy supply network management defining it in three dimensions: behavioral as supply ecosystem, structural as supply network and contextual as complex adaptive system.

Keywords - Supply chain Management, Complex adaptive system, Circular economy, Multi-tier supply chain management, Transition phases management.

4.1 Introduction

Circular Economy literature has been growing in different fields of knowledge such as Business, Engineering, Ecology, and has been deepening its understanding both conceptually and empirically, but there is still scant understanding of its transitional and dynamic nature. Circular Economy can be seen as a transition process, and the importance of viewing this process in the context of industrial and economic transformation has not been satisfactorily addressed by literature (Chizaryfard et al., 2021).

"Supply chain management" (SCM) literature has been developed mostly on linear supply chains(Carter et al., 2015; Nair & Reed-Tsochas, 2019). To understand the relationship between circular economy and "supply chain management", recent researches are proposing nonlinear supply chains (SC) with nonlinear flows through feedback loops more dynamic and complex (Braz & Mello, 2020; Kazancoglu et al., 2020). Circular supply chains have been suggested as an extension of closed loop supply chains (Batista, et al., 2018) and recently, as a CESN with a hybrid loop configuration, closed loop and open loop supply chain combined, integrating different SC and industries (Braz & Mello, 2022). Therefore, in order to enrich our understanding about transition to CE, we should better understand this CESN management over time (Chizaryfard et al., 2021).

Circular economy (CE) has feedback loops and could be considered a system for industrial transformation over time. This is also the central core of system dynamics, that could be used to better understand CESN management variables dynamic relationship over time (Alkhuzaim et al., 2021). However, still is scant in the literature CESN management studies explaining variables dynamic relationships over time connected to quantitative circularity performance measures with the number and types of parameters to be measured (Kravchenko et al., 2020). As well as, system dynamics modelling studying circular and sustainable supply chain management (Rebs et al., 2019), explaining the supplier-buyer and buyer-supplier relationship dynamics between the firms in extreme downstream and upstream supply chains, to implement and sustaining postconsumption products and byproducts circularity over time (Batista et al., 2018).

Thus, the high complexity of supply chains and the scarce knowledge on practice aspects of how to carry the circular economy out in a managerial practice context within SC over time might be the reason of its lag implementation (Frei et al., 2020). To address these aforementioned gaps in literature and practice, this research aims to answer:

RQ 5. How to manage circular economy supply network over time?

RQ 6. Which are the variables relationship dynamic aspects in circular economy supply network management, determining postconsumption products and byproducts recovery?

RQ 7. How this relationship dynamics among circular economy supply network key variables and circularity index, could impact public policies and managerial strategies?

To do so, this research employs system dynamics modelling of CESN real cases, based on Braz and Mello (2022) framework, using three key concepts: internal and external environment, management mechanisms and emergent circularity drawing in complex adaptive system (CAS), multi-tier SCM and transition management perspectives to study their non-linear relationship impact in circularity index over time to implement and manage a CESN.

The main contributions of this article are twofold: for literature, there is an advance about CESN transition phases management dynamics, and its structural, contextual and behavioral conceptualization. Practioners, could use CESN transition phases management to overcome the difficulties to start and maintain a circular supply network over time, and the simulation model scenarios describing and testing various combinations of agents' relations management on CESN circularity performance.

This study approaches these research questions through rich case studies of twenty-five firms and their networks. Our primary contribution is a new, fresh framework for CESN transition phases management. This study's results and implications are crucial for both theory and practice. First, addressing these questions contributes to a deeper theoretical understanding of the unique nature of CESN. Second, CESN knowledge is crucial for providing theoretical guidance on how firms design and manage circular supply networks over time. Following this, CESN can provide a unique portfolio of new managerial approaches and strategies for firms focused on managing the transition from a linear to a circular economy supply network.

The paper is ordered as follows. Part 4.2 brings a theoretical background on CAS, transition phases management and CESN management key constructs. Part 4.3 explain the multi-method used in this study. Part 4.4 presents findings with CESN transition phases management framework and modelling scenarios. Part 4.5 discusses managerial and policy, and theoretical implications. Finally, part 4.6 presents conclusions and further researches.

4.2 Theoretical foundation and construct development

4.2.1 CESN transition phases management

Generally, industrial transformations, such as the transformation envisaged towards the CE, are about understanding the mechanisms and logic of radical systemic changes. Assuming that CE is a transformative mechanism, there is no logic to talk about the evolving and dynamic aspects of change without taking a temporal and systemic perspective. As an evolving system CE consists of several layers, levels, scopes and entities. CE has been mainly investigated and discussed according to three scopes of analysis micro (firms) meso (SC) and macro (cities, provinces and countries), focusing as the main driving forces the technological evolution, trends and constraints in a static perspective (Chizaryfard et al., 2021; Dondi et al., 2021).

CE transition might reverse industrial districts declining trends caused by globalization, economic and pandemic crisis through circular business process and digital technologies to increase and monitor post consumption products and materials return as part of an integrative systems thinking towards sustainable transitions, that could help to understand CESN management transitions phases evolution (Bressanelli et al., 2022; Rusch et al., 2022). Rotmans et al. (Rotmans et al., 2001) proposed a four phases transition model, to simplify the understanding of large-scale and complex transformations. Recently a most simplified three phases transition model has been suggested namely: pre-development and exploration, acceleration and embedding, and stabilization (Kanger and Schot, 2016; Kivimaa et al., 2019). Discussing the role of actors (intermediaries) in a meso level as characterized in Table 15.

Table 15- Transition phases management.

Phase	Characteristics	References

Pre-development and exploration	Actors should be between the motivation to experiment what is possible or hesitating to change the existent configuration.	(Kanger & Schot, 2016; Kivimaa et al., 2019)
Acceleration and embedding phase	Actors bring new solutions to existing system, moving from experimentation to mass production, scaling the solution up attracting more actors and nurturing the system expansion. This niche starts competing to the dominant regime becoming the mainstream market.	(Kanger & Schot, 2016; Kivimaa et al., 2019; Löhr & Mattes, 2022)
Stabilization	Number of actors is too high resulting to economies of scale, occurring incremental changes, achieving a new dynamic equilibrium	(Kanger & Schot, 2016; Kivimaa et al., 2019; Löhr & Mattes, 2022; Rotmans et al., 2001)

Source: elaborated by the author.

While a meso level connection between transition phases management and "CAS" perspectives, suggest a co-evolutionary perspective on emergence and self-organization. Explaining that this happens when initial change results in an effect that is amplified by reinforcing feedbacks, and actors align themselves with the new configuration so that the new configuration slows down and stops growing, and this new alignment often is the emergent property of the system (Grin et al., 2010). In addition, CAS internal mechanisms, in that actors share attributes, analytic and conduct rules, representing the schemas or rules that socially embedded actors need to make decision, over this shared behavior of various actors create patterns producing emergence and self-organization with inter-dependent and constant changes in the interpreted and enacted environment in which decision-makers respond in CAS' inside and outside boundaries. However, this boundary is dynamic and the process by which they affect each other could emerge system characteristics, that, might have the power to impact the environment and actors in a meso level over time is still lacking (Nair & Reed-Tsochas, 2019). This transition will require new strategies to improve communication among customers, suppliers and external stakeholders, understanding the mechanisms that regulate the relationship among them (Gandolfo & Lupi, 2021).

Therefore, CAS and "multi-tier SCM" perspectives focused on the influence of governance mechanisms specially not formalized ones, sourcing strategy, SC leadership and the power of some companies across the SC' interdependence and structure in a buyer-supplier's-supplier relation, over time could overcome this gap (Jia et al., 2019; Sarkis et al., 2019). Next section presents constructs significant to both CAS and Multi-tier SCM.

4.2.2 Circular economy supply network management construct development

Fostering and maintaining, the dyadic, triadic or more relationship among members is a challenging assignment. Several pressures play crucial roles in making this a difficult managerial practice. The follow framework adds some of these key driving pressures that have been found from interdisciplinary literature. The first construct internal and external environment has variables such as: regulations, natural resource lifespan and multi-stakeholders engagement (Batista et al., 2018).

Natural resource extraction reduction by circular supply chains decreasing import dependence and slowing down its scarcity (Fonseca et al., 2018; Kalaitzi et al., 2018). Regulation that might create incentives or barriers to circular economy SC, in turn they might be more or less complex and different for each city, state, region or country, varying its effectiveness (Kalverkamp, 2018), it is an aspect that show how organizations could change (Bertassini et al., 2021), to respond to internal and external stakeholders demand even in a lack of regulation' incentives (Fonseca et al., 2018). With also, internal stakeholders, to get collaboration of consumers, suppliers and distributors that belong to the SC in terms of materials and products flows (Gandolfo & Lupi, 2021) but they have not yet adopted circularity, and external stakeholders that not belong to SC they are external drivers of corporate social responsibility, that could be governmental and non-governmental organizations, people and firms, they could be the potential circularity adopters (Frei et al., 2020). Their relationships dynamically adapt to environmental changes. They influence or are influenced by regulations and natural resource availability. As well as, by management mechanisms resulting in emergent circularity (Braz & Mello, 2022; Kalaitzi et al., 2018).

The second construct management mechanisms have variables such as: coordination and initiating mechanisms, multi-tier SC management, hybrid leadership and circular supplier development and selection (Braz & Mello, 2022; Kazancoglu et al., 2020). The actors in uttermost downstream or upstream nonlinear SC positions. Coordination mechanisms, managing activities interdependencies to accomplish a value creation target, through relations which crucial actors generate, transform and maintain SC activities, leading to more or less buyer-supplier relationship, depending on the distribution of fitness values and interdependences among the parts, developing mechanisms to integrate sustainable development and circularity (Carter et al., 2015).

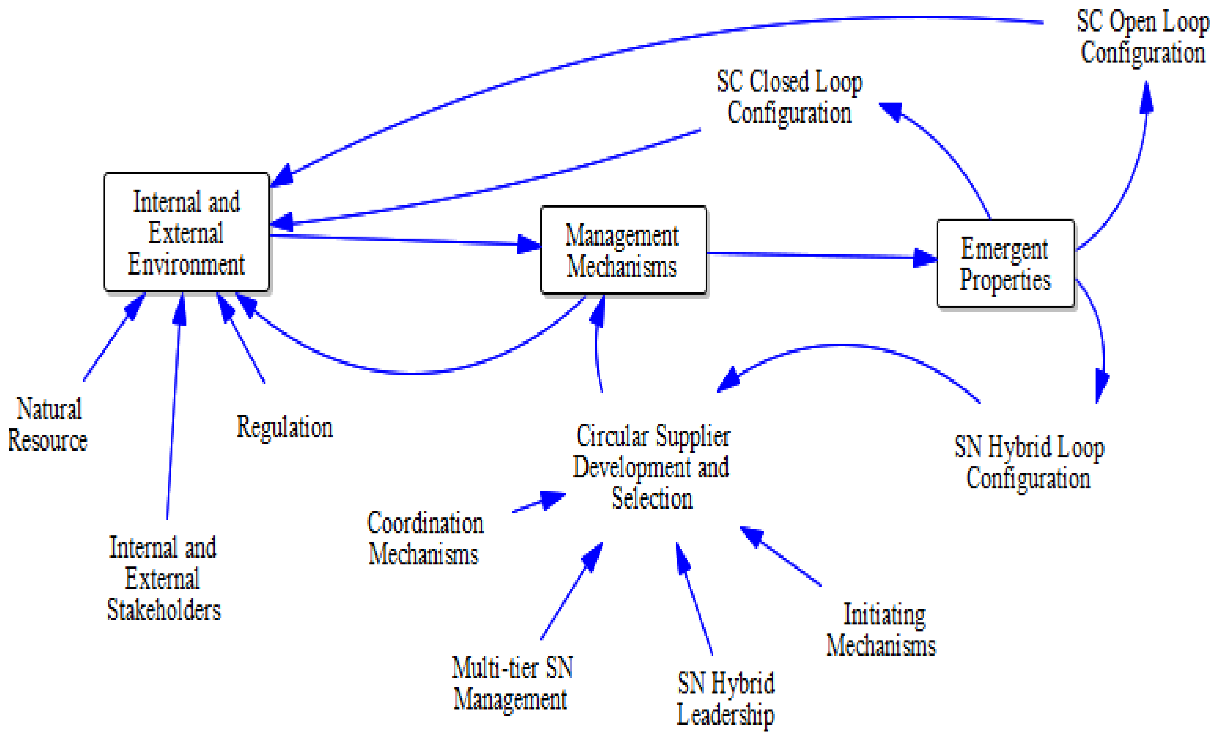
While multi-tier SCM recently has gained importance in SC literature mainly because the influence of governance mechanisms crucial in sourcing strategy specially not formalized ones, by contracts or direct/dyadic flow of orders, products and materials. Focal firms have relationship with tier 1, tier 2 and tier n suppliers, in three multi-tier SC structures: open triad, transitional triad and closed triad, since circular SC are characterized by nonlinear flows and buyer supplier relationship could require not formalized management mechanisms to engage new and current actors in circularity adoption. In identifying the large number of determinants in a nonlinear circular economy SC management, we have focused our efforts to the buyer-supplier dyadic, triadic or more relationship, not only by the focal firms (Jia et al., 2019).

SN hybrid leadership, characterized by combining transformational and transactional leaderships , demonstrating contingent reward, capable of greater influence, creating a vision and long-term relation with other organizations and SC even in others industries (Braz & Mello, 2022). SN transformational leader is characterized for the focus on building long-term relationships in a more holistic way by intellectual stimulation in that leader calling on more creative supporters to bring foremost solutions to problems, inspiration behavior as a vision and mission of a common future defining the way to accomplish the vision, and individualized consideration that is leader's skill to acknowledge each supporter's exclusive skills and learning needs (Jia et al. 2019). SN Transactional leader manages by-exception establishing that leaders indicate supporters' mistakes taking needed actions, and plays contingent recompense that shows that supporters will be recompensed on their forecasted performance and might be penalized if a goal is not achieved (Jia et al., 2019).

Strategically managing initiating mechanisms to value creation, delivery and capture through interdependencies between activities performed, to start the postconsumption products, byproducts or materials (PPBM) physical reverse flow to achieve a goal (Cosenz et al., 2020). Managing a partner at the same time as a supplier of PPBM and costumer of waste management service, combining customer and sourcing strategy (Braz & Mello, 2022). Supplier development and selection, one of the most important and critical decision that a buyer makes in a very rapid growth levels of environment complexity involved in reconfigure nonlinear supplier’s relationship (Cosenz et al., 2020). The selection of innovative small and medium enterprises to start and integrate diverse SC could be even more challenge resulting in SN, requiring to adopt a systemic supplier selection process combining customer and sourcing strategies (Braz & Mello, 2022; Kurpjuweit et al., 2020).

The third and last construct is emergent circularity has variables such as: closed loop SC configuration, open loop SC configuration and hybrid loop SN configuration. To increase the circularity and maintain economic viability, circular SC could be integrated with others SC even with others industries, connected by actors mainly in upstream and downstream SC’ positions, through complex and nonlinear interactions between system elements via feedback loops. A feedback loop is not only to reinforce the system but also to stabilize it. This means that there are two types of feedback loops. The feedback could acts both as a positive (reinforcing) and a negative (balancing) loop (Kazancoglu et al., 2020). Emerging closed and loop SC configurations, and a combined form of them a hybrid loop circular economy SN influenced by circular business models through resource loop flows (Bertassini et al., 2021). They influence and are influenced by internal and external environment and management mechanisms (Braz & Mello, 2022; Nair & Reed-Tsochas, 2019). Finally, it is fundamental that buying firms take initiatives that foster circular relationships in nonlinear SC, thus, this framework depicted in Fig. 18, takes on theoretical definition of a supply network (SN) structure focused on dyad, triad or more relationships, even with others industries' SC to provide mutual benefits (Braz & Mello, 2022).

Figure 17- Circular economy supply network management conceptual framework

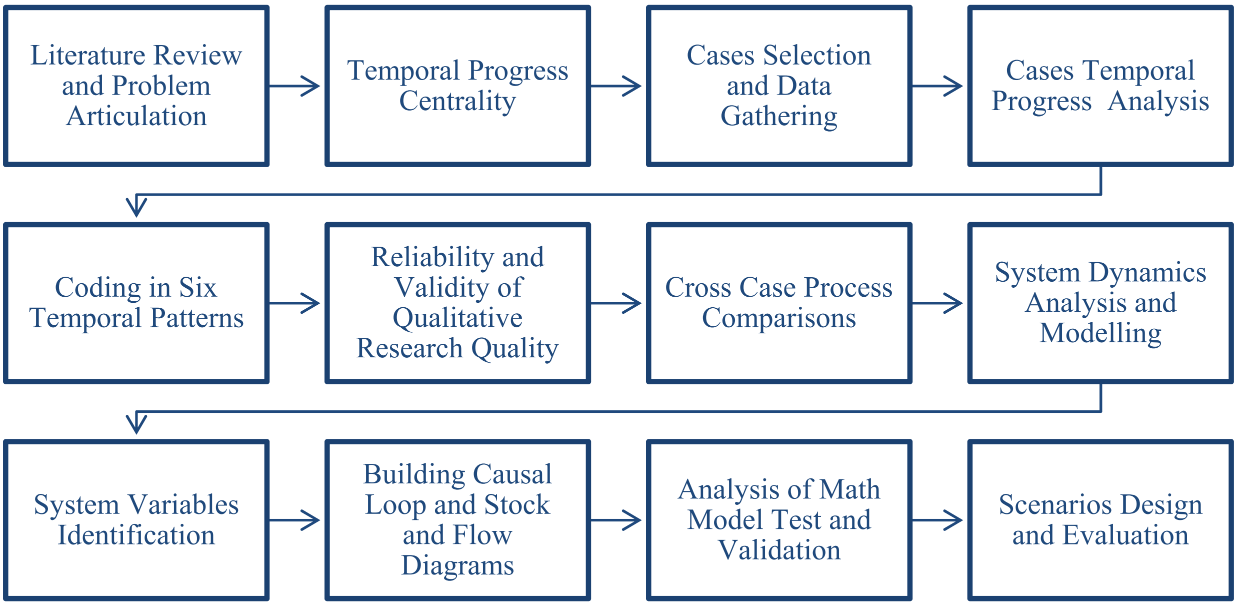


Source: elaborated by the author.

4.3 Methods

Taken together our research questions temporal progression centrality, this research combines two methodologies, multiple case study process comparisons and system dynamics modelling (Langley *et al.*, 2013) as shown in Figure 19.

Figure 18- Schematic representation of research design and methodology



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4.3.1 Cases study

4.3.1.1 Cases Selection

Case selection was driven by our research's questions. We followed a theoretical sampling with the number of cases between four and ten (Eisenhardt,1989).

The criterias applied in selecting CESNs were:

- Actors and their supply networks strong involved in a CESN were selected (Batista et al., 2018);
- Supply networks are operating in reverse loops (Kalverkamp and Young, 2019);
- Most CESNs have upstream flows close to the last-tier supplier, once most innovations occur in supply network upstream position (Sarkis et al., 2011).

We participated business conferences in Brazil (e.g., Fenibat for battery industry, Movimat for logistics industry, and FIEE for electronics industry) where we interacted with business managers to get managerial contacts responsible for each involved firm's reverse supply chain management. We have also gotten contacts from our professional network. Then, we contacted the managers and asked them to schedule a visit and interview explaining the purpose of our study and asking them to sign a confidentiality agreement. Along the visits and interviews, we asked them about their byproducts and postconsumption product operations, suppliers, customers, partners, bill of material circularity, CESN history, etc. The final results and details of this search, with the number of cases (seven) and actor's profiles, is shown in Table 13.

4.3.1.2 Data Gathering

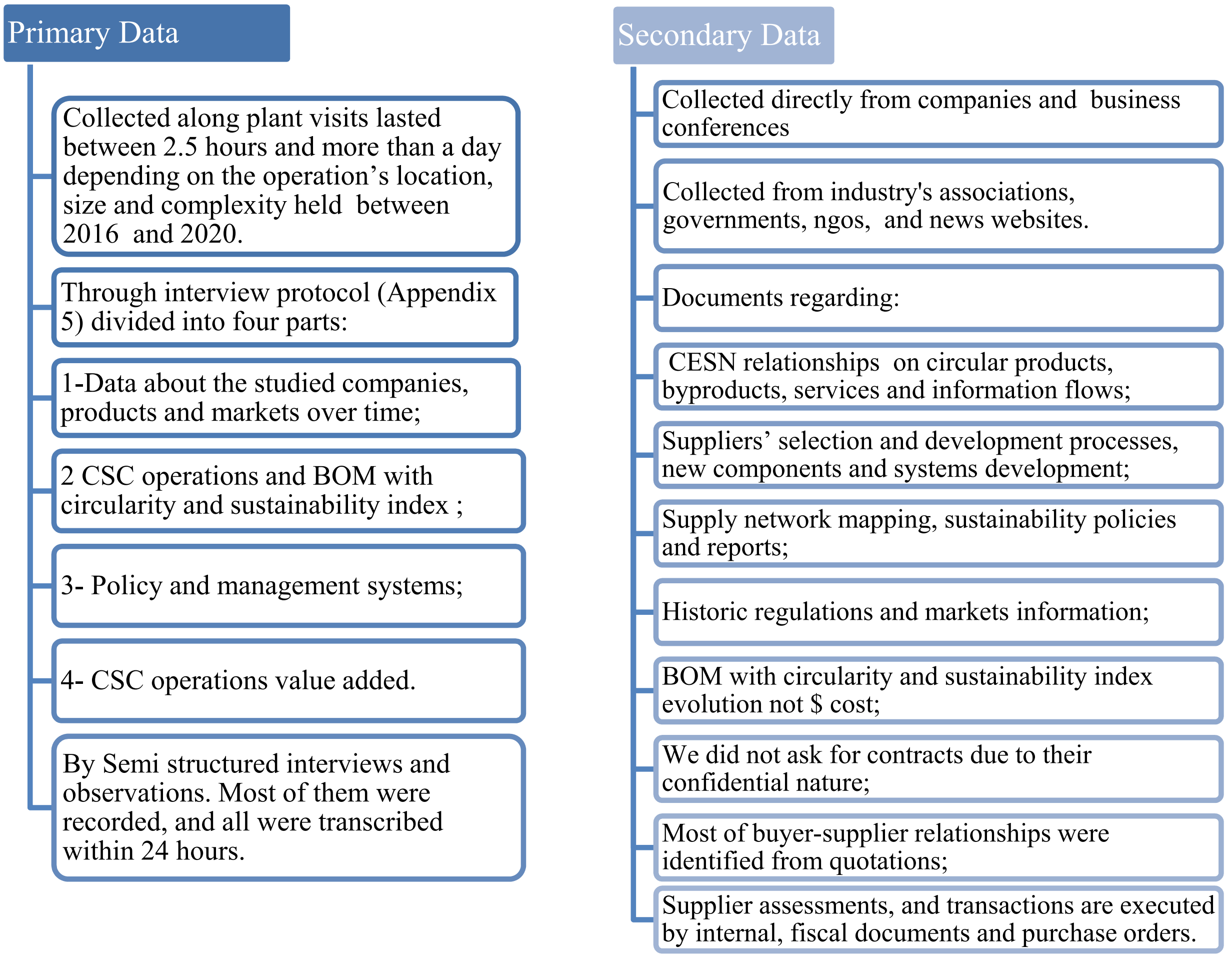
The multiple data collection sources detailed in Figure 20, made it possible to perform data analysis triangulation, improving data analysis reliability and validity as shown in Table 16.

Table 16- Standard**s** for assure qualitative research quality.

Standards	Actions
Reliability	• Uses a case study protocol to orientate field research and analysis. • Create a case study database including transcripts recorded within 24 hours, internal documents, news coverage, sustainability reports and some field photos. • Iterative revision with uninvolved senior academics.
Internal Validity	• Structured data analysis and coding. • Complementary data sources triangulation.
External Validity	• Theoretical sampling method. • Massive descriptive data use. • Several suppliers' plant visits. • Findings are connected to prior theory.
Construct Validity	• Multiple sources of evidence including semi structured interviews, various forms of secondary data and observations as in Figure 18. • A network of evidence: multiple informants, organizations and supply networks.

Source: elaborated by the author.

Figure 19- - Data gathering flow chart



Source: elaborated by the author.

4.3.1.3 Cases temporal progress data analysis

A prerequisite for collecting and analyzing process data is having a set of concepts to focus on the change process, in this study we have three concepts that reflect this process of how managers could manage CESN transition phases over time (Langley et al., 2013; Van De Ven, 2007): pre-development reflects the driving forces on actors between motivation to experiment what is possible or hesitating to change the existent configuration, that could impact customer's wants and needs; acceleration reflects the driving forces on actors bringing new solutions to existing system, moving from experimentation to mass production, scaling the solution up attracting more actors and nurturing the system expansion. This niche starts competing to the dominant regime increasing circular products demand and postconsumption products and byproducts offer, becoming the mainstream market; stabilization occurs when the actors' number is too high resulting to economies of scale, occurring incremental changes, achieving a new dynamic equilibrium when CESN achieves a maximum circularity making incremental changes over time.

Table 15 fully define these concepts and provide references. From the collected data we defined “a bracketed string of words about a discrete incident/event” (Van De Ven, 2007). These strings of words are sentences, text segments that we copied from the collected data or quotes that we recorded during the interviews and then transcribed. This procedure took us to a set of 137 main events and 110 circularity indexes from 25 bill of materials from all cases (detailed in Appendix from 17 to 23).

We coded these 137 events using the concepts defined in Table 15. To check for intercoder reliability we asked a second coder (not part of the research team) improving reliability and validity as shown in Table 16. This temporal progress analysis provided us six temporal patterns. Findings’ section we will present these temporal patterns relationships cross case results.

4.3.1.4 System Dynamics Analysis and Modelling

System dynamics is an approach for modeling and simulating complex social systems and experimenting with the models to design strategies for management, change and focus in feedback loops over time (Sterman, 2000), that are also the central core of CE and CESN research, thus, SD could be used to understand CESN management variables dynamic relationship and their over time management stages (Alkhuzaim et al., 2021). However, it is still scant the literature SD modelling to study circular and sustainable supply chain management, and less than 10% contain a normally distributed random parameter and most of them not present or suggest any equation (Rebs et al., 2019).

A SD model enabling experimenting with systems behavior through interconnected causality to develop theory about patterns of systems behavior (Davis et al., 2007). The three types of data needed to develop the structure and decision rules in models are: numerical, written, and mental data, they can be inductive, deductive or both. Modelling main tools are causal loop and stock and flows diagrams, mapping which variable could cause a behavior in another one, represented by general equation (Morecroft, 2015):

Outflow (t) = Inflow (t-average delay life time)

Stock> Integral Equation: $Stock(t) = \int_{t_0}^{t} \sum^{n} [Inflow(s) - Outflow(s)]ds + Stock(t_o)$

Flow> Differential Equation: d(Stock)/dt = Net Change in Stock = Inflow(t) - Outflow(t)

Model conceptualization involved problem articulation to identify and understand, which are the dynamic aspects in circular economy supply network management variables relationship determining postconsumption products and byproducts recovery and how managing relationship dynamics among circular economy supply network key variables and circularity index, could mitigate public policies and managerial strategies. In addition, understanding how to implement and manage circular economy supply network over time.

Then we formulate the dynamic hypotheses, defining the primary endogenous concepts, structures and hypotheses using both knowledge from comprehensive academic research and practioners available data for robust conceptualization. Conceptual model (Fig. 16), knowledge from CAS, SC types and structures related to CE, described in section 4.2, underpin CESN model. We build algebraic and simulation model employing new and current standard structures available in the SD literature, for instance in the "Business Dynamics" (Sterman, 2000) and "Strategic Modelling and Business Dynamics" reference books (Morecroft, 2015) were adapted (see in Appendix 24).

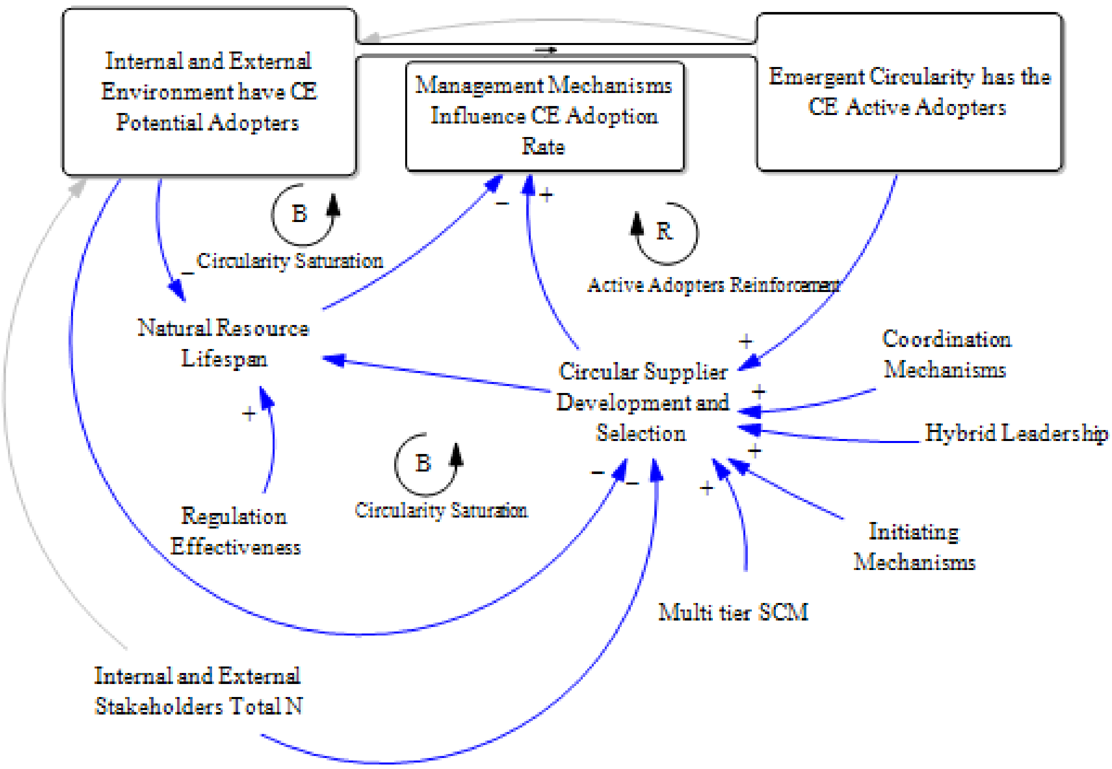
The complete simulation model "behavior was then continuously tested against available data and modelers' expectations for sub-models behavior as a good practice in SD modelling", to increase validity and reliability, model testing for contextual, structural and behavioral categories followed Sterman (2000) guidelines. In addition, empirical primary and secondary data from seven circular supply networks cases, governmental and nongovernmental organizations websites and observations, supported model calibration to a base case scenario, reference modes and several different tests are available in this article's model documentation using the SDM-Doc tool detailed in Appendixes 26 and 27 ((Martinez-Moyano, 2012).

4.4 Results

4.4.1 CESN Management System Dynamics Model

We develop SD model using Vensim PLE 9.0.0 to design SD diagrams and modeling. Combining Innovation diffusion model (Bass, 1969; Morecroft, 2015) and modeling decision making (Sterman, 2000): a retrospective model pre-processes the data collection from 1999 to 2019 drives the prospective model from 2020 to 2035. Proposed model has three constructs: 1) internal and external environment have CE potential adopters, 2) management mechanisms influence CE adoption rate, and 3) emergent circularity has the CE active adopters. Shown in Figure 21.

Figure 20- Circular economy supply network management constructs relationship



Source: elaborated by the author.

The internal and external environments as stock variable have the CE potential adopters' stock, compound by auxiliary variables: supply network internal and external stakeholders influencing natural resource availability, influenced by regulation effectiveness (Braz & Mello, 2022). Reducing natural resource extraction using recovered raw material, through regulation incentives and or reducing barriers to increase the number of CE agents from internal or external stakeholders.

Management mechanisms as flow variable influence on CE adoption rate, is the sum of the adoption resulting from auxiliary variables natural resource lifespan, internal and external stakeholders, and circular supplier development and selection, influenced by hybrid leadership and coordination mechanisms adoption fraction, initiating mechanisms and multi-tier supplier management contact rate.

Emergent circularity as stock variable has the CE active adopters' stock, when a new circular product is introduced the adoption rate is mainly influenced by external sources of information from auxiliary variables such as regulation or supplier development and selection process' social connections. As the stock of CE potential adopters decrease while CE active adopters stock grows, the regulation effectiveness rate contribution falls, resulting in a negative feedback loop (degrowth), while the contribution of circular supplier development and selection, and CE active adopters rises, resulting in a positive feedback loop (growth).

The stock, flow and auxiliary variables cross effects are formulated as multiplicative (assuming the effects of each input are not strong separable in extreme conditions) and additive, (assuming the effects of each input are strongly separable). Hence, nonlinear effects are normalized to their reference values (Morecroft, 2015). Each variable equation is detailed in Appendix 27.

Parameter's selection criteria to run simulation scenarios was the supply network structure that could represent cases' most found management complexity and dynamics. Based on that we chose case 4 empirical data with a hybrid loop supply network configuration. Most of these parameters are constants, and were identified based on semi structured interviews, plant visits, companies report, websites and industry news. Circularity index (from 0 to 1) is defined according to the quantity of postconsumption products and byproducts recovered or renewable materials used in the total quantity of processed material (Haas et al., 2015). The parameters defining circularity index were defined based on companies' bill of material information considering historical data from start circular supply network to time of data collection about 19 years on average.

In addition to these constant parameters, there are other parameters that are not constants, and their value can vary in different ways in the future. The circular supplier development and selection process, could be a typical example of such variable parameter. Although the values in the base scenario are empirically validated, the increased and decreased parameters in simulation model will be hypothetical and cannot be validated. We will compare scenarios with different values of such parameters to analyze a number of resulting what-if alternatives.

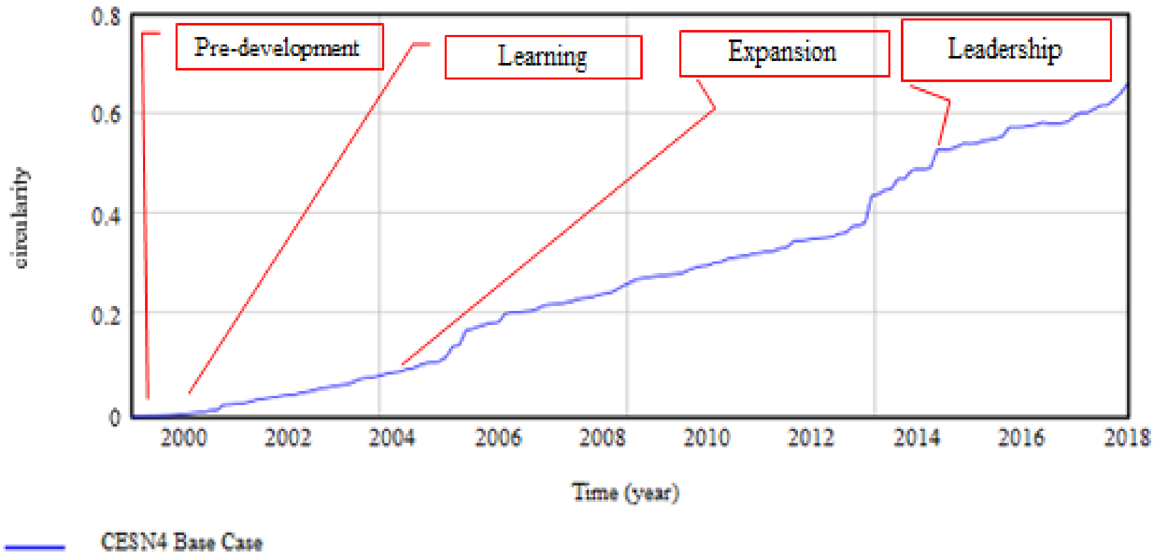
Case4 CESN management scenario is the starting point for our model and fits our observations of practice of most of seven cases, Its empirical historical data and predictions timeline with parameters such as: circular factors, cumulative circularity index and annual growth rate is detailed in Table 19.

PMRec a traditional mining in 1999, due to natural resource extraction economic unviability, and regulation pressure on products coming from civil conflict regions, launched the first circular product, (two circular factors from pre-development phase with CI= 0.01).

From 2000 to 2006, investment was made in mass production technology for recovery of precious metals from used jewelry and catalyst, and electronic waste through a multinational player acquisition, besides PMComp, component producer and PMMan electronic product manufacturer, to reduce primary raw material dependency started to use recycled one (two circular factors from learning phase, with CI= 0.13). From 2007 to 2014, focus to develop strategies to increase postconsumption product recovery, developing PMRevlog reverse logistic supplier and PMCoop waste pickers cooperative, besides orchestrating Brazilian Waste Management Law industry agreement (two circular factors from expansion phase and CI= 0,49), as of 2015, PMRec, PMRevlog and PMCoop add others mining and chemicals SC, increasing overseas operations by intercountry plants byproducts and postconsumption products exchange, focusing on reduce by-products, increasing the number of waste pickers cooperatives as approved suppliers (three circular factors from leadership phase, CI= 0.66).

Case4 CI starts with 0.01 in 1999 on pre-development phase and achieves 0.66 in 2018 in leadership phase as shown in Figure 22. Circularity average growth rate in learning and expansion phases is about 34% mainly due to multi-tier supplier development and value capture from initiating mechanisms. This has encouraged external and internal stakeholders to adopt circularity.

Figure 21- Case4 CESN management circularity index base scenario simulation



Source: elaborated by the author

Table 17- Case 4 CESN management timeline

Phase	Year	Circ. index	Growth rate	Circular factors

Pre-development	1999	0.010	1.00	Natural resource extraction economic unviability.
	2000	0.011	1.10	Regulation pressure: The Rule,3TBG and Sarbanes Oxley Law.
Learning	2001	0.012	1.10	
	2002	0.013	1.10	
	2003	0.024	1.80	Mass production technology development and partner acquisition.
	2004	0.036	1.50	Jewelry and catalyst recovery investment.
	2005	0.065	1.80	Focus to recovery electronic waste.
	2006	0.071	1.10	
Expansion	2007	0.128	1.80	Strategies to increase the post consumption product
	2008	0.131	1.03	and by-product recovery.
	2009	0.236	1.80	Reverse logistics suppliers and waste pickers cooperative development.
	2010	0.425	1.80	
	2011	0.436	1.03	
	2012	0.447	1.03	
	2013	0.467	1.05	Regulation fine tuning.
	2014	0.488	1.05	Brazilian Waste Management Law, industries agreements orchestration.
Leadership	2015	0.534	1.10	Overseas operations expansion increasing intercountry
	2016	0.593	1.11	plants exchange.
	2017	0.655	1.10	Adding others industries byproducts recovery.
Predictions				
	2018	0.688	1.05	Following industry global markert compound annual average growth rate of 5%
	2019	0.722	1.05	Brazilian Waste Management Law Signed Agreement
	2020	0.737	1.02	After Covid-19 industry local market compound annual average growth rate of 2%
	2021	0.751	1.02	Focus to reduce by-products process
	2022	0.759	1.01	
	2023	0.778	1.03	Increase waste pickers cooperatives quantity
	2024	0.778	1.01	
	2025	0.782	1.01	
Stabilization	2025	0.786	1.01	Transportation should use renewable fuel
	2026	0.790	1.01	
	2027	0.794	1.01	
	2028	0.798	1.01	Achieving BOM circularity improvements' technology capacity
	2029	0.802	1.01	
	2030	0.806	1.01	
	2031	0.810	1.01	
	2032	0.814	1.01	
	2033	0.818	1.01	
	2034	0.822	1.01	
Self-renew	2035	0.805	0.98	Renewing or decline the product's SN by a radical innovation

Source: elaborated by the author.

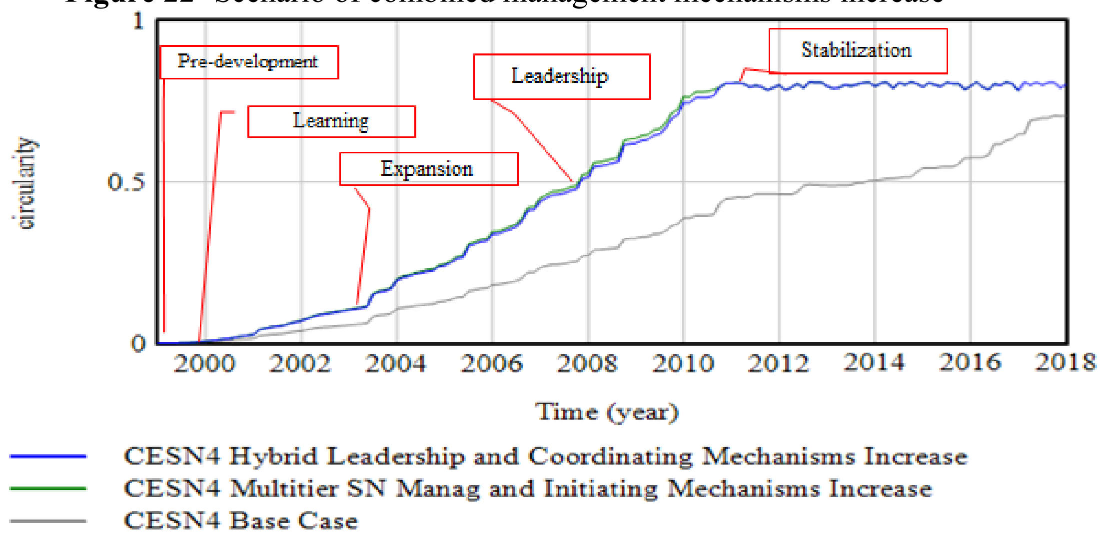
4.4.1.2 Combined impact of management mechanisms in circularity adoption

We then could create additional scenarios in which we'll increase and decrease Case4' parameters by 50%.

We aim to identify the dynamic aspects on variables relationship in the CESN management, and determine how managing this relationship dynamics, could mitigate public policies and managerial strategies to boost CE. Thus, we run a sensitivity analysis varying circularity growth rate in four auxiliary variables: multi-tier supplier management, supply hybrid leadership, initiating and coordinating mechanisms (Braz & Mello, 2022; Jia et al., 2019) to understand how they impact agents in internal and external environment to adopt circularity.

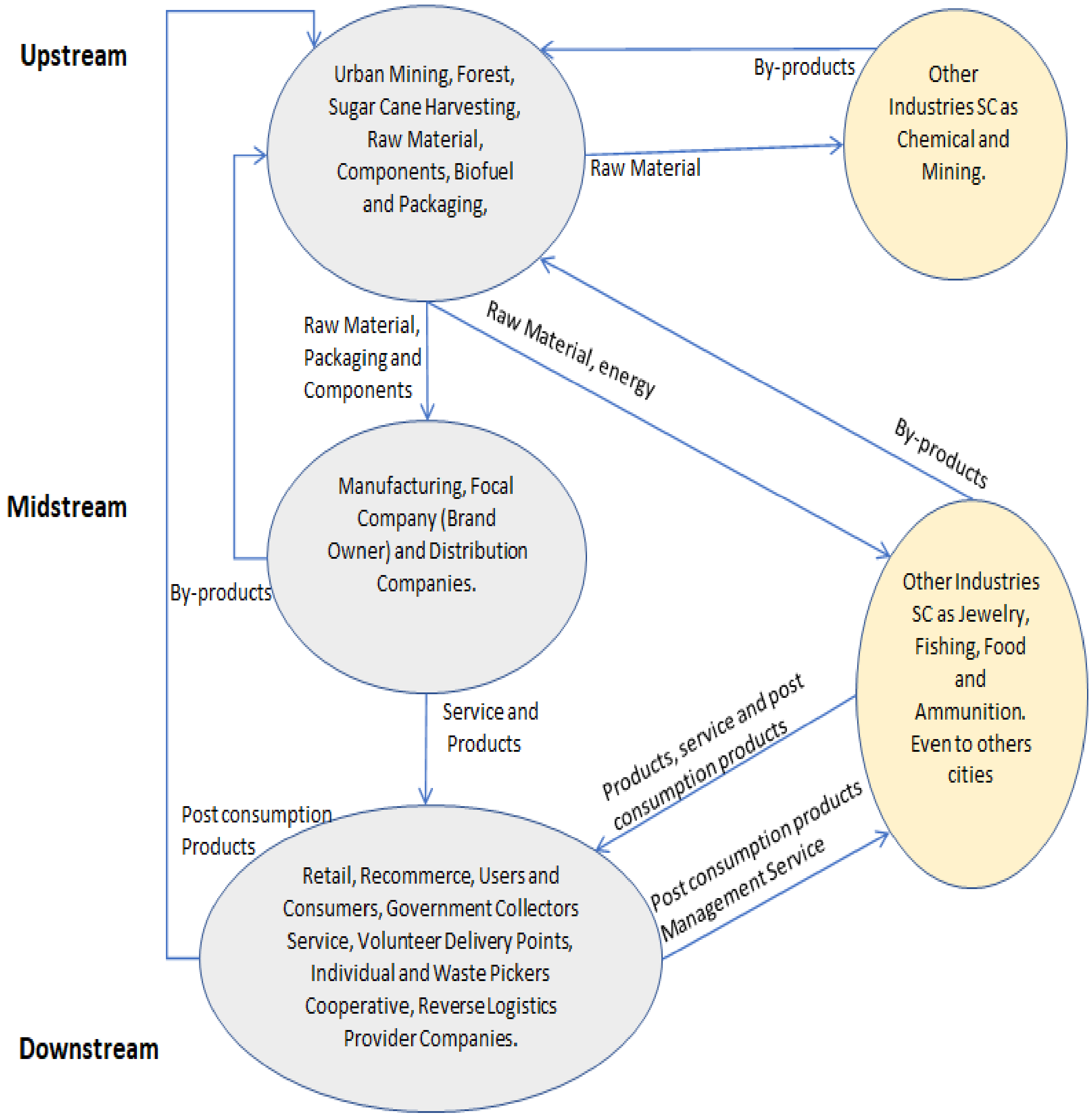
For instance, what if we increase new project buyer resource to work on multitier supplier management and initiating mechanisms or on hybrid leadership and coordinating mechanisms hypothetically in 50%. As result, we'd increase CESN circularity index almost 23%, resulting in thereabout five years gain to achieve leadership phase. This gain could start in learning phase. Case4 could have already achieved stabilization phase with 0.80 CI since 2013, as shown in Figure 23. The agents are integrating this chain with others industries' chains initiating this process, supplying recycled raw material, energy, waste management services and receiving several types of postconsumption products and byproducts. Besides that they are also integrating this chain with others industries' chains supplying raw material and buying by-products, besides coordinating reverse SC physical flow, creating a complex adaptive network (Choi et al., 2001) as shown in Figure 24.

Figure 22- Scenario of combined management mechanisms increase



Source: elaborated by the author.

Figure 23- CESN configuration

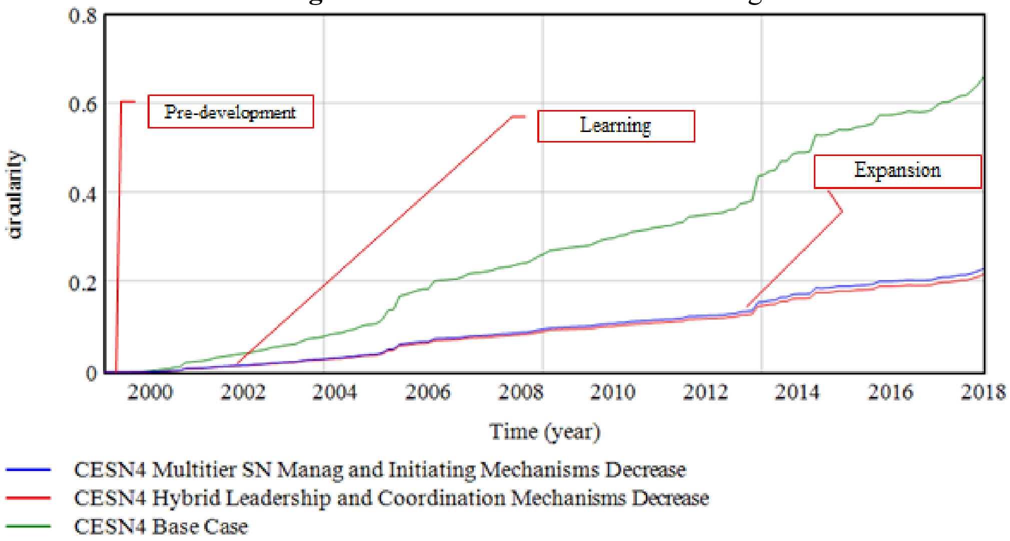


Source: elaborated by the author.

P4. CESN management mechanisms such as: multitier supplier management, hybrid leadership, initiating and coordinating mechanisms converting internal and external stakeholders to CE adopters are characterized by delays. That could be mitigated increasing new project buyers' quantity to manage these mechanisms.

What if we decrease new project buyer resource to work on multitier supplier management and initiating mechanisms or on hybrid leadership and coordinating mechanisms hypothetically also in 50%. As result, we'd decrease CESN CI in almost 67%, needing thereabout more seven years to achieve expansion phase, and do not achieving leadership phase. This delay could start in learning phase, as shown in Figure 25.

Figure 24- Scenario of combined management mechanisms decrease



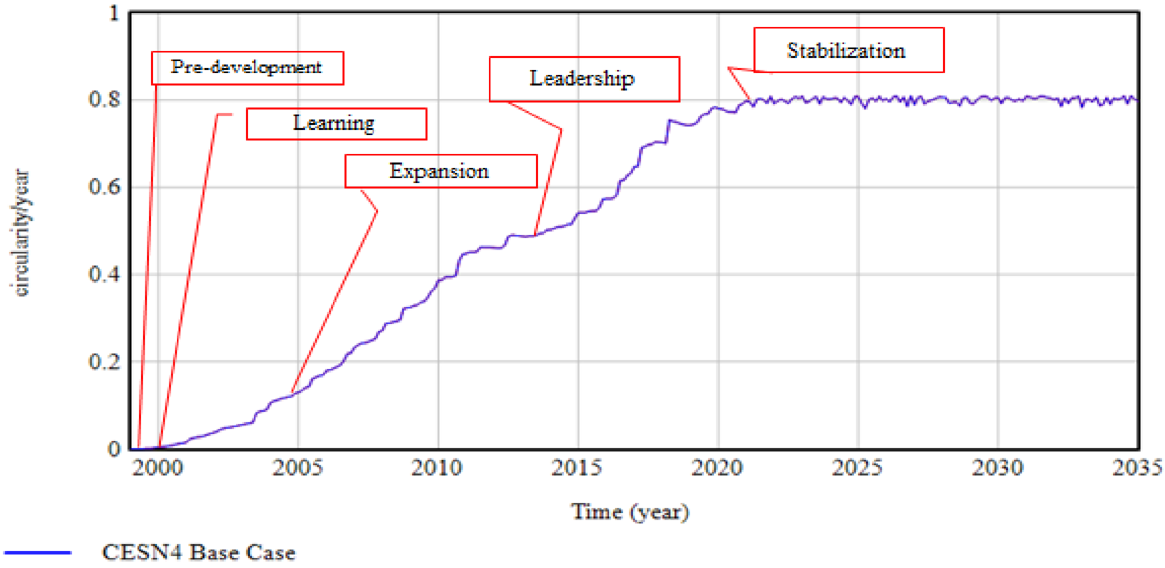
Source: elaborated by the author

Decreasing scenario outcomes are about three times bigger than increasing ones, could be because linear SC still are the dominant system with much more adopters than nonlinear ones, thus, agents do not need making action to return to it. This show that circular economy still is emergent needing more agent's resource. We therefore propose the following:

P5. CESN management mechanisms such as: multitier supplier management, hybrid leadership, initiating and coordinating mechanisms converting internal and external stakeholders to CE adopters, are characterized by delays. That could be intensified decreasing new program buyers' quantity to manage these mechanisms. As result, SN circularity could stagnate and decline over time.

What if we run a Case4 forecast scenario, considering a timeline of 35 years from pre-development to stabilization phase based on parameters of Appendix E. Figure 26 show that as we achieve stabilization phase with 0.80 CI on average (the normalization chosen here defines capacity as the normal rate of output, not the maximum possible rate when heroic efforts are made), the triangular random distribution of the number of external and internal stakeholders adopting circularity could generate more CI oscillation, as well as, new products to be launched could not use similar circular materials, what would need to renew or innovate in multitier supplier management, supply hybrid leadership, initiating and coordinating mechanisms.

Figure 25- CESN circularity index forecast scenario



Source: elaborated by the author.

4.4.2 Circular economy supply network transition phases management temporal progress narrative

Each case temporal progress description, presenting historic circularity index (CI) at data collection time, average time from start circular SN to the data collection and CESN transition phases management, besides, each case SN configuration and year by year CI, are detailed in Table17. We present CESN transition phases management framework in Table 18 with the phases' name, description, circular factors, coopetitive (cooperative and competitive) challenges (that are management mechanisms presented in our conceptual framework in Fig. 18) circularity index (CI) range, growth rate (how making decisions and actions influenced by circular factors and coopetitive challenges contribute to circularity index growth year by year) and annual average time (related to period to start and finish each phase and circular factor).

This framework in Table 18 has six distinct phases: pre-development, learning, expansion, leadership, stabilization and self-renew or decline. In reality each phase could have also specific circular factors, that are most relevant ways or forces to increase circularity, generating cooperative and competitive challenges. Yet we have observed the four first phases in all cases over time across diverse business such as automotive batteries, printers, packaging, bioproducts and precious metals. What remain as pattern from case to case are the circular factors and management mechanisms (Kivimaa et al., 2019b; Moore, 1993; Rusch et al., 2022).

During first year of CESN, in pre-development phase the driving forces that could impact customer's wants and needs, are influenced by circular factors such as: natural resource extraction economic unviability, regulation pressures, and corporate strategy to use sustainability and biodiversity as competitive advantage. Facing cooperative challenges to work with internal and external stakeholders, suppliers and customers to define new circular value proposition around a seed innovation. They are also influenced by circular factors such as: reduce clandestine competitors and large quantity of by-products. Facing competitive challenges to protect their circular ideas from others who might be working toward defining similar supplies. Therefore, coopetitive challenges to create circular supplier development and selection strategy. For instance, in cases 1 and 4, due to natural resource extraction economic unviability they started to recycle used batteries and printed circuit board. Case 2 Prbrand was facing an economic disadvantage due to clandestine companies that, without its approval, refilled used and discarded ink cartridges produced by Prman. Since these competitors did not have the costs for product development and legalizing their own operations, they were able to sell both the refilled cartridges and the recharge service at prices not feasible for Prbrand compete. Cases 3,4,5 and 7, took advantage from waste management policy, supply and governance regulation incentives to start electronics device recommerce, plastics packaging and cardboard recycling, besides, corporate strategy to use sustainability and biodiversity as competitive advantage. Cases 6 and 7, due to by-products from sugarcane harvesting, ethanol production, reforestation companies and corrugated cardboard production.

Then for five years on average of CESN, in learning phase actors acquire knowledge and experiences, influenced by circular factors such as: develop circular product design, business model and mass production technology through partnerships or acquisitions. Facing cooperative challenges to work with internal stakeholders, suppliers and customers to develop and implement this new circular value proposition around this seed innovation. They are also influenced by circular factors such as: reduce primary raw material dependency. Facing competitive challenges to develop and select new suppliers. Therefore, coopetitive challenges to define and implement circular supplier development and selection process. For instance, in cases 1 and 2, developing batteries and printers' local recycling mass production technology through a manufacturer spin-off. Cases 3, 5, 6 and 7, new partnerships and technologies development. Cases 1, 4 and 7, reducing primary raw material dependency, technology owner acquisition, using carbon credits.

Table 18- Cases temporal progress description.

Cases	Temporal Progress Description
Case 1 Batteries	Average time 21 years, average CI=0.63, transition phase leadership, SN configuration hybrid loop (Appendix 8 and 17). This CESN started in 1996 mainly due to lead extraction economic unviability in Brazil to produce automotive batteries. Circularity has increased as of 2001 when current agents created a spin-off and new agents developed lead, acid and plastic recycling mass production technology from used batteries, besides integrate others industries chains such as ammunition and sinker fishing, and initiate a great postconsumption product recovery in batteries' distributors. Most of agents measure sustainability and circularity in a budget balanced score card monitored quarterly using as a criterion in supplier selection to change in current product or to participate in new projects. Between 2016 and 2018 sustainability and circularity index were collected from each agent bill of material.
Case 2 Printers	Average time 14 years and average CI=0.37, transition phase expansion, SN configuration closed loop (Appendix 9 and 18). This CESN started in 2005 mainly due to focal company (the multinational brand owner Prbrand) was facing an economic disadvantage due to clandestine companies that, without its approval, refilled used and discarded ink cartridges produced by Prman and increased as of 2013 when it created a new company (Prrec) with mass production technology to recycle, remanufacture and coordinate postconsumption product recovery developing new agents to initiate it and taking advantage from Brazilian waste management Law. Between 2018 and 2019 sustainability and circularity index were collected from each agent bill of material.
Case 3 Electronics	Average time 9 years and average CI=0.19, transition phase expansion, SN configuration open loop (Appendix 10 and 19). This CESN started in 2010 mainly due to Brazilian Waste Management Law. Circularity has increased as of 2014 when a new agent, a Recommerce company (Elereco) with mass production capability to refurbish and coordinate postconsumption/used electronics product recovery by an app and a partnership with a big retailer to initiate it (Eleret). Between 2018 and 2019 sustainability and circularity index were collected from each agent bill of material, in addition was started a relationship to obtain obsolete electronic components from electronic component producers, electronic product manufacturers and distributors to repair and refurbish the used smartphones. Coordination mechanisms have also been developed to increase the use of recovered materials to refurbish and repair recovered products. In addition, a supplier-buyer/buyer-supplier relationship has been established with the final consumer. For example, the end consumer buys a new smartphone by paying with an used one in an "exchange" operation. On the other hand, used smartphone' buyer can repair and resale it.
Case 4 Precious Metals	Average time 19 years and average CI=0.66, transition phase leadership, SN configuration hybrid loop (Appendix 11 and 20). This CESN started in 1999 mainly due to African countries civil conflicts becoming precious metals extraction and mining economic unviable. Circularity has increased as of 2005 when a current agent (PMrec) acquired another agent, to develop mass production technology to recycle printed wiring board, jewels, chemicals and others mining byproducts, also coordinating postconsumption product recovery

developing new agents to initiate it. Between 2018 and 2019 sustainability and circularity index were collected from each agent bill of material.

Continue

Cases	Temporal Progress Description
Case 5 Plastic Packaging	Average time 20 years and average CI=0.49, transition phase expansion, SN configuration hybrid loop (Appendix 12 and 21). This CESN started in 2001 mainly due to two production engineering students from a public university in Sao Paulo inspired by a sustainability campaign to reduce plastic waste, they created Packrec, a plastic packaging recycler, besides Packbrand incorporated Brazilian biodiversity in its products design. Circularity has increased between 2004 and 2014 when Packrec developed a mass production technology to recycle, got some quality certifications to supply to more industries and coordinate postconsumption product recovery developing new agents to initiate it. In 2019 sustainability and circularity index were collected from each agent bill of material.
Case 6 Bioproducts	Average time 9 years and average CI=0.19, transition phase expansion, SN configuration hybrid loop (Appendix 13 and 22). This CESN started in 2010, when two multinational energy companies created Biogasman one of the biggest biofuel producers in Brazil. However, sugar cane harvesting and biofuel production, generate large quantity of byproducts, that were recovered just in small scale. Circularity has increased between 2019 and 2020, when a new agent Biogassol developed a mass production technology to produce biogas and biofertilizer using these byproducts, taking Biogasman, to build a project with it in one of its ethanol plants to produce biogas, electric energy and biofertilizer to use in the sugar cane farms. Between 2019 and 2021 sustainability and circularity index were collected from each agent bill of material.
Case 7 Cardboard Box	Average time 17 years and average CI=0.57, transition phase leadership, SN configuration hybrid loop (Appendix 14 and 23). This CESN started in 2001 and circularity has increased by multiple actions. Cardman developed a mass production technology, combining the use of large quantity of byproducts from its operations and reforestation, with postconsumption products from Cardcoop, Cardppman and Cardbrand, to produce corrugated, and cardboard box. In 2019 sustainability and circularity index were collected from each agent bill of material.

Source: elaborated by the author.

Table 19- CESN transition phases management framework

Phase	Description	Circular Factors (CF)	Coopetitive Challenges	Circularity Index	Growth Rate	Average Time (Years)
Pre-development	In pre-development, actors should identify what are market driving forces that will impact customer's want and needs.	1-Natural resource extraction economic unviability; 2- Regulation pressures (incentives or barriers); 3- Large quantity of by-products; 4- Corporate strategy to use sustainability and biodiversity as competitive advantage; 5- Reduce clandestine competitors.	Create circular supplier development and selection strategy	0-0.01	0%	1
Learning	Learning process is difficult and timing consuming, could occur by experience but not only by experience. May occur also by knowledge acquisition to get competitive advantage.	6- Circular product design, business model and mass production technology development; 7- New partnerships development or acquisition; 8- Reduce primary raw material dependency.	Define and implement circular supplier development and selection process	0.02 -0.09	28%	5
Expansion	In expansion they should identify driving forces to increase circular products demand and postconsumption products and byproducts offer.	9- Strategies to increase postconsumption product and by-product recovery rate; 10- Regulation fine tuning.	Create and implement initiating and coordination mechanisms	0.10 -0.49	32%	9
Leadership	They are capable of greater influence, creator of a vision and expanding CESN to others industries supply chains.	11- Overseas operations expansion; 12- Adding new networks and industries; 13- Mass production technology fine tuning.	Create and implement multi-tier SN management and hybrid Leadership	0.50 -0.79	3%	10
Stabilization	They achieve maximum capacity between opportunities and necessities, getting incremental improvements every year.	14- Incremental improvements every year.	Keep improving multi-tier SN management and hybrid Leadership	0.80 -0.84	<1%	11
Self-renewal or decline	Self-renew could be difficult and supply network collaboration through complementarities might be a way to avoid CESN decline.	15-Product or service replaced by a radical innovation.	Redesign circular supplier development and selection strategy	<0.85	< 0%	36

Source: elaborated by the author.

Then for nine years on average of CESN, in expansion phase the actors seek to increase circular products demand and postconsumption products and byproducts offer, influenced by circular factors such as: develop strategies to increase postconsumption product and byproducts return rate. Facing cooperative challenges to work with internal and external stakeholders, suppliers and customers to scale up demand and supply to achieve maximum market coverage. They are also influenced by circular factors such as: regulation fine tuning. Facing competitive challenges to defeat alternative implementations of similar competing circular ideas. Therefore, coopetitive challenges to create and implement initiating and coordination mechanisms. For instance, in cases 1, 2 and 3 implementing trade-in with distributors or retails to increase postconsumption products and by-products recovery. Cases 1, 2, 4, 5 and 7, implementing high capillarity reverse logistics network adding new external stakeholders. Cases 1,2,3,4, 5 and 7, Waste Management Law and policy industries agreements. Cases 5 and 6, getting other industries recycled product certifications and developing postconsumption products and by-products recovery solutions partnership.

Then for ten years on average of CESN, in leadership phase, actors should be capable of greater influence, creator of a vision and expanding CESN to others industries SC, influenced by circular factors such as: adding others SC even from others industries and making fine tuning of the mass production technology. Facing cooperative challenges to add not rivalry with others supply networks, providing a compelling vision for the future that encourages internal and external stakeholders, suppliers and customers to work together to continue improve the complete offer, increasing their great influence. They are also influenced by circular factors such as: overseas operations expansion. Facing competitive challenges to enter in others' countries SC. Therefore, coopetitive challenges to create and implement multi-tier SN management and hybrid leadership. For instance, in cases 1, 4 and 7, mass production technology fine tuning, overseas operations expansion. They are adding new industries' SC such as construction, chemical and food. Focus in increase the BOM circularity of the less weighted parts. Influencing partners to take UN SDG goals to all network positions and external stakeholders through social programs.

Then for eleven years on average of CESN, in stabilization phase actors achieve maximum circularity. Facing cooperative challenges to work with internal and external stakeholders, suppliers and customers to bring incremental new circular ideas to the existing SN continuous improvement. Competitive challenges should be maintaining high barriers to entry to prevent innovators from building alternative SN. Keeping to SN members high switching costs in order to buy time to incorporate new circular ideas into SN products and services. Therefore, coopetitive challenges to keep improving multi-tier SN management and hybrid leadership.

Finally, after cumulative thirty-six years on average from all phases in self-renew or decline phase, CESN could be reinvented and restarted by a radical innovation or decline, influenced by a circular factor such as: product or service replaced by a radical innovation. Cooperative challenges could be work with innovators to bring radical new circular ideas to the existing SN, to restart pre-development phase. Competitive challenges could be maintaining flexible and agile operations structure to incorporate these radical circular ideas into CESN. Therefore, coopetitive challenges to redesign circular supplier development and selection strategy.

All cases have already experienced pre-development, learning and expansion phases. Cases 2, 3, 5 and 6 are in the expansion phase, developing strategies to increase postconsumption products and by-products recovery rate, influencing regulation fine tuning to improve circular value creation. Average time from pre-development to expansion phase is about fifth-five years. While cases 1, 4 and 7 have already experienced leadership phase, adding new SC from the same and others industries, mainly due to some management mechanisms, fine tuning the mass production technology and also expanding operations overseas. Average time from pre-development to leadership phase is about twenty-five years. No case has ever reached stabilization achieving circularity capacity limit, they suggest to achieve circularity index from 0.80 to 0.85 in this phase.

For instance, large organizations have a new project buyer role responsible to develop new circular projects supply sources working in a multifunctional and matrix organization close to R&D, engineering, manufacturing, finance, logistics, sustainability, marketing and sales, led by a new project manager. Besides that, they developed many small organizations as suppliers or created spin off to develop a reverse logistics network, also increased by social programs led by a sustainability area. On another hand, small organizations have learned production process from large organizations or circular entrepreneurship to develop new solutions as by-products recovery in case 6 or merged sourcing and customer strategy in cases 1, 4, 5 and 7. We therefore propose the following:

P3. CESN transition phases management have circular factors, such as: natural resource extraction economic unviability, regulation pressures, large quantity of by-products, corporate strategy to use sustainability and biodiversity as competitive advantage, circular product design, mass production technology development; new partnerships development or acquisition, strategies to increase postconsumption product and by-product recovery rate, regulation fine tuning and adding new networks and industries, that generates cooperative and competitive challenges such as: circular supplier selection and development, multi-tier supplier management, supply hybrid leadership, initiating and coordinating mechanisms, mainly in the first four transition phases: pre-development, learning, expansion and leadership.

The propositions we derived in previous sections and the resulting frameworks, apply to the cases and industries we studied. Moving up hierarchical abstraction of inductive reasoning (Van De Ven, 2007). We can now advance the theory, suggesting three-dimensional conceptualization to CESN management:

Structural, as supply network, CESN management has emergent new properties combining at least three configurations: closed loop, in that returned postconsumption products and or by-products could circulate among the same SC members only, an open loop, adding new members with sustainable innovations, and in hybrid loop, adding others industries SC, integrated by agents in upstream and downstream positions in feedback loops.

Behavioral, as supply network ecosystem, CESN management could have six transition phases over time: pre-development or emergence, learning, expansion or acceleration, leadership, stabilization or reorganization and self-renew or decline influenced by circular factors that generates coopetitive management challenges such as: circular supplier selection and development, multi-tier supplier management, supply hybrid leadership, initiating and coordinating mechanisms.

Contextual, as complex adaptive system CESN management has boundaries involving internal and external stakeholders, dynamically changing to increase circularity adopters. In fact, many stakeholders are not aware that have already adopted circularity.

4.5 Discussion

4.5.1 Theoretical Implications

Our primary contribution to theory is our CESN transition phases management framework that suggests circular factors to be managed in transition phases: pre-development, learning, expansion, leadership, stabilization and self-renew or decline, adding to Braz and Mello (2022) framework explaining each circular factor' cooperative and competitive challenges such as:

circular supplier selection and development, multi-tier supplier management, supply hybrid leadership and initiating and coordination mechanisms. Expanding Farooque et al. (2019) CSC management definition, as the “integration of circular thinking into SC and its industrial and natural ecosystem”. Adding also to Frei et al. (2020) explaining how return process strategies could be better coordinated over time.

We also add to transition literature demonstrating how SN leaders change CESN circularity in each transition phase. While pre-development, expansion and stabilization are also critical phases to intermediaries sustainability transitions (Kivimaa et al., 2019), and emergence, growth, stabilization and decline are critical to circular industrial districts evolution (Bressanelli et al., 2022), as well as, start-up, acceleration and stabilization through imitative learning are backbone to multi-level-perspective (Kanger & Schot, 2016), our framework reveals that CESN demands three more phases: learning as specific phase before acceleration for actors experimenting and acquiring knowledge, leadership after acceleration when actors should be capable of greater influence, creator of a vision and expanding CESN to others industries SC with all knowledge and experience granted from previous phases, and self-renew that actors could be capable to reinvent and restart CESN by radical innovation in supply network through collaboration and complementarities management.

Our framework sheds light on circular factors that SN strategic leaders should focus on each transition phase, that could overcome the difficulties to identify end users in the future for the recycled materials and products presented by Rentizelas et al. (2022). While large verticalized companies are critical to emerge circular industrial districts (Bressanelli et al., 2022) and entrepreneurial quality is critical before CE systems achieves stabilization phase (Chizaryfard et al., 2021), our framework also reveals that large quantity of by-products and corporate strategy to use sustainability and biodiversity as competitive advantage are critical to CESN pre-development with 0.0 circularity index on average and adding new SC to CESN even from other industries is critical to achieve leadership phase with 0.50 circularity index on average.

Our study also contributes to the recent scholarship on sustainable reverse SC and circular economy strategic management by showing how CESN management mechanisms improve circularity performance adding more internal and external stakeholders even from others supply chains, This can also overcome the obstacle discussed by Frei et al. (2020) regarding the need to have less return options to reduce complexity and increase efficiency.

Our simulation framework indicates that a more successful CESN is an interplay among the key management mechanisms: (i) multi-tier supplier management, (ii) hybrid leadership (iii) initiating circular flow, (iv) coordinating circular flow and (v) circular supplier selection and development, that could contribute to circular supply network performance much more than their isolated effects. Thus, adding to Mokhtar et al. (2019) arguments that transactional and transformational leaderships could be contributors to supply chain performance and going beyond the recent multi-tier sustainable SC literature, that argues that focal companies tend to orchestrate multi-tier SC (Gong et al., 2018; Jia et al., 2019; Gosling et al., 2016), once our research indicates that different actors not only focal companies could manage multi-tier SC to increase circularity performance. These management mechanisms could also regulate the relationship between not only focal firms and partners but also between partners in different SC roles and positions reducing conflicts within circular SC as pointed by Gandolfo and Lupi, (2021). Once, CESN management has boundaries involving internal and external stakeholders, dynamically changing to increase circularity adopters. In fact, many stakeholders are not aware that have already adopted circularity.

Finally, recent literature in reverse SC argues that reverse logistics planning activities for CE could increase about 26% in five years (Kazancoglu et al., 2020), our transition phases management model deep clarify that circularity annual average growth rate in learning phase is 28% for five years, and 32% in expansion phase for nine years on average, besides our framework also posits that circularity annual average growth rate in leadership phase is 3% for ten years on average, until achieving stabilization phase with less than 1% for eleven years on average.

4.5.2 Managerial and policy implications

The recent literature connecting CE and SCM, such as Frei et al. (2020), Bressaneli et al. (2022) and Batista et al. (2018) recognize how circular SC are dynamic and complex, becoming overly challenge to operations management. Our innovative dynamic framework based on CESN transition phases management could help managers to overcome obstacles to start circular SN, for instance, in pre-development phase in that driving forces could impact customer's wants and needs, influenced by circular factors such as: natural resource extraction economic unviability, regulation pressures and corporate strategy to use sustainability and biodiversity as competitive advantage. Managers should address cooperative challenges to work with internal and external stakeholders, suppliers and customers to define the new circular value proposition around a seed innovation.

Managers could also use this framework to overcome the difficulties to maintain and increase circular SN circularity, as in expansion phase the actors seek to increase circular products demand and postconsumption products and by-products offer, influenced by circular factors such as: develop strategies to increase postconsumption product and by-products return rate, implementing high capillarity reverse logistics network adding new external stakeholders, suppliers and customers to scale up demand and supply to achieve maximum market coverage.

Managers could also use this framework with our simulation model to predict the circularity index over time increasing or decreasing human resources working in circular projects, as well as, to decision make on which circular factor the project team should focus applying a multi-tier supply chain management and hybrid leadership (Jia et al., 2019) with initiating mechanisms (Braz & Mello, 2022), to stimulate internal stakeholders and integrate external stakeholders to adopt circularity, explaining to them the challenges and average time to achieve each transition phase and circularity index.

Regarding policy implications, policy makers could use our simulation model, and framework to create and refine regulations for each CESN transition phase aimed to reduce its average time and increase circularity. This policy tool could be innovative, once most regulations are focusing only in incentivize CE general creation (Genovese et al., 2017). Besides, contribute to sustainable development goals (SDG), notably number 12 - "sustainable consumption and production" (George et al., 2016).

4.5.3 Conclusions

Embracing the principles of the CE is highly challenging, requiring firms to change the way they create, deliver and capture value together in nonlinear and complex supply networks. Therefore, we should conceptualize circular economy supply network management in three-dimensional perspectives, structural, as: supply network, CESN management has emergent new properties combining at least three configurations: closed loop, in that returned postconsumption products and/or by-products could circulate among the same SC members, open loop, adding new members with sustainable innovations, and in hybrid loop adding others industries SC, integrated by agents' feedback loops in upstream and downstream position. Contextual, as: complex adaptive system CESN management has boundaries involving internal and external stakeholders, dynamically changing to increase circularity adopters. In fact, many stakeholders are not aware that have already adopted circularity. Behavioral, as: supply network ecosystem, CESN management could have six transition phases over time, pre-development, learning, expansion, leadership, stabilization and self-renew or decline influenced by circular factors that generates coopetitive management challenges such as: circular supplier selection and development, multi-tier supplier management, supply hybrid leadership, coordination and initiating mechanisms.

The first lesson learned (RQ1) is that transitioning to CE over time could be done by our CESN transition phases management framework, that explain that each phase has circular factors generating coopetitive challenges. For instance, in pre-development phase, circular factors such as: natural resource economic unviability, regulations pressures, large quantity of by-products and block clandestine competitors generate coopetitive challenges to create circular supplier development and selection strategy. While in learning phase, circular factors such as: circular product design, business model and mass production technology development, new partnerships development or acquisition, and reduce primary raw material dependency, generate coopetitive challenge as circular supplier development and selection process implementation defining rules and responsibilities. In expansion phase, circular factors such as: strategies to increase postconsumption product and by-product recovery rate, and regulation fine tuning, generate coopetitive challenges to create and implement initiating and coordination mechanisms. In leadership phase, circular factors such as: Overseas operations expansion, adding new networks and industries, and mass production technology fine tuning, generate coopetitive challenges to create and implement multi-tier SN management and hybrid leadership. While in stabilization phase, circular factors such as: incremental improvement every year generates coopetitive challenges to keep improving it. Finally, in self-renew phase, circular factor such as: product or service replaced by a radical innovation generate coopetitive challenges to redesign circular supplier development and selection strategy focusing to bring new circular radical innovations.

The second lesson learned (RQ2) is that the most important dynamics aspects in CESN management are two feedback loops: one negative as potential CE adopters stock decline, since they are converted to CE active adopters by management mechanisms, regulation effectiveness also reduce over time. One positive as CE active adopters stock rise, circular supplier development and selection also rise over time, since we'll have already more circular suppliers to select. These positive and negative feedback loops result in system stabilization over time. Once, circularity has technical and managerial limits as pointed out by Mayers et al. (2021) and Bressanelli et al. (2022): since materials cannot be recovered forever, and couldn't progress through lifespan just in circles or lines. They move through tremendously complex SN, achieving 80% of circularity then oscillating over time due to incremental or radical product innovations and new adopter's circularity performance, besides, declining by SN fragmentation. However, our model suggests ways to smooth these obstacles by, rising circular supplier development and selection' social connections mainly from active CE adopters over time.

The third lesson learned (RQ3) is that our empirical findings could support managers and policy makers to develop more efficient strategies. For instance, in pre-development phase incentivizing companies to become circular by using their by-products as raw material and biodiversity to get competitive advantage, or create and increasing barriers to natural resource extraction becoming it economic unviable. In learning phase improving government waste collectors' governance through circular business model. In expansion phase adjusting regulation to reduce tax on post-consumption product returns. Lastly, in leadership phase policy makers could make more easy financials streams to incentivize circular research and development to improve mass production technology, besides reduce tax and bureaucracy helping companies to expand CESN overseas and add others industries SC. All these policies could be suited for others industries and countries context, since most of the circular factors such as: natural resource extraction economic unviability, regulation pressures and corporate strategy to use sustainability and biodiversity as competitive advantage; and coopetitive challenges such as: circular supplier development and selection strategy and process, multi-tier SN management and hybrid leadership could be common.

4.5.4 Future research opportunities and limitations

The generalization of the findings is limited to SN industries and context studied. As early mentioned regarding the case study and system dynamics methods' limitations, further studies should be conducted to investigate more variables relationship in our model using other modelling technique. As well as, CI and transition phases management timeline in others industries, drawing in other theoretical lens such as: resource dependence theory studying how agents' relationship affect organizational capabilities to obtain resources, or theory of planned behavior studying how individual perceived behavior could maximize CESN social benefits. Besides, studying CESN management under ecosystem lens, exploring similarities, differences and complementarities among multi-tier SCM and ecosystem complementors orchestration, to better understand SC, business and Innovation Ecosystems theories' connection to accelerate sustainability and transition towards CE.

4.6 Acknowledgments

The authors gratefully acknowledge the financial support of Brazilian research funding agencies via CNPq project number 423467/2018–2 and CAPES.

5 CONTRIBUTIONS

This thesis aims to fill the following research gaps:

- Circular economy supply chains have increasing complexity, face internal and external environment changes. However, is limited the understanding of these supply chains' sources of complexity and configurations;
- Available tools and frameworks insufficiently address the experimenting needs of theoretical explanation of the buyer-supplier and supplier-buyer relationship management dynamics between the firms in extreme upstream and downstream positions in supply networks to implement and manage circular economy supply networks over time.

Thus, answering the general research question how can SCM contribute to understand and foster CE transition over time? This general research question was unfolded into six work packages through multiple case study combined to variance and process analysis, and system dynamics modelling and simulation that allowed the development of descriptive and prescriptive knowledge useful for the theory and practice.

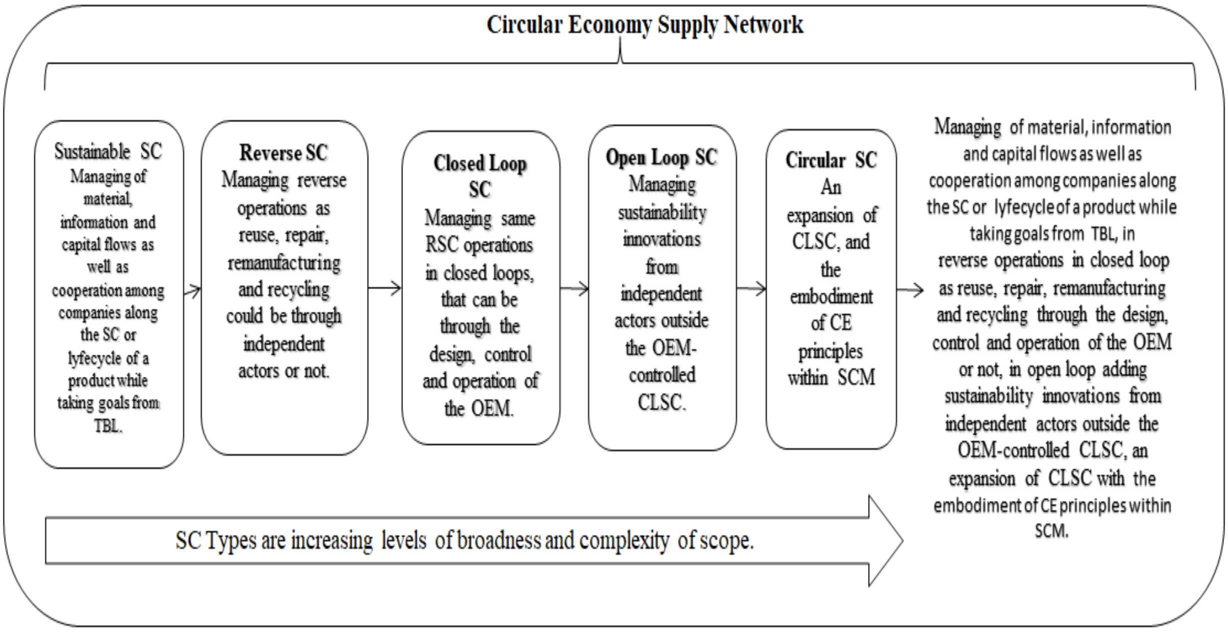
Previous sections bring our contribution to answer the overall research question, as well as the theoretical and practical goals defined. The supply chain types related to circular economy (section 2), the circular economy supply network management as a complex adaptive system (section 3), the depiction of the circular economy supply network management dynamics and its transition phases over time (section 4) constitute the primary grounding knowledge for understanding the role of SCM to CE transitions. The circular economy supply network management model (sub-section 4.4.3), constitute the primary prescriptive knowledge contained in the thesis, which allows for the reproduction and further development of simulation models to investigate CE systems and transition phases based on scenarios obtained (section 4.4.5.) constitute the initial descriptive knowledge generated from the use of the models. The insights obtained in the three studies demonstrate different ways of how supply network management can support decision-making in CE transitions.

The contributions of this thesis to the field of SCM to CE transitions and to decision-makers participating in CE transitions are following summarized. Finally, further avenues of investigation that can help to continue developing the role of SCM to CE transitions are presented.

5.1 Theoretical contributions to the field of SCM and CE transitions.

This thesis articles' content makes five significant contributions to SCM and CE literature. The first contribution **is a framework for supply chains types in circular economy**, showing five supply chains types contributing to CE transitions and clarifying that they are increasing the level of broadness and complexity since they are applying different reverse supply chain process and materials recovery activities. The less complex and broad supply chain type is the sustainable supply chain that focus in address the three dimensions of sustainable development overall in linear supply chain. Thus, integrating CE principles would begin to expand sustainable supply chains boundaries by reducing the need of virgin materials which could increase the circulation of resources within supply chains systems, shown in Figure 27.

Figure 26- SC types framework for CE



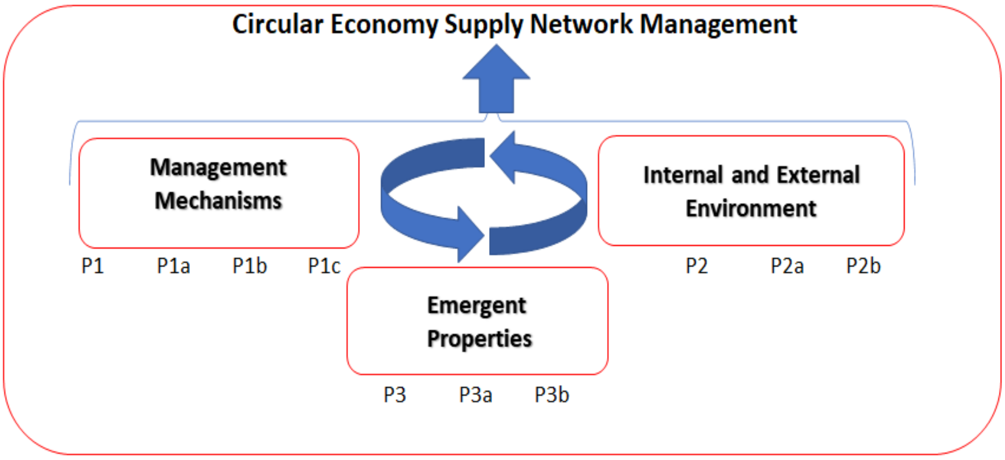
Source: elaborated by the author.

Extending sustainable supply chain broadness through reverse supply chains that focus in the reverse flows of materials from the same or different players through activities such as: reuse, repair, refurbish, remanufacture or recycle. While closed loop supply chains increase the complexity adding to these activities the design, control and operation of the original equipment manufacturer, open loop supply chains add sustainability innovations from independent actors outside the control of the original equipment manufacturers.

Finally, We argue that SC types framework shows an evolution related the complexity and broadness of scope of each SC type from more focused and still linear SSCM to more comprehensive and nonlinear, a circular economy supply chain that could be conceptualized as a connected network of organizations involved in the design and management of circular value adding processes and the value recovery of a product, component or material.

The second contribution to academic literature is to characterize the circular economy supply chain management through complex adaptive system lens proposing a **circular economy supply network management framework,** identifying and characterizing the key elements that influence its configuration and dynamics, shown in Figure 28.

Figure 27- CESN management conceptual framework and propositions



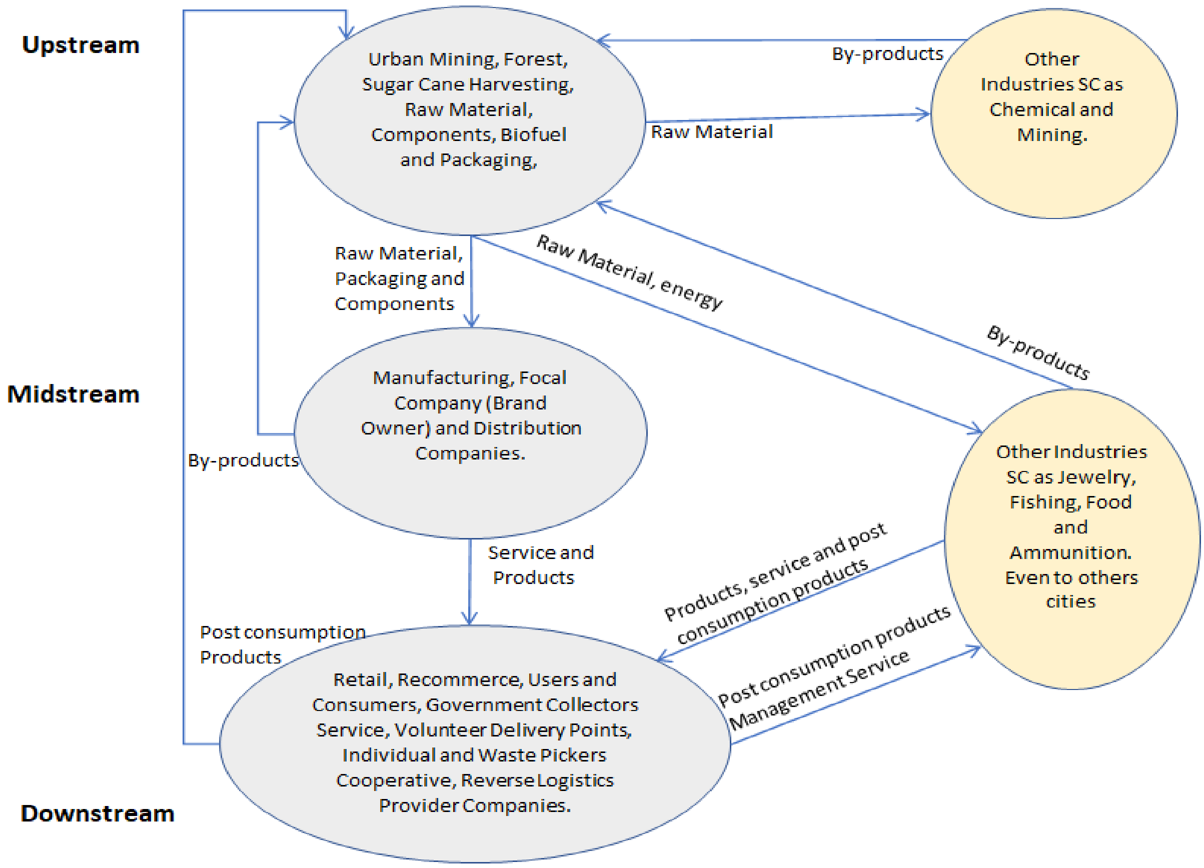
Source: elaborated by the author.

Article 2 presents this framework with three key elements, their subcategories and characteristics, the first key element is the management mechanisms involving mainly agents in extreme upstream and downstream positions at supply chain, compound by the subcategories multi-tier supply chain management in triad or larger relationships as in proposition P1c, responsible to increase the postconsumption product return rate; the coordination mechanisms might generate two types of inflection points as in proposition P1, that act as leverage points in the circular economy supply network management, with one related to which agent initiates postconsumption product or byproduct physical reverse flow and with the other related to which agent coordinates this activity; the supplier selection process as in proposition P1b, merging sourcing and customer strategies is influenced by a lack of quality and supply due to high variability in the quantity of postconsumption products and byproducts; Finally, as in proposition P1a, CESN agents' role and position might also indicate the types of supply network leadership they should play, agents in extreme upstream or downstream positions could play hybrid leadership, combining transformational and transactional leadership, managing by exception, rewarding a supplier by achieves a goal or punishing it if not, besides creates a vision of a better future and inspiring the supplier to become more circular. As well as, transformational supply chain leadership managing by inspiration as a role model, creating a vision of a better circular future is played by agents also in midstream position. While transactional supply chain leadership is played most by agents closer to downstream positions in role as distributors or retailers, managing by exception, rewarding a supplier by achieves a goal or punishing it if not.

The second key element is the internal and external environment compound by the subcategory's: regulation impacting positively by incentivizing brand owner involvement or negatively by increasing costs through high tax complexity as in proposition P2a, also internal and external stakeholders influence or are influenced by regulations and taxes; natural resource scarcity or extraction economic unviability, is a restriction that can initiate a circular economy supply network as in proposition P2b natural resource scarcity may trigger CESN formation; external stakeholders that are outside of SC, can influence relationships and flows of products, materials, by-products, information, knowledge and finance among CESN agents; internal stakeholders that are in the CESN can influence postconsumption product or by-product quality and quantity variability, as preferred suppliers and new agents in performing new roles in the CESN as in proposition P2, their relationships dynamically adapts to internal and external environmental changes.

The last key element is the emergent properties compound by the subcategory's: nonlinear change as in proposition P3a, caused by the lack of competitivity, may lead to emerging small emergent agents as cooperatives that can cause major changes in the CESN by increasing postconsumption product and byproduct competitiveness and brand owner and final consumer involvement; nonrandom future as in proposition P3b, since CESN trends to show common patterns of behavior once agents follow similar reverse schemas, such as cooperative business models and business spin-offs, and through self-organization a lack of government incentives and companies' corporate strategies can be overcome to explore sustainable development; hybrid loop configuration, as in proposition P3, might be led by multi-tiered CESN management and external stakeholders since the CESN expands to others SNs even in other industries, the flows of recovered products and byproducts can be governed by the same or new agents "with (in a closed loop) or without (in an open loop) brand owner direct" involvement. Then emerging CESN configuration integrating agents in SC upstream position with other industries SC' agents, as well as, agents in SC downstream position with other industries SC' agents, in both they have linear and reverse flow of material, by-products, postconsumption products and information regarding their quality, quantity, technical specification, design and price as synthetized in Fig. 29.

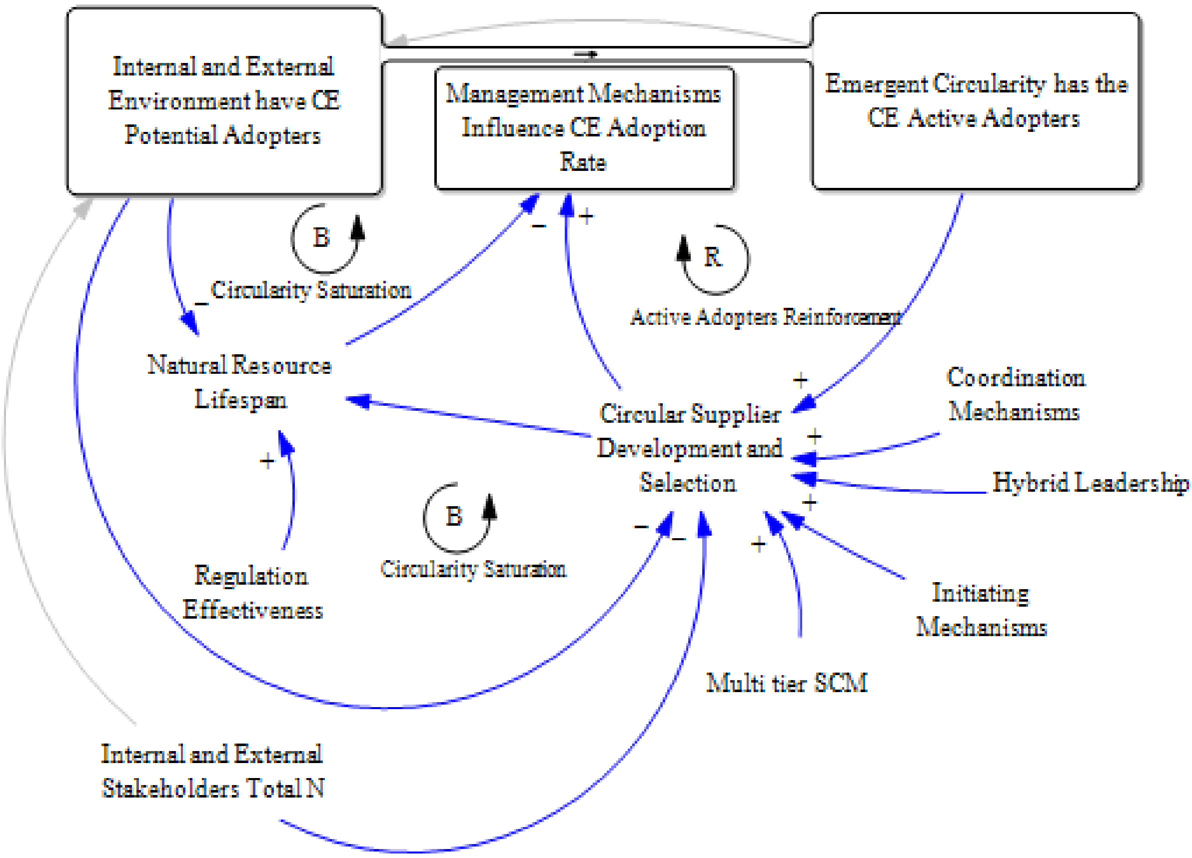
Figure 28- Circular economy supply network configuration



Source: elaborated by the author.

This **CESN management framework system dynamics modelling** is the key to understand how CESN variables relationship management can impact in its circularity performance over time and constitute the third contribution of this thesis to academic literature, shown in Figure 30.

Figure 29- Circular economy supply network management constructs relationship



Source: elaborated by the author.

The interaction between internal and external environment that has CE potential adopters stock with management mechanisms that influence CE adoption rate causing emergent circularity that has the CE active adopters' stock, when a new circular product is introduced the adoption rate is mainly influenced by external sources of information such as regulation effectiveness or supplier development and selection process' social connections. As the stock of CE potential adopters decline while CE active adopters stock grows, the regulation effectiveness rate contribution falls, resulting in a negative feedback loop (circularity saturation and limiting engine), while the contribution of circular supplier development and selection, and CE active adopters rises, resulting in a positive feedback loop (CE active adopter's reinforcement) to management mechanisms and internal and external environment.

Proposition P5, posits that CESN key management mechanisms such as: multi-tier supplier management, hybrid leadership, initiating and coordinating mechanisms converting internal and external stakeholders to CE active adopters are characterized by delays. That could be mitigated increasing new program buyers' quantity to manage these mechanisms. While in proposition P6, posits that these key CESN management mechanisms converting internal and external stakeholders to CE adopters are characterized by delays, that could be intensified decreasing new program buyers' quantity to manage these mechanisms. As result, SN circularity could stagnate, and decline over time.

The **CESN transition phases management' circular factors and events framework** is the cornerstone to understand how supply chain management can contribute to CE transition over time and constitute the fourth contribution of this thesis to academia, shown in Figure 31.

Figure 30- - CESN transition phases management framework

Phase	Description	Circular Factors (CF)	Coopetitive Challenges	Circularity Index	Growth Rate	Average Time (Years)
Pre-development	In pre-development, actors should identify what are market driving forces that will impact customer's want and needs.	1-Natural resource extraction economic unviability; 2- Regulation pressures (incentives or barriers); 3- Large quantity of by-products; 4- Corporate strategy to use sustainability and biodiversity as competitive advantage; 5- Reduce clandestine competitors.	Create circular supplier development and selection strategy	0-0.01	0%	1
Learning	Learning process is difficult and timing consuming, could occur by experience but not only by experience. May occur by knowledge acquisition and to get competitive advantage.	6- Circular product design, business model and mass production technology development; 7- New partnerships development or acquisition; 8- Reduce primary raw material dependency.	Define and implement circular supplier development and selection process	0.02 -0.09	28%	5
Expansion	In expansion they should identify driving forces to increase circular products demand and postconsumption products and byproducts offer.	9- Strategies to increase postconsumption product and by-product recovery rate; 10- Regulation fine tuning.	Create and implement initiating and coordination mechanisms	0.10 -0.49	32%	9
Leadership	They are capable of greater influence, creator of a vision and expanding CESN to others industries supply chains.	11- Overseas operations expansion; 12- Adding new networks and industries; 13- Mass production technology fine tuning.	Create and implement multi-tier SN management and hybrid Leadership	0.50 -0.79	3%	10
Stabilization	They achieve a maximum capacity between opportunities and necessities, getting incremental improvements every year.	14- Incremental improvements every year.	Keep improving multi-tier SN management and hybrid Leadership	0.80 -0.84	<1%	11
Self-renewal or decline	Self-renew through supply network collaboration complementarities and radical innovation might be a way to avoid CESN gets the end.	15-Product or service replaced by a radical innovation.	Redesign circular supplier development and selection strategy	<0.85	< 0%	36

Source: elaborated by the author.

In article 3 this framework proposition P4 posits that CESN transition phases management have circular factors that generates cooperative and competitive challenges mainly in the first four transition phases: pre-development or emergence, learning, expansion or acceleration, and leadership.

During first year of a CESN, in pre-development or emergence phase the driving forces that could impact customer's wants and needs, are influenced by circular factors such as: natural resource extraction economic unviability, regulation pressures and corporate strategy to use sustainability and biodiversity as competitive advantage. Facing cooperative challenges to work with internal and external stakeholders, suppliers and customers to define the new circular value proposition around a seed innovation. They are also influenced by circular factors such as: reduce clandestine competitors and large quantity of by-products. Facing competitive challenges to protect their circular ideas from others who might be working toward defining similar supplies. For instance, in cases 1 and 4, due to natural resource extraction economic unviability they started to recycle used batteries and printed circuit board.

Then for five years on average of a CESN, in learning phase the actors acquire knowledge and experiences, influenced by circular factors such as: develop circular product design and business model, and mass production technology through partnerships or acquisitions. Facing cooperative challenges to work with internal stakeholders, suppliers and customers to develop and implement this new circular value proposition around this seed innovation. They are also influenced by circular factors such as: reduce primary raw material dependency. Facing competitive challenges to develop and select new suppliers. For instance, in cases 1 and 2, developing batteries and printers' local recycling mass production technology through a product manufacturer spin-off.

Then for nine years on average of a CESN, in expansion or acceleration phase the actors seek to increase circular products demand and postconsumption products and byproducts offer, influenced by circular factors such as: develop strategies to increase postconsumption product and byproducts return rate. Facing cooperative challenges to work with internal and external stakeholders, suppliers and customers to scale up demand and supply to achieve maximum market coverage. They are also influenced by circular factors such as: regulation fine tuning. Facing competitive challenges to defeat alternative implementations of similar competing circular ideas. For instance, in cases 1, 2 and 3 implementing trade-in transaction with distributors or retails to increase postconsumption products and waste returns.

Then for ten years on average of a CESN, in leadership phase, actors should be capable of greater influence, creator of a vision and expanding CESN to others industries supply chains, influenced by circular factors such as: adding others SC even from others industries and making fine tuning of the mass production technology. Facing cooperative challenges to add not rivalry with others supply networks, providing a compelling vision for the future that encourages internal and external stakeholders, suppliers and customers to work together to continue improving the complete offer, increasing their great influence. They are also influenced by circular factors such as: overseas operations expansion. Facing competitive challenges to enter in others' countries SC. For instance, in cases 1, 4 and 7, they are adding new others industries' SC such as construction, chemical and food.

Then for eleven years on average of a CESN, in stabilization or reorganization phase actors achieve maximum circularity. Facing cooperative challenges to work with internal and external stakeholders, suppliers and customers to bring incremental new circular ideas to the existing SN continuous improvement. Competitive challenges should be maintaining high barriers to entry to prevent innovators from building alternative SN. Keeping to SN members high switching costs in order to buy time to incorporate new circular ideas into SN products and services.

Then, after cumulative thirty-six years on average from all phases to self-renew or decline phase, CESN could be reinvented by a radical innovation or decline, influenced by a circular factor such as: product or service replaced by a radical innovation. Cooperative challenges could be work with innovators to bring radical new circular ideas to the existing SN, to restart pre-development phase. Competitive challenges could be maintaining a flexible and agile operations structure to incorporate these radical circular ideas into CESN.

Finally, **defining CESN in three-dimensional perspective** constitute the fifth contribution of this thesis to academia, structural, as: a supply network, CESN management has emergent new properties combining at least three configurations: closed loop, in that returned postconsumption products and/or by-products could circulate among the same SC members, an open loop, adding new members with sustainable innovations, and in a hybrid loop adding others industries SC, integrated by agents in upstream and downstream position in feedback loops.

Contextual, as: a complex adaptive system CESN management has boundaries involving internal and external stakeholders, dynamically changing to increase circularity adopters. In fact, many stakeholders are not aware that have already adopted circularity.

Behavioral, as: a supply network ecosystem, CESN management could have six transition phases over time, pre-development or emergence, learning, expansion or acceleration, leadership, stabilization or reorganization and self-renew or decline influenced by circular factors that generates coopetitive (cooperative and competitive) management challenges such as: multi-tier supplier management, supply hybrid leadership and, coordinating and initiating mechanisms.

5.2 Contributions for practice

In the article 1 the identification and verification of which **supply chain management tactics and strategies could foster circular economy** is the first contribution of this research to decision makers. The supply chain management strategical and tactical framework for CE, connects supply chain management strategies to tactics and types.

Managers of different industries and countries, as well as policy makers, can use our strategies and tactics in Table 10 and Appendix 3 as a guide to implement CE in their firms and SCs or to develop public policies aiming to foster CE implementation.

The supply chain competitive advantage management strategy, that we argue it is an antecedent as motivator for circular economy supply chain strategic arrangement, precisely because it motivates companies', to use tactics such as management of new circular business models, that requires circular supplier selection and circular performance indicators creation and implementation. Consequently, developing circular economy supply networks, through positive (reinforcing) or negative (balancing) feedbacks for the antecedents.

The supply chain collaboration management strategy using tactics to manage consumers' relationship to increase their participation in postconsumption products collection process with donations or prioritize new circular design products, managing government relationship to spread out responsibilities among members to provide incentives or reduce barriers, facilitating the buyer-supplier relationship management to organizations' sharing ideas to improve product's recovery and developing new sustainable materials.

Finally, the supply chain systemic effectiveness management strategy using tactics to postconsumption product recovery process management by aligning product portfolio with reverse logistics activities, implementing a web-based traceability creating and supporting connections between suppliers and buyers.

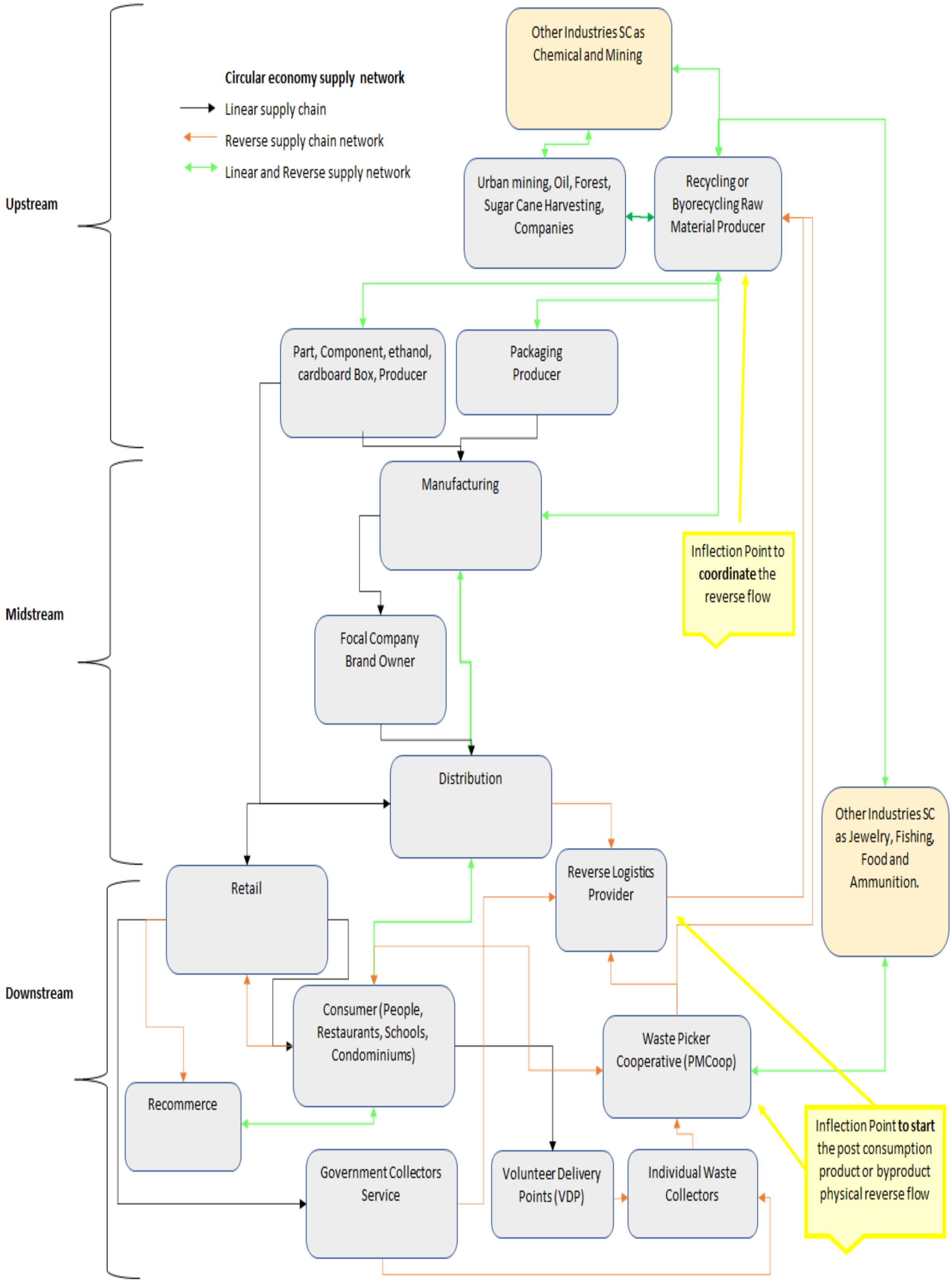
In the article 2 the **circular economy supply network management variables and propositions are** the second contribution of this research to decision makers. Offering a systemic approach based on framework key elements and propositions and thus helping managers determine how to foster CE implementation in their companies, even amid a lack of government incentives and regulation complexity.

Showing how supplier selection can be managed as part of a combined sourcing and customer strategy to deal with a lack of quality and supply due to high variability in the quantity of post consumption products and byproducts. Agents' managers in downstream SN positions as waste picker cooperatives have developed a combined supplier and customer selection and management process whereby, they must approach the same agent as a supplier to buy postconsumption products and byproducts and as also a customer of waste management services, merging sourcing and customer strategy and ensuring the economic viability of this circular operation.

In addition, companies in upstream SN positions, such as mining, oil, reforestation and primary raw material extraction firms, as well as companies in the SN midstream position, such as focal companies (brand owners), could coordinate operations for agents in downstream SN positions in multi-tier supply network management (subsection 3.4.2.1). They can also use presented the results to enter the CESN and become more sustainable and reduce risks related to operations such as environmental and social disasters and NRS, as they can reduce or stop primary raw material extraction by initiating urban mining operations by using the presented cases as guidance and framework management mechanisms (cases 1 batteries, 4 precious metals, 5 plastic packaging and 7 cardboard box). Focal companies could also apply CESN transformational leadership by influencing and creating visions for suppliers related to benefits of recovering postconsumption products and byproducts, stimulating sustainable entrepreneurship, supporting cooperative business models creation (cases 2 printers, 4 precious metals, 5 plastic packaging and 7 cardboard box). Hence, such actors can promote the sustainable entrepreneurship of small and medium-sized enterprises, which can enter the CESN as coordinators of postconsumption product and byproduct flows or as firms responsible for initiating physical reverse flows as cooperatives or solution providers (cases 2 printers, 4 precious metals, 5 plastic packaging, 6 bioproducts and 7 cardboard box). Managers could use our results on each industry CESNs to transform their SNs and promote local sourcing and reduce supply disruption risks (all cases).

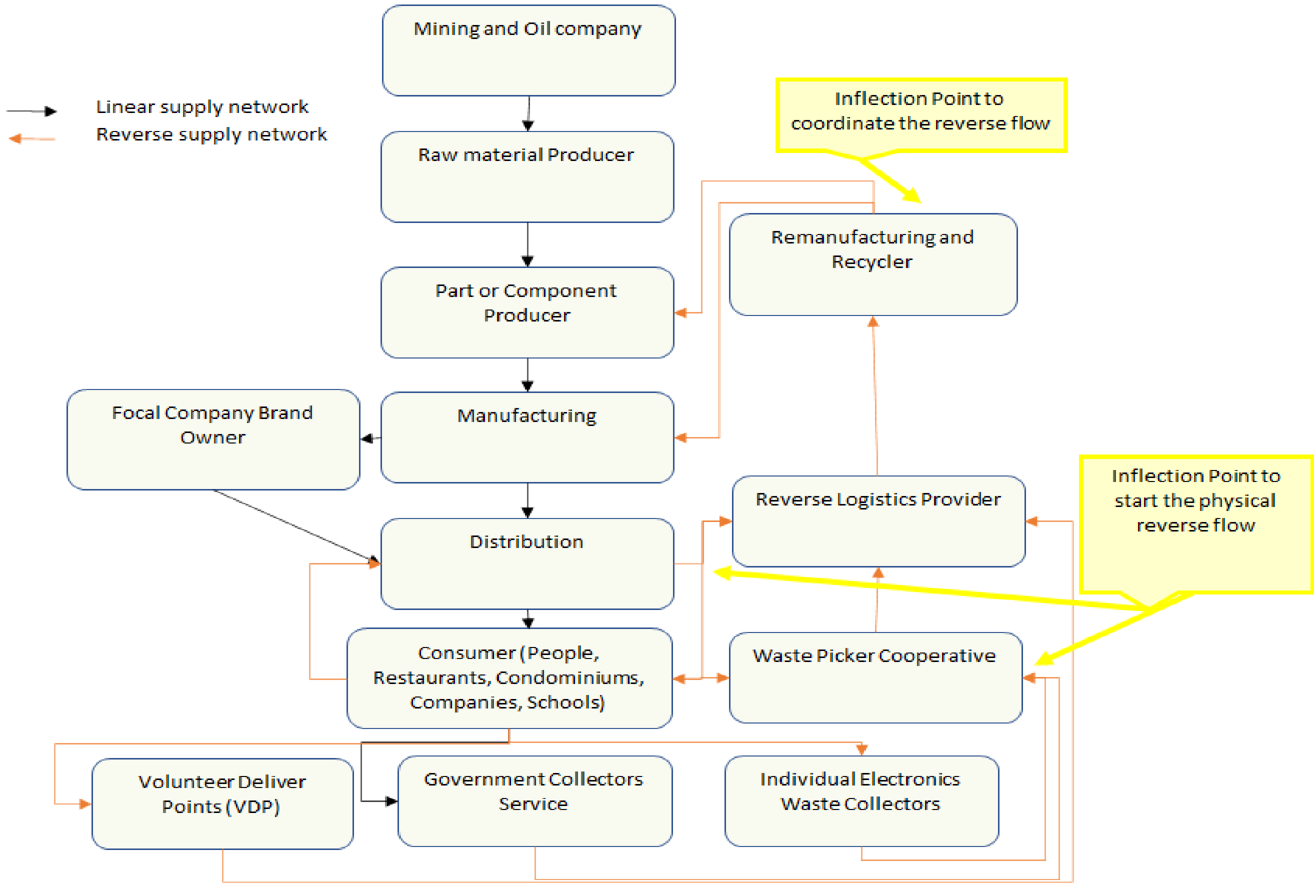
Managers can use the CESN configuration and supply network leadership type frameworks (Figs. 32, 33, 34 and 35) to identify which roles and positions they occupy in the current SN to make decisions on what they should do in terms of leadership and coordination mechanism types and which agent should be responsible for coordinating or initiating postconsumption products and byproduct reverse physical flows. Regarding policy implications, policy-makers could use the results of these frameworks to create regulations aimed at agents based on the role and position of each agent in a given supply network, such as to incentivize companies in upstream SN positions, such as mining, oil, reforestation and primary raw material extraction firms, to assume recycling activities such as the coordination of postconsumption products and byproduct recovery for small agents' downstream SN positions. This kind of policy is innovative, as most regulations focus on downstream flow, mainly in focal companies (brand owners).

Figure 31- CESN integrating closed and open loop configuration



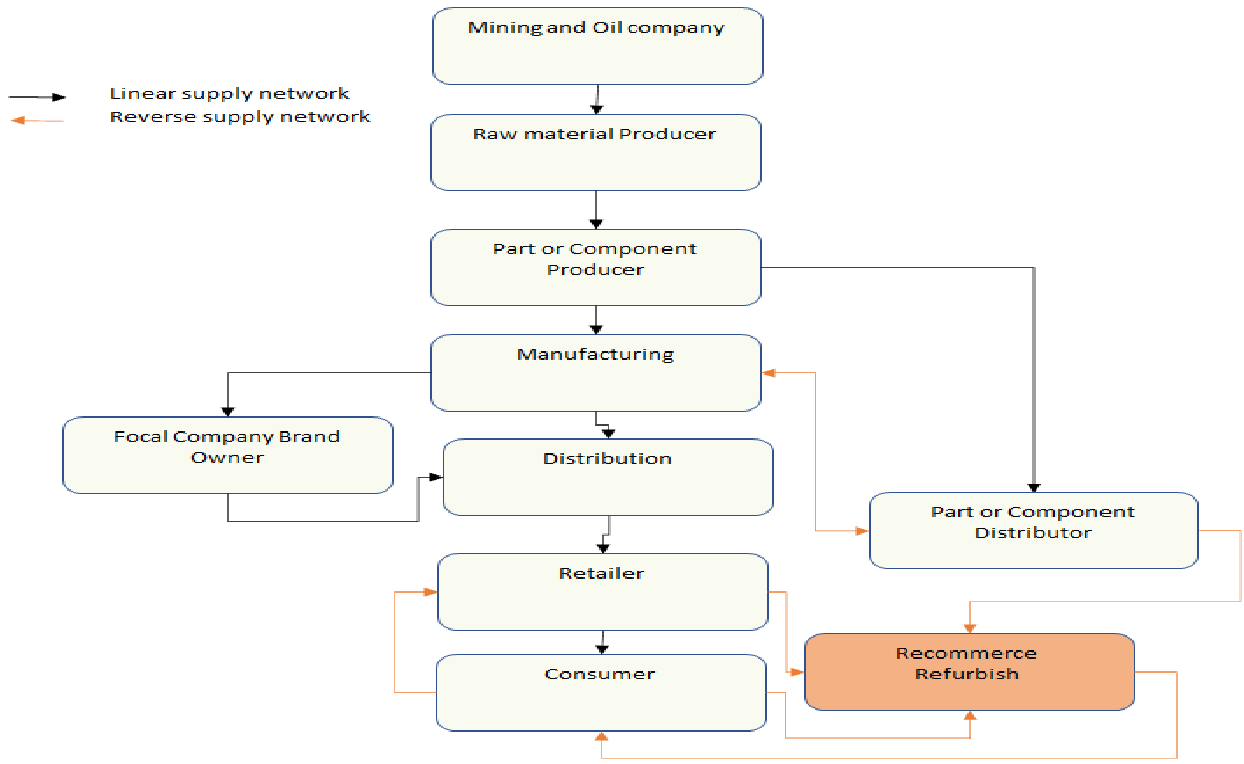
Source: elaborated by the author.

Figure 32- Closed loop configuration



Source: elaborated by the author.

Figure 33- Open loop configuration



Source: elaborated by the author.

Figure 34- Types of SN leadership and SN across all cases.

SN Types	Closed loop SN	Open loop SN	Hybrid loop SN = Closed loop + Open loop supply network + Others industries supply chains				
Supply network cases	Case 2	Case 3	Case 1	Case 4	Case 5	Case 6	Case 7
Interviewed SC Agents	4	3	3	5	4	2	4
Agent's role and position				Extreme Upstream			
Mining, oil, reforestation and primary raw material extraction company	Mining and Oil	Mining and Oil	Mining and Oil	PMrec	Mining and Oil	Biogasman	Cardman
Raw material producer and or recycler	Prrec	Raw Material Producer	Batrec	PMrec	Packrec	Biogasol	Cardman
Raw material producer and or recycler	N	N	Plastic Recycler	N	Raw Material Producer	N	N
Raw material producer and or recycler	N	N	Acid Recycler	N	N	N	N
Other supply chains	N	N	Sinker Fish industry	Jewelry Industry	N	Cities	Chemical Industry
Other supply chains	N	N	Bullet industry	Chemichal Industry	N	Food industry	Construction Industry
Other supply chains	N	N	Battery Industry US	Mining Industry	Food industry	N	Food Industry
Part or component or packaging producer	Component Producer	Components Producers	Components Producers	PMcomp	Packman	N	Cardppman
Manufacturing	Prman	Products Manufacturers	Batman	PMman	N	N	N
Focal company (brand owner)	Prbrand	Mobiles,Tablets, PC Brand	Automotive OEM	Mobiles,Tablet, TV, Appliance, Machinery Brand Owners	Packbrand	N	Cardbrand
Part or component distribution		Eledist	N	Component Distributor	N	N	N
Product distribution	Distributor	Product Distributor	Batdis	Distributor	Distributor	Distributor	Distributor
Retailer or other services		Eleret	Resales	N	N	Gas Station	N
Recommerce		Elereco	N	N	N	N	N
Scrap dealers or reverse logistics provider		N	N	Pmrevlog	Scrap dealer	N	Scrap dealer
Waste picker cooperative	Prcoop	N	N	PMCoop	Packcoop	N	Cardcoop
Consumer individuals or condominiums	Consumers	Consumers	Consumers	Consumers	Consumers	Consumers	Consumers
Government collectors service; volunteer delivery points; individual waste collectors	GCS or VDP or IWC	GCS or VDP or IWC	GCS or VDP or IWC	GCS or VDP or IWC	GCS or VDP or IWC	GCS or VDP or IWC	GCS or VDP or IWC
Supply Network Leadership Type				Extreme Downstream			
Transactional	Demonstrates contingent reward and management-by-exception.						
Transformational	Based on inspiration, intellectual stimulation, greater influence and individualized consideration, establishing long term relationships.						
Hybrid	Transformational and transactional combined, they demonstrate contingent reward and are capable of greater influence, creator of the vision and establishes a long term relationship with other supply network organizations.						

Source: elaborated by the author.

The innovative **dynamic framework based on CESN transition phases management and system dynamics simulation model** presented in article 3 constitutes the third contribution of this research to decision makers. Showing how managers could use it to overcome the difficulties to start a circular supply network as in pre-development or emergence phase in that driving forces could impact customer's wants and needs, influenced by circular factors such as: natural resource extraction economic unviability, regulation pressures and corporate strategy to use sustainability and biodiversity as competitive advantage. Managers should address cooperative challenges to work with internal and external stakeholders, suppliers and customers to define the new circular value proposition around a seed innovation.

Managers could also use our framework to overcome the difficulties to maintain and increase circular supply network circularity, as in expansion phase the actors seek to increase circular products demand and postconsumption products and by-products offer, influenced by circular factors such as: develop strategies to increase postconsumption product and by-products return rate. Managers should address cooperative challenges to work with internal and external stakeholders, suppliers and customers to scale up demand and supply to achieve maximum market coverage.

Our simulation model and CESN transition phases management to predict the circularity index over time increasing or decreasing human resources working in circular projects, as well as, to help managers making decision on which circular factor the project team should focus applying a multi-tier supplier management and hybrid leadership (Jia et al., 2019) with initiating mechanisms (Braz & Mello, 2022), to stimulate internal stakeholders and integrate external stakeholders to adopt circularity, explaining to them the challenges and average time to achieve each transition phase and circularity index.

This policy tool could be innovative, since most regulations are focusing only in incentivize CE general creation (Genovese et al., 2017), policy makers could use our simulation model, and framework to create and refine regulations aimed at achieve each CESN transition phase management.

In addition, circularity has technical and managerial limits as pointed out by Mayers et al. (2021) and Bressanelli et al. (2022): since materials cannot be recovered forever, and couldn't progress through lifespan just in circles or lines. They move through tremendously complex SN, achieving 80% of circularity then oscillating over time due to incremental or radical product innovations and new adopter's circularity performance, besides, declining by SC fragmentation. However, our model suggests ways to smooth these obstacles by, rising circular supplier development and selection' social connections mainly from active CE adopters, that results in a positive feedback loop (growth).

Finally, our empirical findings can help policy-makers and managers achieve several sustainable development goals outlined by the United Nations (George et al., 2016), such as those related to "sustainable cities and communities", "the elimination of poverty" and "good jobs and economic growth", by organizing waste picker individuals in cooperatives who participate in a CESN to enhance their wage, reducing waste generation, as in cases 2, 4, 5 and 7. "Innovation and infrastructure" and "drinking water and sanitation" goals can be met by organizing more sustainability campaigns that reduce plastic waste in public or private universities and inspire students to engage in innovative entrepreneurship, as in case 5. "Renewable energy" and "climate action" can be pursued by taking CESNs as means to use high sugar cane harvesting and biofuel production byproduct quantities to produce biogas and biofertilizers generating electric energy, as in case 6. "Responsible production and consumption" can be pursued by incentivizing more SN extreme upstream companies to implement multi-tiered sustainable network management developing individual waste picker in waste picker cooperatives or scrap dealers in addition to show focal companies how to improve the use of cardboard boxes, as in case 7. They could also use our simulation model to simulate the relation between regulations and management mechanisms to increase circularity and reduce each transition phase average time.

5.3 Further avenues of investigation

Our systematic literature review in article 1 showed that most of the documents were published in interdisciplinary sources, in more than twenty countries, which are evidence that CE and SCM are interdisciplinary concepts with broad research areas, resulting in strong complexity and great opportunities for future research. The three articles suggest that social dimension of sustainable development in CE still is neglected in the literature, for instance the moral obligation of waste places, the social impact to move from a linear to a circular economy, assessing created jobs quality, the relationship between waste pickers' cooperatives and government collectors' services.

Investigating circularity and sustainability index in the transition phases framework in others industries and context, drawing in theoretical lens such as: resource dependence theory, studying how agents' relationship affect organizational capabilities to obtaining resources, or theory of planned behavior, studying how individual perceived behavior could maximize CESN social benefits. Besides, studying CESN management under ecosystem management lens, exploring social impacts of similarities, differences and complementarities among multi-tier supply chain management, supply network hybrid leadership and ecosystem complementors orchestration, to better understand SC and Innovation Ecosystem theories' connection to accelerate sustainability and transition towards CE.

Moreover, the hybrid loop configuration described by Rosa & Terzi (2018) could be used to assess circular, economic, social and environmental impacts once the automotive sector is connected to the electronics and battery industries. Studies could also explore why some focal companies adopt transformational CESN leadership while others do not, and how brand owner's firms could work closer with mining, oil, reforestation and primary raw material extraction companies that apply hybrid CESN leadership to increase social impacts in the supply network.

We also can see, that more empirical studies on integration of environmental, social and economic dimensions are needed, to understand how sustainable circular supply networks are and to assess whether going circular makes a supply network more sustainable or not, this is a huge gap to foster circular economy in real world context. These empirical studies could focus in meso level (the relationship between two or more firms/organizations), small and medium companies' value creation and capture mechanisms in the supply chain, using circular ecosystem management perspective.

Investigating more variables relationship in our model using others modelling techniques to understand how feedback loops could enhance or reduce circularity, sustainability, demand, offer, price, competitive advantage and CE adopters. More studies also are needed considering micro (firm), meso (supply network) and macro (cities) levels integrated perspective, using transition theory.

Finally, as mentioned early regarding the limitations of the case study method, the generalization of the findings is limited to supply network industries and context studied, further studies should be conducted to test suggested propositions, circular factors, variables and constructs derived from this research, as confirmation measurement of our model, using confirmatory factor analysis (CFA), to expand the generalizability of the findings to others countries and industries context.

5.4 University of São Paulo data management plan

Following University of Sao Paulo Resolution number 7900, of November 2019, I have created a data management plan using DMPTool based on USP Template DCC detailed in Appendix 27 and 29.

REFERENCES

Abuabara, L., Paucar-Caceres, A., & Burrowes-Cromwell, T. (2019). Consumers' values and behaviour in the Brazilian coffee-in-capsules market: promoting circular economy. *International Journal of Production Research*, *57*(23), 7269–7288. https://doi.org/10.1080/00207543.2019.1629664

Alkhuzaim, L., Zhu, Q., & Sarkis, J. (2021). Evaluating Emergy Analysis at the Nexus of Circular Economy and Sustainable Supply Chain Management. *Sustainable Production and Consumption*, *25*, 413–424. https://doi.org/10.1016/j.spc.2020.11.022

Anderson, P. (1999). Complexity Theory and Organization Science. *Organization Science*, *10*(3), 216–232. https://doi.org/10.1287/orsc.10.3.216

Bartolini, M., Bottani, E., & Grosse, E. H. (2019). Green warehousing : Systematic literature review and bibliometric analysis. *Journal of Cleaner Production*, *226*, 242–258. https://doi.org/10.1016/j.jclepro.2019.04.055

Bass, F. M. (1969). A New Product Growth for Model Consumer Durables. In *Management Science* (Vol. 15, pp. 215–227). http://www.uvm.edu/~pdodds/files/papers/others/1969/bass1969a.pdf%5Cnhttp://marketingscience.info/assets/documents/195/20654.pdf

Batista, L., Bourlakis, M., Liu, Y., Smart, P., & Sohal, A. (2018). Supply chain operations for a circular economy. *Production Planning and Control*, *29*(6), 419–424. https://doi.org/10.1080/09537287.2018.1449267

Batista, L., Bourlakis, M., Smart, P., & Maull, R. (2018a). In search of a circular supply chain archetype–a content-analysis-based literature review. *Production Planning and Control*, *29*(6), 438–451. https://doi.org/10.1080/09537287.2017.1343502

Batista, L., Bourlakis, M., Smart, P., & Maull, R. (2018b). In search of a circular supply chain archetype–a content-analysis-based literature review. *Production Planning and Control*, *29*(6), 438–451. https://doi.org/10.1080/09537287.2017.1343502

Batista, L., Gong, Y., Pereira, S., Jia, F., & Bittar, A. (2018). Circular supply chains in emerging economies–a comparative study of packaging recovery ecosystems in China and Brazil. *International Journal of Production Research*, *7543*. https://doi.org/10.1080/00207543.2018.1558295

Bernon, M., Tjahjono, B., & Ripanti, E. F. (2018a). Aligning retail reverse logistics practice with circular economy values: an exploratory framework. *Production Planning and Control*, *29*(6), 483–497. https://doi.org/10.1080/09537287.2018.1449266

Bernon, M., Tjahjono, B., & Ripanti, E. F. (2018b). Aligning retail reverse logistics practice with circular economy values: an exploratory framework. *Production Planning and Control*, *29*(6), 483–497. https://doi.org/10.1080/09537287.2018.1449266

Bertassini, A. C., Ometto, A. R., Severengiz, S., & Gerolamo, M. C. (2021). Circular economy and sustainability: The role of organizational behaviour in the transition journey. *Business Strategy and the Environment*, *March*, 1–34. https://doi.org/10.1002/bse.2796

Blessing, L. T. M., & Chakrabarti, A. (2009). DRM, a design research methodology. *Proceedings of Les Sciences de La Conception, March 15-16, 2009, INSA de Lyon, Lyon*, 1–397. https://doi.org/10.1007/978-1-84882-587-1

Botezat, E. A., Dodescu, A. O., Vaduva, S., & Fotea, S. L. (2018). An exploration of circular economy practices and performance among Romanian producers. *Sustainability (Switzerland)*, *10*(9), 1–17. https://doi.org/10.3390/su10093191

Braun, A. T., Kleine-Moellhoff, P., Reichenberger, V., & Seiter, S. (2018). Case study analysing potentials to improve material efficiency in manufacturing supply chains, considering circular economy aspects. *Sustainability (Switzerland)*, *10*(3). https://doi.org/10.3390/su10030880

Braz, A. C., De Mello, A. M., de Vasconcelos Gomes, L. A., & de Souza Nascimento, P. T. (2018a). The bullwhip effect in closed-loop supply chains: A systematic literature review. *Journal of Cleaner Production*, *202*, 376–389. https://doi.org/10.1016/j.jclepro.2018.08.042

Braz, A. C., De Mello, A. M., de Vasconcelos Gomes, L. A., & de Souza Nascimento, P. T. (2018b). The bullwhip effect in closed-loop supply chains: A systematic literature review. *Journal of Cleaner Production*, *202*, 376–389. https://doi.org/10.1016/j.jclepro.2018.08.042

Braz, A. C., & Mello, A. M. (2022). Circular economy supply network management: A complex adaptive system. *International Journal of Production Economics*, *243*(June 2020), 108317. https://doi.org/10.1016/j.ijpe.2021.108317

Braz, A. C., & Mello, A. M. de. (2020). Supply Chains Types and Strategies for Circular Economy Transitions. *9th International Workshop Advances in Cleaner Production Conference Proceedings, Melbourne, Australia. May 26th*, *1*(Melbourne, Australia), 271.

Braz, A. C., & Mello, A. M. de. (2021). Circular economy supply network management : A complex adaptive system. *Intern. Journal of Production Economics*.

Bressanelli, G., Visintin, F., & Saccani, N. (2022). Circular Economy and the evolution of industrial districts: a supply chain perspective. *International Journal of Production Economics*, *243*(October 2021), 108348. https://doi.org/10.1016/j.ijpe.2021.108348

Carter, C. R., Rogers, D. S., & Choi, T. Y. (2015). Toward the theory of the supply chain. *Journal of Supply Chain Management*, *51*(2), 89–97. https://doi.org/10.1111/jscm.12073

Chen, I. J., & Paulraj, A. (2004). Towards a theory of supply chain management: The constructs and measurements. *Journal of Operations Management*, *22*(2), 119–150. https://doi.org/10.1016/j.jom.2003.12.007

Chizaryfard, A., Trucco, P., & Nuur, C. (2021). The transformation to a circular economy: framing an evolutionary view. *Journal of Evolutionary Economics*, *31*(2), 475–504. https://doi.org/10.1007/s00191-020-00709-0

Choi, T. Y., Dooley, K. J., & Rungtusanatham, M. (2001). Supply networks and complex adaptive systems: Control versus emergence. *Journal of Operations Management*, *19*(3), 351–366. https://doi.org/10.1016/S0272-6963(00)00068-1

Coenen, J., van der Heijden, R. E. C. M., & van Riel, A. C. R. (2018). Understanding approaches to complexity and uncertainty in closed-loop supply chain management: Past findings and future directions. *Journal of Cleaner Production*, *201*, 1–13.

https://doi.org/10.1016/j.jclepro.2018.07.216

Cosenz, F., Rodrigues, V. P., & Rosati, F. (2020). Dynamic business modeling for sustainability: Exploring a system dynamics perspective to develop sustainable business models. *Business Strategy and the Environment*, *29*(2), 651–664. https://doi.org/10.1002/bse.2395

Dangerfield, B. (2014). Systems thinking and system dynamics: A primer. *Discrete-Event Simulation and System Dynamics for Management Decision Making*, *9781118349*(2007), 26–51. https://doi.org/10.1002/9781118762745.ch03

Davis, J. P., Eisenhardt, K. M., & Bingham, C. B. (2007). Developing theory through simulation methods. *Academy of Management Review*, *32*(2), 480–499. https://doi.org/10.5465/AMR.2007.24351453

De Angelis, R, Howard, M., & Miemczyk, J. (2018). Supply chain management and the circular economy: towards the circular supply chain. *Production Planning and Control*, *29*(6), 425–437. https://doi.org/10.1080/09537287.2018.1449244

De Angelis, Roberta, Howard, M., & Miemczyk, J. (2018). Supply chain management and the circular economy: towards the circular supply chain. *Production Planning and Control*, *29*(6), 425–437. https://doi.org/10.1080/09537287.2018.1449244

de Kok, T., Grob, C., Laumanns, M., Minner, S., Rambau, J., & Schade, K. (2018). A typology and literature review on stochastic multi-echelon inventory models. *European Journal of Operational Research*, *269*(3), 955–983. https://doi.org/10.1016/j.ejor.2018.02.047

Defee, C. C., Stank, T. P., & Esper, T. (2010). Performance implications of transformational supply chain leadership and followership. *International Journal of Physical Distribution and Logistics Management*, *40*(10), 763–791. https://doi.org/10.1108/09600031011093205

Dondi, M., García-Ten, J., Rambaldi, E., Zanelli, C., & Vicent-Cabedo, M. (2021). Resource efficiency versus market trends in the ceramic tile industry: Effect on the supply chain in Italy and Spain. *Resources, Conservation and Recycling*, *168*(July 2020). https://doi.org/10.1016/j.resconrec.2020.105271

Doni, F., Corvino, A., & Bianchi Martini, S. (2019). Servitization and sustainability actions. Evidence from European manufacturing companies. *Journal of Environmental Management*, *234*(January), 367–378. https://doi.org/10.1016/j.jenvman.2019.01.004

Duriau, V. J., Reger, R. K., & Pfarrer, M. D. (2007). A Content Analysis of the Content Analysis Literature in Organization Studies. *Organizational Research Methods*, *10 number*(February 2005), 5–34.

Eisenhardt, K. M. (1989). Building Theories from Case Study Research. *Academy of Management Review*, *14*(4), 532–550. https://doi.org/10.5465/amr.1989.4308385

Ellram, L. M., Tate, W. L., & Billington, C. (2008). Offshore outsourcing of professional services: A transaction cost economics perspective. *Journal of Operations Management*, *26*(2), 148–163. https://doi.org/10.1016/j.jom.2007.02.008

European Commission. (2014). Communication from the Commission - Towards a circular economy: A zero waste programme for Europe. *European Commission*, *398*, 1–14.

https://ec.europa.eu/environment/circular-economy/pdf/circular-economy-communication.pdf

Farooque, M., Zhang, A., Thürer, M., Qu, T., & Huisingh, D. (2019). Circular supply chain management: A definition and structured literature review. *Journal of Cleaner Production*, *228*, 882–900. https://doi.org/10.1016/j.jclepro.2019.04.303

Fonseca, L. M., Domingues, J. P., Pereira, M. T., Martins, F. F., & Zimon, D. (2018). Assessment of circular economy within Portuguese organizations. *Sustainability (Switzerland)*, *10*(7), 1–24. https://doi.org/10.3390/su10072521

Forrester, J. W. (1980). Information sources for modeling the national economy. *Journal of the American Statistical Association*, *75*(371), 555–566. https://doi.org/10.1080/01621459.1980.10477508

Franco, M. A. (2017). Circular economy at the micro level: A dynamic view of incumbents' struggles and challenges in the textile industry. *Journal of Cleaner Production*, *168*(September), 833–845. https://doi.org/10.1016/j.jclepro.2017.09.056

Frei, R., Jack, L., & Krzyzaniak, S. A. (2020). Sustainable reverse supply chains and circular economy in multichannel retail returns. *Business Strategy and the Environment*, *29*(5), 1925–1940. https://doi.org/10.1002/bse.2479

Gandolfo, A., & Lupi, L. (2021). Circular economy , the transition of an incumbent focal firm : How to successfully reconcile environmental and economic sustainability ? *Business Strategy and the Environment*, *April*, 1–12. https://doi.org/10.1002/bse.2803

Gaustad, G., Krystofik, M., Bustamante, M., & Badami, K. (2018). Circular economy strategies for mitigating critical material supply issues. *Resources, Conservation and Recycling*, *135*(January 2017), 24–33. https://doi.org/10.1016/j.resconrec.2017.08.002

Gehman, J., Glaser, V. L., Eisenhardt, K. M., Gioia, D., Langley, A., & Corley, K. G. (2018). Finding Theory–Method Fit: A Comparison of Three Qualitative Approaches to Theory Building. *Journal of Management Inquiry*, *27*(3), 284–300. https://doi.org/10.1177/1056492617706029

Geissdoerfer, M., Morioka, S. N., de Carvalho, M. M., & Evans, S. (2018). Business models and supply chains for the circular economy. *Journal of Cleaner Production*, *190*, 712–721. https://doi.org/10.1016/j.jclepro.2018.04.159

Genovese, A., Acquaye, A. A., Figueroa, A., & Koh, S. C. L. (2017). Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications. *Omega (United Kingdom)*, *66*, 344–357. https://doi.org/10.1016/j.omega.2015.05.015

George, G., Howard-Grenville, J., Joshi, A., & Tihanyi, L. (2016). Understanding and tackling societal grand challenges through management research. *Academy of Management Journal*, *59*(6), 1880–1895. https://doi.org/10.5465/amj.2016.4007

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, *114*, 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007

Gong, Y., Jia, F., Brown, S., & Koh, L. (2018). Supply chain learning of sustainability in multi-tier supply chains: A resource orchestration perspective. *International Journal of Operations and Production Management*, *38*(4), 1061–1090. https://doi.org/10.1108/IJOPM-05-2017-0306

Gosling, J., Jia, F., Gong, Y., & Brown, S. (2016). The role of supply chain leadership in the learning of sustainable practice: toward an integrated framework. *Journal of Cleaner Production*, *137*, 1458–1469. https://doi.org/10.1016/j.jclepro.2014.10.029

Govindan, K., & Hasanagic, M. (2018). A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective. *International Journal of Production Research*, *56*(1–2), 278–311. https://doi.org/10.1080/00207543.2017.1402141

Grin, J., Rotmans, J., Schot, J., Geels, F., & Derk, L. (2010). Transitions To Sustainable Development. In *Book* (1st ed.). Taylor & Francis.

Guide, V. D. R., & Van Wassenhove, L. N. (2002). The Reverse Supply Chain. *Harvard Business Review*, *80*(2), 1–16. http://www.mendeley.com

Guide, V. D. R., & Van Wassenhove, L. N. (2009). The evolution of closed-loop supply chain research. *Operations Research*, *57*(1), 10–18. https://doi.org/10.1287/opre.1080.0628

Haas, W., Krausmann, F., Wiedenhofer, D., & Heinz, M. (2015). How circular is the global economy?: An assessment of material flows, waste production, and recycling in the European union and the world in 2005. *Journal of Industrial Ecology*, *19*(5), 765–777. https://doi.org/10.1111/jiec.12244

Hahladakis, J. N., & Iacovidou, E. (2018a). Closing the loop on plastic packaging materials: What is quality and how does it affect their circularity? *Science of the Total Environment*, *630*, 1394–1400. https://doi.org/10.1016/j.scitotenv.2018.02.330

Hahladakis, J. N., & Iacovidou, E. (2018b). Closing the loop on plastic packaging materials: What is quality and how does it affect their circularity? *Science of the Total Environment*, *630*, 1394–1400. https://doi.org/10.1016/j.scitotenv.2018.02.330

Halstenberg, F. A., Lindow, K., & Stark, R. (2017). Utilization of Product Lifecycle Data from PLM Systems in Platforms for Industrial Symbiosis. *Procedia Manufacturing*, *8*(October 2016), 369–376. https://doi.org/10.1016/j.promfg.2017.02.047

Haneef, M., Nasir, A., Genovese, A., Acquaye, A. A., Koh, S. C. L., & Yamoah, F. (2017). Int . J . Production Economics Comparing linear and circular supply chains : A case study from the construction industry. *Intern. Journal of Production Economics*, *183*, 443–457. https://doi.org/10.1016/j.ijpe.2016.06.008

Homrich, A. S., Galvão, G., Abadia, L. G., & Carvalho, M. M. (2018). The circular economy umbrella: Trends and gaps on integrating pathways. *Journal of Cleaner Production*, *175*, 525–543. https://doi.org/10.1016/j.jclepro.2017.11.064

Husgafvel, R., Poikela, K., Honkatukia, J., & Dahl, O. (2017). Development and piloting of sustainability assessment metrics for arctic process industry in Finland-The biorefinery investment and slag processing service cases. *Sustainability (Switzerland)*, *9*(10). https://doi.org/10.3390/su9101693

Huybrechts, D., Derden, A., Van den Abeele, L., Vander Aa, S., & Smets, T. (2018). Best available techniques and the value chain perspective. *Journal of Cleaner Production*, *174*, 847–856. https://doi.org/10.1016/j.jclepro.2017.10.346

Irani, Z., & Sharif, A. M. (2018). Food security across the enterprise: a puzzle, problem or mess for a circular economy? *Journal of Enterprise Information Management*, *31*(1), 2–9. https://doi.org/10.1108/JEIM-03-2017-0045

Islam, M. T., & Huda, N. (2018). Reverse logistics and closed-loop supply chain of Waste Electrical and Electronic Equipment (WEEE)/E-waste: A comprehensive literature review. *Resources, Conservation and Recycling*, *137*(June), 48–75. https://doi.org/10.1016/j.resconrec.2018.05.026

Jain, S., Jain, N. K., & Metri, B. (2018a). Strategic framework towards measuring a circular supply chain management. *Benchmarking*, *25*(8), 3238–3252. https://doi.org/10.1108/BIJ-11-2017-0304

Jain, S., Jain, N. K., & Metri, B. (2018b). Strategic framework towards measuring a circular supply chain management. *Benchmarking*, *25*(8), 3238–3252. https://doi.org/10.1108/BIJ-11-2017-0304

Jensen, J. P., & Remmen, A. (2017). Enabling Circular Economy Through Product Stewardship. *Procedia Manufacturing*, *8*(October 2016), 377–384. https://doi.org/10.1016/j.promfg.2017.02.048

Jia, F., Gong, Y., & Brown, S. (2019). Multi-tier sustainable supply chain management: The role of supply chain leadership. *International Journal of Production Economics*, *217*(July 2018), 44–63. https://doi.org/10.1016/j.ijpe.2018.07.022

Jiménez-Rivero, A., & García-Navarro, J. (2018). Best practices for the management of end-of-life gypsum in a circular economy. *Journal of Cleaner Production*, *167*, 1335–1344. https://doi.org/10.1016/j.jclepro.2017.05.068

Kalaitzi, D., Matopoulos, A., Bourlakis, M., & Tate, W. (2018). Supply chain strategies in an era of natural resource scarcity. *International Journal of Operations and Production Management*, *38*(3), 784–809. https://doi.org/10.1108/IJOPM-05-2017-0309

Kalmykova, Y., Sadagopan, M., & Rosado, L. (2018a). Circular economy - From review of theories and practices to development of implementation tools. *Resources, Conservation and Recycling*, *135*(October 2017), 190–201. https://doi.org/10.1016/j.resconrec.2017.10.034

Kalmykova, Y., Sadagopan, M., & Rosado, L. (2018b). Circular economy - From review of theories and practices to development of implementation tools. *Resources, Conservation and Recycling*, *135*(February 2017), 190–201. https://doi.org/10.1016/j.resconrec.2017.10.034

Kalverkamp, M. (2018). Hidden potentials in open-loop supply chains for remanufacturing. *International Journal of Logistics Management*, *29*(4), 1125–1146. https://doi.org/10.1108/IJLM-10-2017-0278

Kalverkamp, M., & Young, S. B. (2019a). In support of open-loop supply chains: Expanding the scope of environmental sustainability in reverse supply chains. *Journal of Cleaner Production*, *214*, 573–582. https://doi.org/10.1016/j.jclepro.2019.01.006

Kalverkamp, M., & Young, S. B. (2019b). In support of open-loop supply chains: Expanding the scope of environmental sustainability in reverse supply chains. *Journal of Cleaner Production*, *214*, 573–582. https://doi.org/10.1016/j.jclepro.2019.01.006

Kanger, L., & Schot, J. (2016). User-made immobilities: a transitions perspective. *Mobilities*, *11*(4), 598–613. https://doi.org/10.1080/17450101.2016.1211827

Kazancoglu, Y., Ekinci, E., Mangla, S. K., Sezer, M. D., & Kayikci, Y. (2020). Performance evaluation of reverse logistics in food supply chains in a circular economy using system dynamics. *Business Strategy and the Environment*, *March*, 1–21. https://doi.org/10.1002/bse.2610

Kazancoglu, Y., Kazancoglu, I., & Sagnak, M. (2018). A new holistic conceptual framework for green supply chain management performance assessment based on circular economy. *Journal of Cleaner Production*, *195*, 1282–1299. https://doi.org/10.1016/j.jclepro.2018.06.015

Kazemi, N., Modak, N. M., & Govindan, K. (2018). A review of reverse logistics and closed loop supply chain management studies published in IJPR: a bibliometric and content analysis. *International Journal of Production Research*, *7543*, 1–24. https://doi.org/10.1080/00207543.2018.1471244

Ketchen, D. J., Crook, T. R., & Craighead, C. W. (2014). From supply chains to supply ecosystems: Implications for strategic sourcing research and practice. *Journal of Business Logistics*, *35*(3), 165–171. https://doi.org/10.1111/jbl.12057

Ketokivi, M., & Choi, T. (2014). Renaissance of case research as a scientific method. *Journal of Operations Management*, *32*(5), 232–240. https://doi.org/10.1016/j.jom.2014.03.004

Kirchherr, J., Reike, D., & Hekkert, M. (2017a). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*(April), 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kirchherr, J., Reike, D., & Hekkert, M. (2017b). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*(September), 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kivimaa, P., Hyysalo, S., Boon, W., Klerkx, L., Martiskainen, M., & Schot, J. (2019). Passing the baton: How intermediaries advance sustainability transitions in different phases. *Environmental Innovation and Societal Transitions*, *31*(July 2018), 110–125. https://doi.org/10.1016/j.eist.2019.01.001

Kravchenko, M., McAloone, T. C., & Pigosso, D. C. A. (2020). To what extent do circular economy indicators capture sustainability? *Procedia CIRP*, *90*, 31–36. https://doi.org/10.1016/j.procir.2020.02.118

Kurpjuweit, S., Wagner, S. M., & Choi, T. Y. (2020). Selecting Startups as Suppliers: A Typology of Supplier Selection Archetypes. *Journal of Supply Chain Management*, 1–25. https://doi.org/10.1111/jscm.12230

Langley, A., Smallman, C., Tsoukas, H., & Van De Ven, A. H. (2013). Process studies of change in organization and management: Unveiling temporality, activity, and flow. *Academy of Management Journal*, *56*(1), 1–13. https://doi.org/10.5465/amj.2013.4001

Larsen, S. B., Masi, D., Jacobsen, P., & Godsell, J. (2018a). How the reverse supply chain contributes to a firm's competitive strategy: a strategic alignment perspective. *Production Planning and Control*, *29*(6), 452–463. https://doi.org/10.1080/09537287.2017.1390178

Larsen, S. B., Masi, D., Jacobsen, P., & Godsell, J. (2018b). How the reverse supply chain contributes to a firm's competitive strategy: a strategic alignment perspective. *Production Planning and Control*, *29*(6), 452–463. https://doi.org/10.1080/09537287.2017.1390178

Leising, E., Quist, J., & Bocken, N. (2018). Circular Economy in the building sector: Three cases and a collaboration tool. *Journal of Cleaner Production*, *176*, 976–989. https://doi.org/10.1016/j.jclepro.2017.12.010

Lejeune, M. A., & Yakova, N. (2005). On characterizing the 4 C's in supply chain management. *Journal of Operations Management*, *23*(1), 81–100. https://doi.org/10.1016/j.jom.2004.09.004

Liu, B., Chen, D., Zhou, W., Nasr, N., Wang, T., Hu, S., & Zhu, B. (2018). The effect of remanufacturing and direct reuse on resource productivity of China's automotive production. *Journal of Cleaner Production*, *194*, 309–317. https://doi.org/10.1016/j.jclepro.2018.05.119

Liu, J., Feng, Y., Zhu, Q., & Sarkis, J. (2018). Green supply chain management and the circular economy Reviewing theory for advancement of both fields. *International Journal of Physical Distribution & Logistics Management*, *48*(8), 794–817.

Lohmann, G., & Meyers, R. (2015). Encyclopedia of Complexity and Systems Science. In *Encyclopedia of Complexity and Systems Science*. https://doi.org/10.1007/978-3-642-27737-5

Löhr, M., & Mattes, J. (2022). Facing transition phase two: Analysing actor strategies in a stagnating acceleration phase. *Technological Forecasting and Social Change*, *174*(November 2020). https://doi.org/10.1016/j.techfore.2021.121221

Lopes de Sousa Jabbour, A. B., Jabbour, C. J. C., Godinho Filho, M., & Roubaud, D. (2018). Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations. *Annals of Operations Research*, *270*(1–2), 273–286. https://doi.org/10.1007/s10479-018-2772-8

Maaß, O., & Grundmann, P. (2018). Governing transactions and interdependences between linked value chains in a circular economy: The case of wastewater reuse in Braunschweig (Germany). *Sustainability (Switzerland)*, *10*(4), 1–29. https://doi.org/10.3390/su10041125

Mangla, S. K., Luthra, S., Mishra, N., Singh, A., Rana, N. P., Dora, M., & Dwivedi, Y. (2018). Barriers to effective circular supply chain management in a developing country context. *Production Planning and Control*, *29*(6), 551–569. https://doi.org/10.1080/09537287.2018.1449265

Marchi, B., & Zanoni, S. (2017). Supply chain management for improved energy efficiency: Review and opportunities. *Energies*, *10*(10). https://doi.org/10.3390/en10101618

Martín-Gómez, A., Aguayo-González, F., & Luque, A. (2019). A holonic framework for managing the sustainable supply chain in emerging economies with smart connected metabolism. *Resources, Conservation and Recycling*, *141*(October 2018), 219–232. https://doi.org/10.1016/j.resconrec.2018.10.035

Martinez-Moyano, I. J. (2012). Documentation for model transparency. *System Dynamics Review*, *28*(2), 199–208. https://doi.org/10.1002/sdr.1471

Masi, D., Day, S., & Godsell, J. (2017). Supply chain configurations in the circular economy: A systematic literature review. *Sustainability (Switzerland)*, *9*(9). https://doi.org/10.3390/su9091602

Masi, D., Kumar, V., Garza-Reyes, J. A., & Godsell, J. (2018). Towards a more circular economy: exploring the awareness, practices, and barriers from a focal firm perspective. *Production Planning and Control*, *29*(6), 539–550. https://doi.org/10.1080/09537287.2018.1449246

Matos, S., & Hall, J. (2007). Integrating sustainable development in the supply chain: The case of life cycle assessment in oil and gas and agricultural biotechnology. *Journal of Operations Management*, *25*(6), 1083–1102. https://doi.org/10.1016/j.jom.2007.01.013

Mayers, K., Davis, T., & van Wassenhove, L. (2021). The Limits of the “Sustainable” Economy. *2Harvard Business Review*, *26*(2), 214–217. https://doi.org/10.1016/j.polgeo.2006.10.007

Mayring, P. (2014). Qualitative Content Analysis. *Forum Qualitative Social Reseach*, *1*(2), 10. https://doi.org/10.1016/S1479-3709(07)11003-7

Meadows, D. (1999). Leverage Points: Places to Intervene in a System donellameadows.org/archives/leverage-points-places-to-intervene-in-a-system. *Sustainability Institute*, 1–18.

Meherishi, L., Narayana, S. A., & Ranjani, K. S. (2019). Sustainable packaging for supply chain management in the circular economy : A review. *Journal of Cleaner Production*, *237*, 117582. https://doi.org/10.1016/j.jclepro.2019.07.057

Mena, C., Humphries, A., & Choi, T. Y. (2013). Toward a theory of multi-tier supply chain management. *Journal of Supply Chain Management*, *49*(2), 58–77. https://doi.org/10.1111/jscm.12003

Mendoza, J. M. F., Sharmina, M., Gallego-Schmid, A., Heyes, G., & Azapagic, A. (2017). Integrating Backcasting and Eco-Design for the Circular Economy: The BECE Framework. *Journal of Industrial Ecology*, *21*(3), 526–544. https://doi.org/10.1111/jiec.12590

Mentzer, J. T., Keebler, J. S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining supply chain Management. *Journal of Business Logistics*, *22*(2), 1–25.

Merli, R., Preziosi, M., & Acampora, A. (2018). How do scholars approach the circular economy? A systematic literature review. *Journal of Cleaner Production*, *178*, 703–722. https://doi.org/10.1016/j.jclepro.2017.12.112

Mew, M. C., Steiner, G., & Geissler, B. (2018). Phosphorus supply chain-scientific, technical, and economic foundations: A transdisciplinary orientation. *Sustainability (Switzerland)*, *10*(4). https://doi.org/10.3390/su10041087

Miles, M., Huberman, M., & Saldaña, J. (2014). *Qualitative Data Analysis - A Methods Sourcebook*.

Mishra, J. L., Hopkinson, P. G., & Tidridge, G. (2018). Value creation from circular economy-led closed loop supply chains: a case study of fast-moving consumer goods. *Production Planning and Control*, *29*(6), 509–521. https://doi.org/10.1080/09537287.2018.1449245

Mokhtar, A. R. M., Genovese, A., Brint, A., & Kumar, N. (2019). Improving reverse supply chain performance: The role of supply chain leadership and governance mechanisms. *Journal of Cleaner Production*, *216*, 42–55. https://doi.org/10.1016/j.jclepro.2019.01.045

Moktadir, M. A., Rahman, T., Rahman, M. H., Ali, S. M., & Paul, S. K. (2018). Drivers to sustainable manufacturing practices and circular economy: A perspective of leather industries in Bangladesh. *Journal of Cleaner Production*, *174*, 1366–1380. https://doi.org/10.1016/j.jclepro.2017.11.063

Moore, J. F. (1993). Predators and Prey: A New Ecology of Competition. *Harvard Business Review*, *71*(3), 75–86. http://blogs.law.harvard.edu/jim/files/2010/04/Predators-and-Prey.pdf

Morecroft, J. D. W. (2015). Strategic Modelling and Business Dynamics. In *Strategic Modelling and Business Dynamics*. https://doi.org/10.1002/9781119176831

Mulrow, J. S., Derrible, S., Ashton, W. S., & Chopra, S. S. (2017). Industrial Symbiosis at the Facility Scale. *Journal of Industrial Ecology*, *21*(3), 559–571. https://doi.org/10.1111/jiec.12592

Muñoz-Torres, M. J., Fernández-Izquierdo, M. ángeles, Rivera-Lirio, J. M., Ferrero-Ferrero, I., Escrig-Olmedo, E., Gisbert-Navarro, J. V., & Marullo, M. C. (2018). An assessment tool to integrate sustainability principles into the global supply chain. *Sustainability (Switzerland)*, *10*(2). https://doi.org/10.3390/su10020535

Murray, A., Skene, K., & Haynes, K. (2017). The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. *Journal of Business Ethics*, *140*(3), 369–380. https://doi.org/10.1007/s10551-015-2693-2

Nair, A., & Reed-Tsochas, F. (2019). Revisiting the complex adaptive systems paradigm: Leading perspectives for researching operations and supply chain management issues. *Journal of Operations Management*, *65*(2), 80–92. https://doi.org/10.1002/joom.1022

O'Connor, M. P., Zimmerman, J. B., Anastas, P. T., & Plata, D. L. (2016). A strategy for material supply chain sustainability: Enabling a circular economy in the electronics industry through green engineering. *ACS Sustainable Chemistry and Engineering*, *4*(11), 5879–5888. https://doi.org/10.1021/acssuschemeng.6b01954

Papetti, A., Marconi, M., Rossi, M., & Germani, M. (2019). Web-based platform for eco-sustainable supply chain management. *Sustainable Production and Consumption*, *17*, 215–228. https://doi.org/10.1016/j.spc.2018.11.006

Park, J., Sarkis, J., & Wu, Z. (2010). Creating integrated business and environmental value within the context of China's circular economy and ecological modernization. *Journal of Cleaner Production*, *18*(15), 1494–1501. https://doi.org/10.1016/j.jclepro.2010.06.001

Perey, R., Benn, S., Agarwal, R., & Edwards, M. (2018). The place of waste: Changing business value for the circular economy. *Business Strategy and the Environment*, *27*(5), 631–642. https://doi.org/10.1002/bse.2068

Piezer, K., Petit-Boix, A., Sanjuan-Delmás, D., Briese, E., Celik, I., Rieradevall, J., Gabarrell, X., Josa, A., & Apul, D. (2019a). Ecological network analysis of growing tomatoes in an urban rooftop greenhouse. *Science of the Total Environment*, *651*, 1495–1504. https://doi.org/10.1016/j.scitotenv.2018.09.293

Piezer, K., Petit-Boix, A., Sanjuan-Delmás, D., Briese, E., Celik, I., Rieradevall, J., Gabarrell, X., Josa, A., & Apul, D. (2019b). Ecological network analysis of growing tomatoes in an urban rooftop greenhouse. *Science of the Total Environment*, *651*, 1495–1504. https://doi.org/10.1016/j.scitotenv.2018.09.293

Pishchulov, G. V., Richter, K. K., Pakhomova, N. V., & Tsenzharik, M. K. (2019). A circular economy perspective on sustainable supply chain management: an updated survey. *St Petersburg University Journal of Economic Studies*, *34*(2), 267–297. https://doi.org/10.21638/11701/spbu05.2018.204

Principles, C. I. G., Measures, C. V. I., & Principles, C. I. G. (2009). *Translation by lawinfochina.com*. *4*, 1–11. https://ppp.worldbank.org/public-private-partnership/sites/ppp.worldbank.org/files/documents/China_CircularEconomyLawEnglish.pdf

Raynolds, L. T. (2004). The globalization of organic agro-food networks. *World Development*, *32*(5), 725–743. https://doi.org/10.1016/j.worlddev.2003.11.008

Rebs, T., Brandenburg, M., & Seuring, S. (2019). System dynamics modeling for sustainable supply chain management: A literature review and systems thinking approach. *Journal of Cleaner Production*, *208*, 1265–1280. https://doi.org/10.1016/j.jclepro.2018.10.100

Rentizelas, A., Trivyza, N., Oswald, S., & Siegl, S. (2022). Reverse supply network design for circular economy pathways of wind turbine blades in Europe. *International Journal of Production Research*, *60*(6), 1795–1814. https://doi.org/10.1080/00207543.2020.1870016

Rosa, P., & Terzi, S. (2018). Improving end of life vehicle's management practices: An economic assessment through system dynamics. *Journal of Cleaner Production*, *184*, 520–536. https://doi.org/10.1016/j.jclepro.2018.02.264

Rotmans, J., Kemp, R., & Van Asselt, M. (2001). Emerald Article: More evolution than revolution: transition management in public policy Jan Rotmans, René Kemp, Marjolein van Asselt. *Foresight*, *3*(1), 15–31.

Rusch, M., Schöggl, J. P., & Baumgartner, R. J. (2022). Application of digital technologies for sustainable product management in a circular economy: A review. *Business Strategy and the Environment*, *September 2021*, 1–16. https://doi.org/10.1002/bse.3099

Saldaña, J. (2013). *The Coding Manual for Qualitative Researchers* (2nd Editio). Sage Publications.

Salim, H. K., Stewart, R. A., Sahin, O., & Dudley, M. (2019a). Drivers, barriers and enablers to end-of-life management of solar photovoltaic and battery energy storage systems: A systematic literature review. *Journal of Cleaner Production*, *211*, 537–554. https://doi.org/10.1016/j.jclepro.2018.11.229

Salim, H. K., Stewart, R. A., Sahin, O., & Dudley, M. (2019b). Green supply chain management and the circular economy: Reviewing theory for advancement of both fields. *Journal of*

Cleaner Production, *211*, 537–554. https://doi.org/10.1016/j.jclepro.2018.11.229

Sarkis, J., Santibanez Gonzalez, E. D., & Koh, S. C. L. (2019). Effective multi-tier supply chain management for sustainability. *International Journal of Production Economics*, *217*, 1–10. https://doi.org/10.1016/j.ijpe.2019.09.014

Sarkis, J., & Talluri, S. (2002). A Model for Strategic Supplier Selection. *Journal of Supply Chain Management*, *38*(4), 18–28. https://doi.org/10.1111/j.1745-493X.2002.tb00117.x

Sarkis, J., Zhu, Q., & Lai, K. (2011a). Int . J . Production Economics An organizational theoretic review of green supply chain management literature. *Intern. Journal of Production Economics*, *130*(1), 1–15. https://doi.org/10.1016/j.ijpe.2010.11.010

Sarkis, J., Zhu, Q., & Lai, K. H. (2011b). An organizational theoretic review of green supply chain management literature. *International Journal of Production Economics*, *130*(1), 1–15. https://doi.org/10.1016/j.ijpe.2010.11.010

Scavarda, A., Daú, G. L., Scavarda, L. F., & Korzenowski, A. L. (2019). A proposed healthcare supply chain management framework in the emerging economies with the sustainable lenses: The theory, the practice, and the policy. *Resources, Conservation and Recycling*, *141*(October 2018), 418–430. https://doi.org/10.1016/j.resconrec.2018.10.027

Schallehn, H., Seuring, S., Strähle, J., & Freise, M. (2019). Customer experience creation for after-use products: A product–service systems-based review. *Journal of Cleaner Production*, *210*, 929–944. https://doi.org/10.1016/j.jclepro.2018.10.292

Schleper, M. C., Blome, C., & Stanczyk, A. (2019). Archetypes of sourcing decision-making: The influence of contextual factors on consensus, argumentation and cabal. *International Journal of Operations and Production Management*, *40*(2), 117–143. https://doi.org/10.1108/IJOPM-07-2017-0397

Schraven, D., Maio, F. Di, & Hertogh, M. (2019a). *Circular transition : Changes and responsibilities in the Dutch stony material supply chain*. *150*(May). https://doi.org/10.1016/j.resconrec.2019.05.035

Schraven, D., Maio, F. Di, & Hertogh, M. (2019b). *Resources , Conservation & Recycling Circular transition : Changes and responsibilities in the Dutch stony material supply chain*. *150*(May). https://doi.org/10.1016/j.resconrec.2019.05.035

Seuring, S., & Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production*, *16*(15), 1699–1710. https://doi.org/10.1016/j.jclepro.2008.04.020

Sgarbossa, F., & Russo, I. (2017). A proactive model in sustainable food supply chain: Insight from a case study. *International Journal of Production Economics*, *183*(2017), 596–606. https://doi.org/10.1016/j.ijpe.2016.07.022

Simatupang, T. M., Wright, A. C., & Sridharan, R. (2002). The knowledge of coordination for supply chain integration. *Business Process Management Journal*, *8*(3), 289–308. https://doi.org/10.1108/14637150210428989

Skjott Linneberg, M., & Korsgaard, S. (2019). Coding qualitative data: a synthesis guiding the novice. *Qualitative Research Journal*, *19*(3), 259–270. https://doi.org/10.1108/QRJ-12-2018-0012

Smart, P., Hemel, S., Lettice, F., Adams, R., & Evans, S. (2017). Pre-paradigmatic status of industrial sustainability: a systematic review. *International Journal of Operations and Production Management*, *37*(10), 1425–1450. https://doi.org/10.1108/IJOPM-02-2016-0058

Sterman, J. (2000). *Systems Thinking and Modeling for a Complex World*. McGraw-Hill Higher Education.

Susanty, A., Tjahjono, B., & Sulistyani, R. E. (2020). The Management of Operations An investigation into circular economy practices in the traditional wooden furniture industry. *Production Planning & Control*, *0*(0), 1–13. https://doi.org/10.1080/09537287.2019.1707322

Tachizawa, E. M., & Wong, C. Y. (2014). Towards a theory of multi-tier sustainable supply chains: A systematic literature review. *Supply Chain Management*, *19*, 643–653. https://doi.org/10.1108/SCM-02-2014-0070

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. *British Journal of Management*, *14*(3), 207–222. https://doi.org/10.1111/1467-8551.00375

Tura, N., Hanski, J., Ahola, T., Ståhle, M., Piiparinen, S., & Valkokari, P. (2019). Unlocking circular business: A framework of barriers and drivers. *Journal of Cleaner Production*, *212*, 90–98. https://doi.org/10.1016/j.jclepro.2018.11.202

Van De Ven, A. H. (2007). Engaged Scholarship A Guide for Organizational and Social Research. In *Published in the United States by Oxford University Press Inc., New York*. Oxford University Press Inc., New York.

van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3

van Loon, P., Delagarde, C., & Van Wassenhove, L. N. (2018a). The role of second-hand markets in circular business: a simple model for leasing versus selling consumer products. *International Journal of Production Research*, *56*(1–2), 960–973. https://doi.org/10.1080/00207543.2017.1398429

van Loon, P., Delagarde, C., & Van Wassenhove, L. N. (2018b). The role of second-hand markets in circular business: a simple model for leasing versus selling consumer products. *International Journal of Production Research*, *56*(1–2), 960–973. https://doi.org/10.1080/00207543.2017.1398429

van Loon, P., & Van Wassenhove, L. N. (2018). Assessing the economic and environmental impact of remanufacturing: a decision support tool for OEM suppliers. *International Journal of Production Research*, *56*(4), 1662–1674. https://doi.org/10.1080/00207543.2017.1367107

Veleva, V., & Bodkin, G. (2018). Corporate-entrepreneur collaborations to advance a circular economy. *Journal of Cleaner Production*, *188*, 20–37. https://doi.org/10.1016/j.jclepro.2018.03.196

Vlajic, J. V., Mijailovic, R., & Bogdanova, M. (2018). Creating loops with value recovery: empirical study of fresh food supply chains. *Production Planning and Control*, *29*(6), 522–

538. https://doi.org/10.1080/09537287.2018.1449264

Vonderembse, M. A., Uppal, M., Huang, S. H., & Dismukes, J. P. (2006). Designing supply chains: Towards theory development. *International Journal of Production Economics*, *100*(2), 223–238. https://doi.org/10.1016/j.ijpe.2004.11.014

Walker, S., Coleman, N., Hodgson, P., Collins, N., & Brimacombe, L. (2018). Evaluating the environmental dimension of material efficiency strategies relating to the circular economy. *Sustainability (Switzerland)*, *10*(3), 1–14. https://doi.org/10.3390/su10030666

Wang, Y., & Hazen, B. T. (2016). Consumer product knowledge and intention to purchase remanufactured products. *International Journal of Production Economics*, *181*, 460–469. https://doi.org/10.1016/j.ijpe.2015.08.031

Winkler, H. (2011). Closed-loop production systems-A sustainable supply chain approach. *CIRP Journal of Manufacturing Science and Technology*, *4*(3), 243–246. https://doi.org/10.1016/j.cirpj.2011.05.001

Winkler, H., & Kaluza, B. (2006). Sustainable supply chain networks - A new approach for effective waste management. *WIT Transactions on Ecology and the Environment*, *92*, 501–510. https://doi.org/10.2495/WM060521

Yang, M., Smart, P., Kumar, M., Jolly, M., & Evans, S. (2018). Product-service systems business models for circular supply chains. *Production Planning and Control*, *29*(6), 498–508. https://doi.org/10.1080/09537287.2018.1449247

Zeng, H., Chen, X., Xiao, X., & Zhou, Z. (2017). Institutional pressures, sustainable supply chain management, and circular economy capability: Empirical evidence from Chinese eco-industrial park firms. *Journal of Cleaner Production*, *155*(May 2014), 54–65. https://doi.org/10.1016/j.jclepro.2016.10.093

Zhu, Q., Geng, Y., & Lai, K. hung. (2011). Environmental supply chain cooperation and its effect on the circular economy practice-performance relationship among Chinese manufacturers. *Journal of Industrial Ecology*, *15*(3), 405–419. https://doi.org/10.1111/j.1530-9290.2011.00329.x

Zhu, Q., Sarkis, J., & Lai, K. hung. (2015). Reprint of "Supply chain-based barriers for truck-engine remanufacturing in China." *Transportation Research Part E: Logistics and Transportation Review*, *74*, 94–108. https://doi.org/10.1016/j.tre.2014.12.004

APPENDIX

APPENDIX 1- Article 1 - Searching Details

Date	Keyword with String	Database	Search Field	Filter Criteria	Step 1	Step 2	Step 3	Step 4	Step 4.1
					Search	Remove Duplicates	Each Document's Abstract and Title was Manually Reviewed	Not Available Documents (e.g. PayWall)	Each Document Full-Text Review was conducted
27-Mar-21	" Supply chain Management " AND "Circular Economy"	Scopus	TITLE-ABS-KEY	Language:English - Types: Article and Review - Source Journals -until Dec, 2019	88	76	55	3	52
		Web of Science	TITLE-ABS-KEY		94	80	61	0	61
		Both	TITLE-ABS-KEY				27	0	27
				Sub total	182	156	143	3	140

Date	Keyword with String	Database	Search Field	Filter Criteria	Step 1	Step 2	Step 3	Step 4	Step 4.1
27-Mar-21	" Supply chain Management " AND "Circular Economy" AND "Strategies" AND "Types" AND Tactics"	Scopus	ALL	Language:English - Types: Article and Review - Source Journals	57				
27-Mar-21		Web of Science	ALL		64				
				Sub total	121	0	0	0	0

APPENDIX 2 – Article 1 Codebook.

Main subject	Categories - Theme	Codes	Fq.	Documents (Sample)
Circular Economy	CE - Process Cycle	Supply chain loops; reduce; reuse; recycle; remanufacturing; refurbishing	48	(Park, Sarkis and Wu, 2010; O'Connor *et al.*, 2016; Wang and Hazen, 2016; Jensen and Remmen, 2017; Kirchherr, Reike and Hekkert, 2017; Franco, 2017; Marchi and Zanoni, 2017; Masi, Day and Godsell, 2017; Mendoza *et al.*, 2017; Murray, Skene and Haynes, 2017; Nasir *et al.*, 2017; Halstenberg, Lindow and Stark, 2017; Botezat *et al.*, 2018; Braz *et al.*, 2018; Irani and Sharif, 2018; Islam and Huda, 2018; Jain, Jain and Metri, 2018; Kalmykova, Sadagopan and Rosado, 2018; Kalverkamp, 2018; Kazancoglu, Kazancoglu and Sagnak, 2018; Leising, Quist and Bocken, 2018; Lopes de Sousa Jabbour *et al.*, 2018; Masi *et al.*, 2017, 2018; Mew, Steiner and Geissler, 2018; Muñoz-Torres *et al.*, 2018; Gaustad *et al.*, 2018; van Loon, Delagarde and Van Wassenhove, 2018; Veleva and Bodkin, 2018; Walker *et al.*, 2018; Geissdoerfer *et al.*, 2018; Yang *et al.*, 2018; Govindan and Hasanagic, 2018; Hahladakis and Iacovidou, 2018; Homrich *et al.*, 2018; Huybrechts *et al.*, 2018; Kalverkamp and Young, 2019; Piezer *et al.*, 2019; Pishchulov *et al.*, 2019; Rebs, Brandenburg and Seuring, 2019; Salim *et al.*, 2019; Tura *et al.*, 2019); (Batista, Bourlakis, Smart, et al., 2018, 2018; Batista, Gong, et al., 2018; Doni et al., 2019; Genovese et al., 2017; Jain et al., 2018
	CE Principles, Sustainability and Sustainable Development	"An industrial system that is restorative or regenerative by intention and design; to maximize the circulation between the points of use and production', where "products, components and materials are kept in the market at their highest utility and value in the long term"	23	(Ghisellini, Cialani and Ulgiati, 2016; Kirchherr, Reike and Hekkert, 2017; Mulrow *et al.*, 2017; Murray, Skene and Haynes, 2017; Nasir *et al.*, 2017; Smart *et al.*, 2017; Genovese *et al.*, 2017; Halstenberg, Lindow and Stark, 2017; Husgafvel *et al.*, 2017; Batista, Bourlakis, Liu, *et al.*, 2018; Batista, Gong, *et al.*, 2018; Larsen *et al.*, 2018; Merli, Preziosi and Acampora, 2018; Mishra, Hopkinson and Tidridge, 2018; Moktadir *et al.*, 2018; Perey *et al.*, 2018; Bernon, Tjahjono and Ripanti, 2018; Braun *et al.*, 2018; Fonseca *et al.*, 2018; Jiménez-Rivero and García-Navarro, 2018; Schallehn *et al.*, 2019; Ghani *et al.*, 2017)
		CE roots in different disciplines	3	(R De Angelis et al., 2018; Merli et al., 2018; Vlajic et al., 2018)
	CE Implementation Levels	The CE requires efforts at different levels (micro, meso and macro) for effective implementation	8	(Haneef et al., 2017; B. Liu et al., 2018; Maaß & Grundmann, 2018; Mangla et al., 2018; Masi et al., 2017, 2018; Vlajic et al., 2018; Yang et al., 2018)

Continue

Main subject	Categories - Theme	Codes	Fq.	Documents (Sample)
Supply Chain Management	Sustainable Supply Chains	Integration of the TBL perspective; Efficiently managing material and information flows	13	(Batista, Bourlakis, Smart, et al., 2018; Batista, Gong, et al., 2018; Doni et al., 2019; Genovese et al., 2017; Jain et al., 2018; Liu et al., 2018; Alejandro Martín-Gómez et al., 2019; Moktadir et al., 2018; Muñoz-Torres et al., 2018; Papetti et al., 2019; Rebs et al., 2019; Sarkis et al., 2011; Scavarda et al., 2019; Yadav et al., 2020),
	Closed-Loop, Open-Loop and Reverse Supply Chains	SC loops; value recovery; remanufacturing; return; recycle	32	(Batista, Bourlakis, Smart, et al., 2018; Botezat et al., 2018; Braz et al., 2018; Fonseca et al., 2018; Hahladakis & Iacovidou, 2018; Haneef et al., 2017; Husgafvel et al., 2017; Jain et al., 2018; Kalaitzi et al., 2018; Kalverkamp, 2018; Kalverkamp & Young, 2019; Kirchherr et al., 2017; Larsen et al., 2018; Leising et al., 2018; B. Liu et al., 2018; Marchi & Zanoni, 2017; Mew et al., 2018; Mishra et al., 2018; Muñoz-Torres et al., 2018; O'Connor et al., 2016; Park et al., 2010; Pishchulov et al., 2019; Smart et al., 2017; Tura et al., 2019; van Loon & Van Wassenhove, 2018; Vlajic et al., 2018; Walker et al., 2018; Wang & Hazen, 2016; Winkler, 2011; Yang et al., 2018; Zeng et al., 2017)
	Circular Supply Chains	Circular flows and an expansion of CLSCs	7	(Batista, Bourlakis, Smart, et al., 2018; Batista, Gong, et al., 2018; Jain et al., 2018; Masi et al., 2018; Perey et al., 2018; Vlajic et al., 2018 Mew et al., 2018)
	Green Supply Chains	Evaluation of the environmental impacts on SC operations Integration of the environmental dimension in SCs	6	(Batista, Bourlakis, Smart, et al., 2018; Haneef et al., 2017; Jain et al., 2018; B. Liu et al., 2018; Masi et al., 2018; Papetti et al., 2019)

APPENDIX 3 – Article 1 -Supply chain management strategies and tactics for CE across industries, countries, SC types and dimensions

Item	Tactics	Strategies	SC type	SC Dimension			Industry	Country	Source
				Level	**Process**	**Sust.**			
1	Manage consumers to return their products to manufacturers.	Collaboration Management	CLSC	Micro	Recovery	E, E.	Automotive	Germany	(van Loon & Van Wassenhove, 2018)
2	Involve the consumer to know remanufactured quality.	Collaboration Management	CLSC	Micro	Remanufacture	E, E.	Automotive	China	(Wang & Hazen, 2016)
3	Manage a deep and committed customer participation.	Collaboration Management	CLSC OLSC	Micro	Recovery	E, E.	Coffee	Brazil	(Abuabara et al., 2019)
4	Intearct with government to provide incentives.	Collaboration Management	CLSC	Meso	Recovery	E, E.	Construction	Netherlands	(Schraven et al., 2019)
5	Create cohesion among changes, since both are otherwise lacking.	Collaboration Management	CLSC	Meso	Recovery	E, E.	Construction	Netherlands	(Schraven et al., 2019)
6	The adoption of new business models based on the use of “closed” cycles and cooperation throughout the value chain and on eco-design, eco-innovation.	Collaboration Management	CLSC	Micro	Recovery	E, E.	Cross industry	Portugal	(Fonseca et al., 2018)
7	Working with consumers to design furniture products that are easy to 3R.	Collaboration Management	CLSC	Micro	Recovery	E, E.	Furniture	Indonesia	(Susanty et al., 2020)
8	Manage the cooperation between organizations’ R&D.	Collaboration Management	CSC	Micro	Recycling and Reuse	E, E.	Cross industry	Australia	(Perey et al., 2018)
9	Manage the collaboration and sharing ideas in the buyer-supplier’ relationship.	Collaboration Management	CSC	Micro	Recycling and Reuse	E, E.	Cross industry	Australia	(Perey et al., 2018)
10	Manage a low number of suppliers by intensive relational mechanisms.	Collaboration Management	RSC	Micro	Recycling	E, E..	Automotive and Aluminum	UK	(Kalaitzi et al., 2018)
11	Manage suppliers long term relationships to enhance product recovery.	Collaboration Management	RSC	Micro	Recovery	E, E.	Cross Industry	Finland	(Tura et al., 2019)
12	Manage suppliers long term relationships to enhance product recovery.	Collaboration Management	RSC	Micro	Reuse and waste repurposing	E, E.	Cross Industry	USA	(Veleva & Bodkin, 2018)
13	EOL’ products are taken out of the market and recycled.	Competitive Adv. Mag.	CLSC	Micro	Recovery	E, E.	Automotive	Germany	(van Loon & Van Wassenhove, 2018)
14	Using the return process as value creator to distributors.	Competitive Adv. Mag.	CLSC	Micro	Recycling	E, E.	Cross Industry	Europe	(Larsen et al., 2018)
15	Collection systems requires a combination of incentives to return goods, plus convenience and the ability to transfer to the next stage of recovery cost effectively.	Competitive Adv. Mag.	CLSC	Micro	Reuse, Recycling and Recovery	E, E.	Retail	UK	(Mishra et al., 2018)

Continue

16	Outsource energy supply.	Competitive Adv. Mag.	CSC	Micro	Disassembly and reuse	E, E, S	Construction	Netherlands	(Leising et al., 2018)
17	Reduce dependency of imports commodity-priced materials with high carbon emission and turned into heavy investments in new technology to produce with high percentage of recycled material.	Competitive Adv. Mag.	CSC	Micro	Recycling, Remanufacture and sharing	E, E.	Cross industry	UK and Brazil	(Geissdoerfer et al., 2018)
18	Developing new suppliers to a new role in SC.	Competitive Adv. Mag.	CSC	Micro	Recycling and Reuse	E, E.	Cross industry	Australia	(Perey et al., 2018)
19	Manage suppliers upstream to develop basic materials and buyers downstream to develop circular collections.	Competitive Adv. Mag.	CSC	Micro	Recycling	E, E.	Textile	Switzerland, Germany and Austria.	(Franco, 2017)
20	Adding third partiers outside of CLSC	Competitive Adv. Mag.	OLSC	Macro	Remanufacture	E, E.	Automotive	Chile, Japan Europe and USA	(Kalverkamp & Young, 2019)
21	Planning, execution and maintaining actions to segregate the post consumption materials to define the best way to recycle them.	Competitive Adv. Mag.	RSC	Micro	Recycling	E, E.	Healthcare	Brazil	(Scavarda et al., 2019)
22	Aligning reverse logistics with product portfolio.	Competitive Adv. Mag.	RSC	Meso	Retail Reverse Logistics	E, E.	Retail	UK	(Bernon et al., 2018)
23	Lead the shape of circular supply chain, creating and supporting supplier's links to implement the product recovery.	System Effectiveness	CSC	Macro	Recycling	E, E, S	Food packaging	Brazil and China	(Batista, Gong, et al., 2018)
24	Manage suppliers to supplement chemicals needed to recycle the post consumption products.	System Effectiveness	CSC	Macro	Recycling	E, E, S	Food packaging	Brazil and China	(Batista, Gong, et al., 2018)
25	Manage the synergy between the SSC members through product recovery.	System Effectiveness	AISSC	Micro	Recovery	E, E.	Urban Furniture	Spain	(Martín-Gómez et al., 2019)
26	Manage the supplier's relationship in a PSS model, selling or leasing products and providing technical services.	System Effectiveness	CLSC	Micro	Recycle, Recovery And Reuse	E, E.	Air	China	(Yang et al., 2018)
27	Products cannot be leased to consumers more than the maximum number of lives.	System Effectiveness	CLSC	Micro	Recovery	E, E.	Automotive	Germany	(van Loon & Van Wassenhove, 2018)
28	Products with inferior quality are recycled, they cannot be refurbished.	System Effectiveness	CLSC	Micro	Recovery	E, E.	Automotive	Germany	(van Loon & Van Wassenhove, 2018)
29	Integrate the environment and economic performance in the corporate assessment	System Effectiveness	CLSC	Micro	Recovery	E, E, S	Biorefinery	Finland	(Husgafvel et al., 2017)
30	Manage the final customer donations to recovery post consumption products.	System Effectiveness	CLSC	Macro	Reuse, Remanufacture and Recycling	E, E, S	Food	UK	(Vlajic et al., 2018)
31	Perform GW traceability, from source to final destination.	System Effectiveness	CLSC	Micro	Recycling	E, E.	Gypsum	Europe	(Jiménez-Rivero et al, 2018)
32	Increase the leasing time for any kind of product.	System Effectiveness	CLSC	Micro	Refurbish	E, E.	OEM baby stroller	Europe	(van Loon et al., 2018)

Continue									
33	Integrate product design, business model innovation and reverse network.	System Effectiveness	CLSC	Micro	Reuse, Recycling and Recovery	E, E.	Retail	UK	(Mishra et al., 2018)
34	Use ENA instead of LCA to measure the environmental impacts	System Effectiveness	CLSC	Micro	Recovery	E, E.	Urban Agriculture	Spain	(Piezer et al., 2019)
35	Manage the optimization of recovery waste and byproducts of suppliers.	System Effectiveness	CSC	Micro	Recycling	E, E.	Automotive	Germany	(Braun et al., 2018)
36	Negotiate to pay for the service of light instead of buy lamps.	System Effectiveness	CSC	Micro	Disassembly and reuse	E, E, S	Construction	Netherlands	(Leising et al., 2018)
37	Develop alternative solutions for ownership in which suppliers own the materials instead of the buyers.	System Effectiveness	CSC	Micro	Disassembly and reuse	E, E, S	Construction	Netherlands	(Leising et al., 2018)
38	Manage the secondary resources from reprocessing to replace virgin raw materials.	System Effectiveness	CSC	Micro	Recovery	E, E.	Cross industry	UK	(Genovese et al., 2017)
39	Changing the type of collection vehicle from a small to a bigger reducing the frequency of collection.	System Effectiveness	CSC	Micro	Recycling	E, E.	Textile and construction	UK	(Nasir et al., 2017)
40	Manage the resources scarcity replacing virgin raw material by recycled.	System Effectiveness	RSC	Micro	Recycling	E, E.	Automotive and Aluminum	UK	(Kalaitzi et al., 2018)
41	Use best availability alternative (BAT) to manage the inspection and selection of input recovered materials	System Effectiveness	RSC	Micro	Recovery	E, E.	Cross Industry	Europe	(Huybrechts et al., 2018)
42	Reducing the transportation cost and environmental impact adding the supplier in an EIP.	System Effectiveness	RSC	Meso	Recycling	E, E.	IT and Electronics	China	(Park et al., 2010)
43	Implement traceability and eco-sustainability web-based platform.	System Effectiveness	SSCM	Meso	Recovery	E, E.	Fashion	Italy	(Papetti et al., 2019)

APPENDIX 4 – Article 1 - Supply chain management measurements across industries, countries and SC types and dimensions.

Measurement	Strategies	SC type	SC Dimension			Industry	Country	Source
			Level	Process	**Sust.**			
Remains challenge due to SC complexity, non-standardized data and the life cycle assessment method chosen	System Effectiveness	CSC	Micro	Recycling	E and E.	Textile and construction	UK	(Nasir et al., 2017)
NRS measures like price fluctuation, water and minerals consumption.	System Effectiveness	RSC	Micro	Recycling	E and E.	Automotive and Aluminum	UK	(Kalaitzi et al., 2018)
Measuring the reintroduced material in SC	System Effectiveness	CSC	Micro	Recycling	E and E.	Automotive	Germany	(Braun et al., 2018)
Using BAT to define the most effective measures	System Effectiveness	RSC	Micro	Recovery	E and E.	Cross Industry	Europe	(Huybrechts et al., 2018)
Measuring the recycling plastic and the discarded waste, as recommendation.	Collaboration management.	RSC	Micro	Recycling	E and E.	Healthcare	Brazil	(Scavarda et al., 2019)
Integrate environmental, social and economic indicators	System Effectiveness	CLSC	Micro	Recovery	E, E and S.	Biorefinery	Finland	(Husgafvel et al., 2017)
One of the main challenges is the lack of data and indicators to measure the impacts.	Collaboration management.	RSC	Micro	Reuse and waste reporpusing	E. and E.	Cross Industry	USA	(Veleva & Bodkin, 2018)
Value creation is not easy to measure.	Collaboration management.	CLSC	Micro	Reuse, Recycling and Recovery	E., And E.	Retail	UK	(Mishra et al., 2018)
The cases recognized the importance of performance measurement but none offered any experience of their use.	System Effectiveness	RSC	Meso	Retail Reverse Logistics	E., And E.	Retail	UK	(Bernon et al., 2018)
Necessary develop additional value indicators.	Collaboration management.	CLSC	Meso	Recovery	E. And E.	Construction	Netherlands	(Schraven et al., 2019)
Internal environmental management, eco-design and corporate asset management and recovery.	Collaboration management.	SSC	Micro	Recovery	E. And E.	Cross Industry	China	(Zhu et al., 2011)

Continue

Measurement	Strategies	SC type	SC Dimension			Industry	Country	Source
			Level	Process	**Sust.**			
Maybe the most important barrier is the lack of, standardized, quantitative, clear measurement and objectives for assessing the performance of a circular sustainable development.	Collaboration management.	GSC	Micro	Recovery	E. and E.	Cross Industry	Across the world	(Masi et al., 2018)
The major limitations is the exclusion of financial and profit performance indicators.	Collaboration management.	GSC	Micro	Recovery	E. and E.	Cross Industry	Romania	(Botezat et al., 2018)
The preponderance of economic indicators in decision making could be a barrier to CE solutions.	Collaboration Management	RSC	Micro	Recovery	E. and E.	Cross Industry	Finland	(Tura et al., 2019)
Few studies have investigated CEC as an indicator of firm performance for sustainable supply chains, as our sample.	Collaboration management.	GSC	Meso	Recovery	E. and E.	EIP	China	(Zeng et al., 2017)
A web-based platform to measure SC impact.	Collaboration management	SSCM	Meso	Recovery	E.and E.	Fashion	Italy	(Papetti et al., 2019)
Input output Analysis (IO) and Ecological network analysis (ENA) to replace LCA.	System Effectiveness	CLSC	Micro	Recovery	E.and E.	Urban Agriculture	Spain	(Piezer et al., 2019)
Lack of technical standards for remanufactured products	System Effectiveness	CLSC	Micro	Remanufacture	E.and E.	Automotive	China	(Zhu et al., 2015)
Measure to total cost of ownership (TCO) and profit.	System Effectiveness	CLSC	Micro	Refurbish	E.and E.	OEM baby stroller	Europe	(van Loon et al., 2018)

APPENDIX 5- Article 2 - The interview protocols.

Company Date

Name Position

Introduction

Explain context of the research and clarify the interview will focus on the specific relationships within the supply chain

Remind interviewer that the information will be presented as anonymous

Part 1- General respondent information:

1.1 Tell us about your role and your company products and operations?

1.2 Who are your main customers and suppliers?

1.3 What products and byproducts are recovered/?

1.4 Who are your competitors in the market?

Part 2 - Recovered operations information:

2.1 Can you explain how is the collect process to get the post consumption' products or byproducts?

2.2 Can you explain how is the relationship between your company and the post consumption' products or byproducts suppliers?

2.3 Can you explain how is the relationship between your company and your customers regarding the post consumption' products or byproducts?

2.4 Can you explain/mapping how is the whole supply chain for this operation and provide BOM circular material content over time?

Part 3 - Policy and management systems information:

3.1 What management systems certifications related these operations you have?

3.2 Can you explain the management systems certifications contribution to these operations management?

3.3 Can you explain what sustainability report or index you have adhered, and why?

3.4 Can you provide the official regulations you follow?

3.5 Can you explain what are the main factors to select a supplier?

Part 4 - The value-added information:

4.1 Can you provide examples of positive experiences with post consumption and byproducts suppliers?

4.2 Can you provide examples of negative experiences with post consumption and byproducts suppliers?

4.3 Can you explain the main driver to start this operation?

4.4 Can you explain the main barrier to start this operation?

4.5 Can you explain the success factors to sustain this operation?

4.6 Can you explain the challenges to sustain this operation?

4.7 Can you explain the main activity to value creation?

4.8 Can you explain the main activity to value capture?

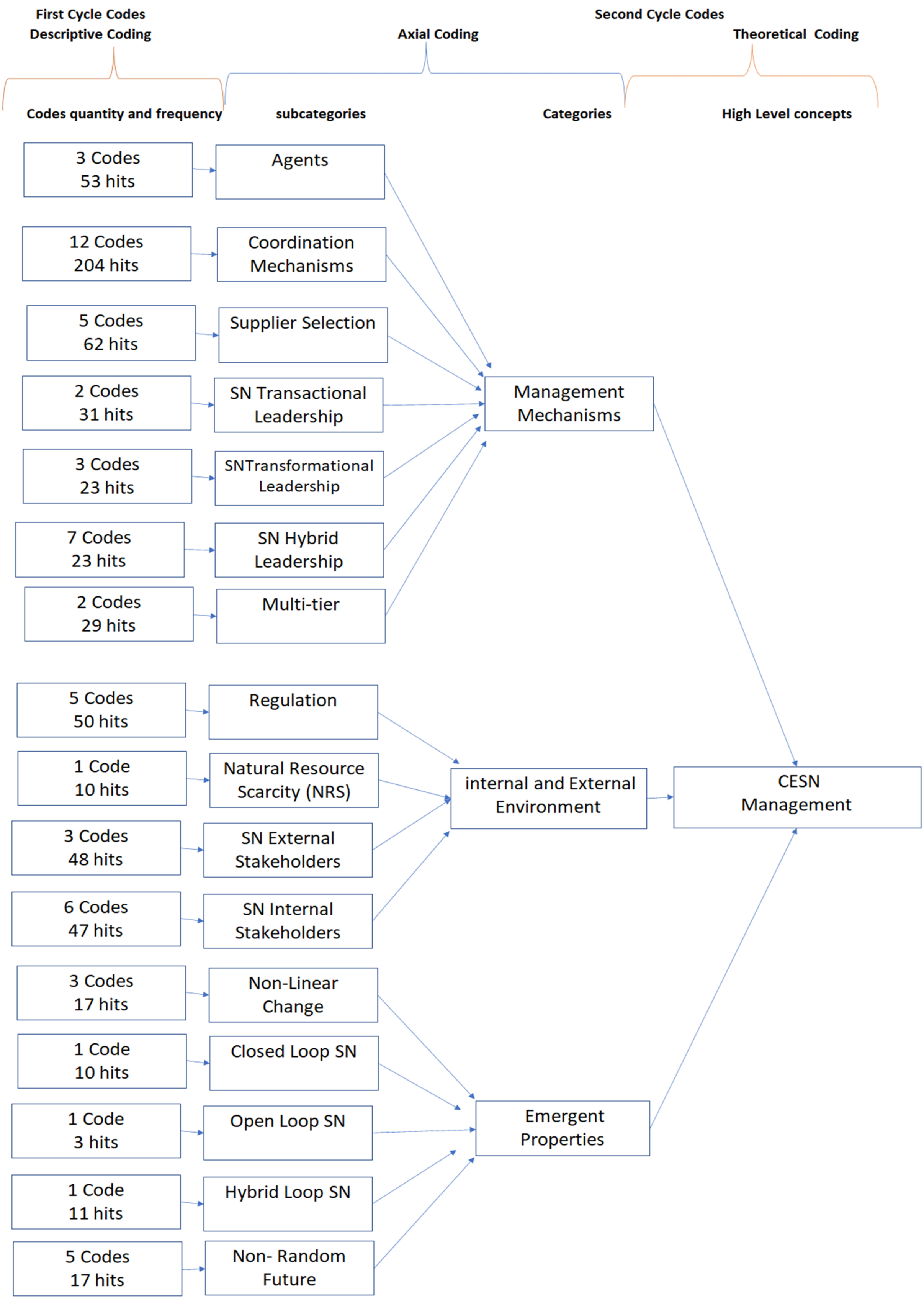
4.9 Can you explain how is the innovation management in this SC?

4.10 Can you explain what could be improved in this operation to add more value?

Any questions you'd like to ask us about the research?

Thank you!

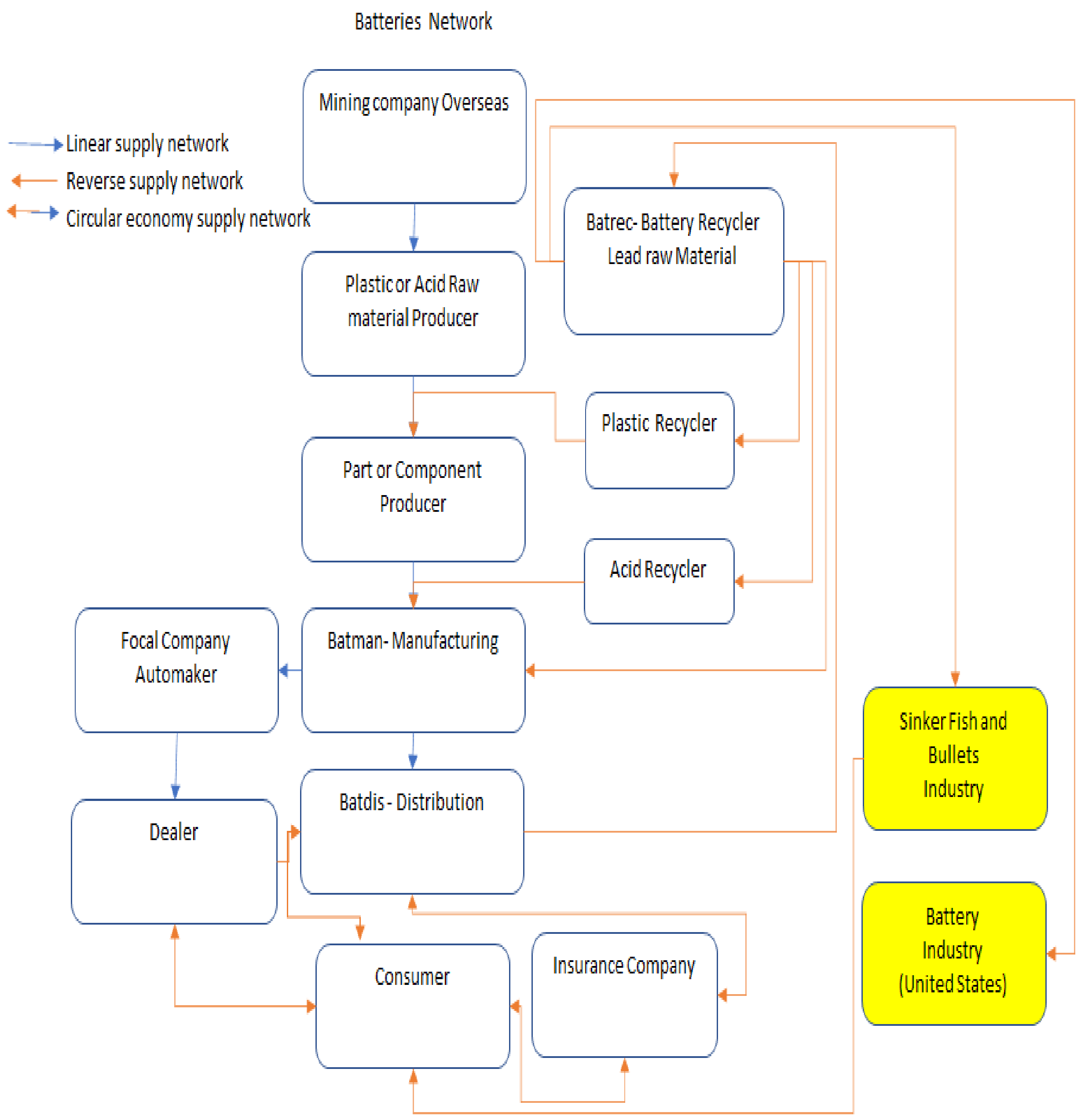
APPENDIX 6- Article 2- Coding Analysis Tree.



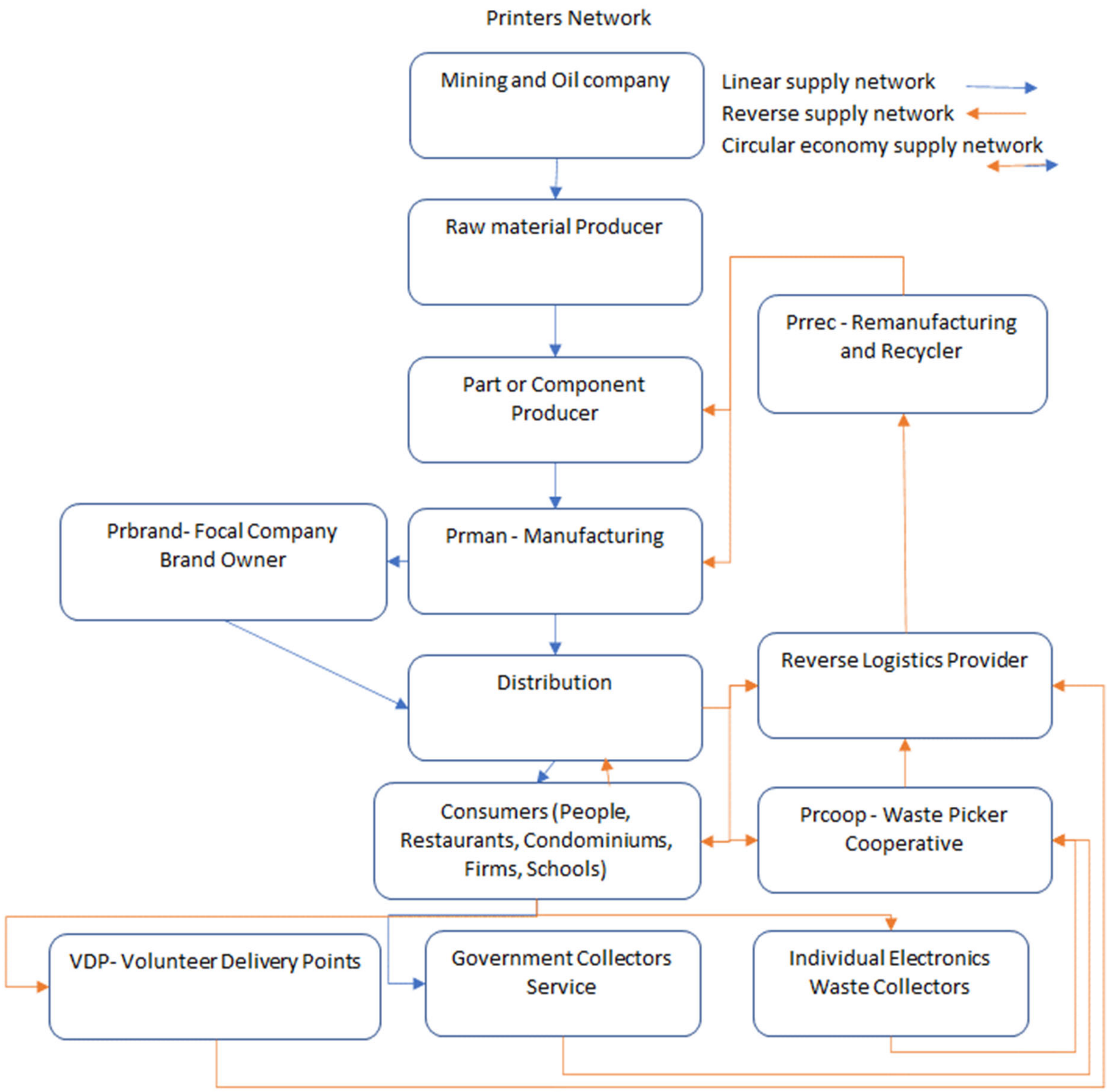
APPENDIX 7- Article 2 -Complete Coding Analysis.

codes	Theoretical Background	subcategories
Agent Role and Position	Agents share interpretive and behavioral rules, attributes at different levels of scale, degrees of freedom (Choi et al 2001; Nair and Tsoshas, 2019).	Agents
Agents Reverse Schemata		
Organizational structure change		
Manage recycling tech and process development	Act of managing interdependencies between activities performed to achieve a goal for value creation (Simatupang et al., 2002) The relations through which key actors create, maintain, and potentially transform network activities. (Gosling et al, 2016) (Raynolds, 2004).	Coordination Mechanisms
Manage value capture		
Combine product and byproduct recyclin w renewable		
Combine product and byproduct recycling		
Manage value creation		
Management and coordination mechanisms		
Operations improvement		
Overcome the lack of gov. incentives		
Reduce supply to competitors		
SC Management capability development		
Sustainability measurements management		
supply management strategy to change raw material	Focal companies work with Tier 1 and Tier 2 suppliers,in three types of multi-tier supply chain structures: open triad, transitional triad and closed triad, the forms of triad are linked with management resources (Mena et al. (2013). In a multi-tier supply chain, focal companies can apply four approaches on their lower tier suppliers: “Direct”, “Indirect” (via Tier 1 suppliers), “Work with third parties” and “Don’t bother” and "a combined and dynamic manner of them" (Jia et al. 2019).	SN Multi-tier Management
multi tier supplier development		
Improve the sustainb measurements	Transformational and transactional combined =hybrid leadership, they demonstrate contingent reward, is capable of greater influence, creator of the vision and establishes a relationship with other supply chain organizations (Jia et al. 2019).	SN Hybrid leadership
Manage collect process		
Raw material producer behavior changing		
Self initiative to develop new rm solution		
Sustainable entrepreneuship		
Manage an agent as supplier and costumer at same time		
Supplier and customer selection are connected		
Supplier competitivity assessment	The supply chain leader is characterized as the organization that demonstrates higher levels of the four elements of leadership in relation to other member organizations (i.e., the organization capable of greater influence, readily identifiable by its behaviours, creator of the vision, and that establishes a relationship with other supply chain organizations.The transactional leadership demonstrates contingent reward and management-by-exception . Contingent reward indicates that followers will be rewarded on their expected performance and be punished if a target is not achieved; active management by exception asserts that leaders point out followers' mistakes and take actions when needed(Jia et al., 2019).	SN Transactional leadership
Supplier self assessment		
Increase competitiveness recycled versus virgin	Transformational leadership exhibits inspiration, intellectual stimulation and individualized consideration more frequently. Transformational leaders focus on developing longterm relationships and do not seek to control followers' behaviour through the use of contingent rewards but manage in a more holistic way . Inspiration behaviour as a mission and vision of a desirable future and the definition of the path to achieve the vision; intellectual stimulation indicates leaders calling on followers to be more innovative and creative to provide better solutions to problems; individualized consideration means a leader's ability to recognize each individual follower's unique skills and development needs (Jia et al.,2019).	SN Transformational leadership
Lack of technology to start the CESC		
Monitoring agents are not in the SC like competitors		
Commodity strategy	This is one of the most fundamental, important and critical decision that a buyer makes. Mainly due to the increased levels of complexity involved in considering various supplier performance and relationship factors. Such as quality, process capability, cost, financial and regulation issues (Sarkis and Talluri, 2002).	Supplier Selection
Incentive offer to improve post con product return		
Mixed commodity and customer strategy		
Post consumption and byproducts		
Post Consumption Products and Materials		
Lack of a company to recover byproduct	In a non-linear system, large changes in input may lead to small changes in outcome, and small changes in input may lead to large changes in outcomes (Choi, et al, 2001). The most relevant nonlinear dynamics are those that emerge as system properties from the underlying interactions, not those coded into the initial specifications (Nair and Tsoshas, 2019). Complex systems change inputs to outputs in a nonlinear way because their components interact with one another via a web of feedback loops (Anderson, 1999)	Non-Linear change
Lack of brand owner and final consumer involvem		
Lack of competitiveness of recycled versus virgin		
Company Corporate strategy	Small changes may lead to drastically different future paths; however, the same characteristic pattern of behavior emerges despite the change. One finds that systems will tend to be involved in certain prototypical ways and, thus, our predictive capacity, although limited to the exact prediction at a future point in time, can benefit from the knowledge of these patterns.Common patterns of behavior are observable (Choi et al,2001)	Non-Random Future
Cooperative business model		
current supplier transfer to new one		
Operations spin off		
Product ecodesign		
Closed Loop	The SC type is defined regarding the characteristics, such as the type and level of SC integration, the type of process, (Lejeune and Yakova, 2005) the type of issues faced (Vonderembse et al., 2006) and structure (de Kok et al., 2018).	SC Config. Closed
Hybrid		SC Config. Hybrid
Open Loop		SC Config. Open Loop
NRS as factor to start a CESN	Natural resource scarcity	NRS
Lack of fiscal documentation	Regulation regarding reversesupply chains in each city, state, region or country	Regulation
regulation and context		
Regulation complexity should be reduced		
Regulation incentive and brand owner involvement		
Regulation to reduce illegal importation copyright issue		
Agents that influence the SN	Stakeholders that do not belong to the SN in terms of materials, products or byproducts flow.	SN External Stakeholders
Increase society and government involvement		
People cultural and behavioural differences		
Lack of quality	Stakeholders that belong to the SN in terms of the flow of materials, products or by products.	SN Internal Stakeholders
Lack of recyclers		
Lack of supply due to high variability in quantity		
Main agents in the SN		
Post Consumption Product low volume return		
Preferred supplier adding list		

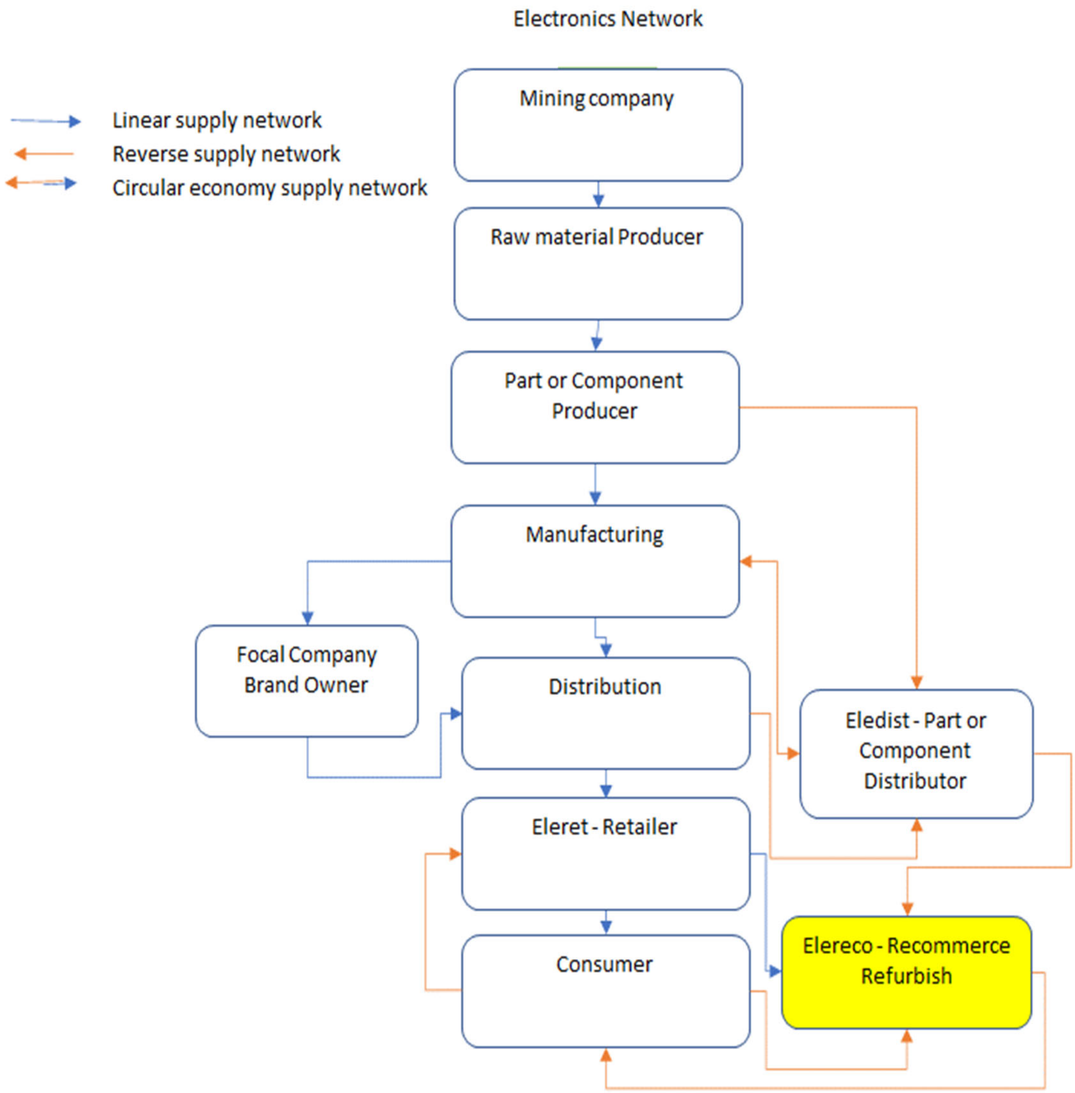
APPENDIX 8 – Article 2 – Case 1 - Batteries Network Structure



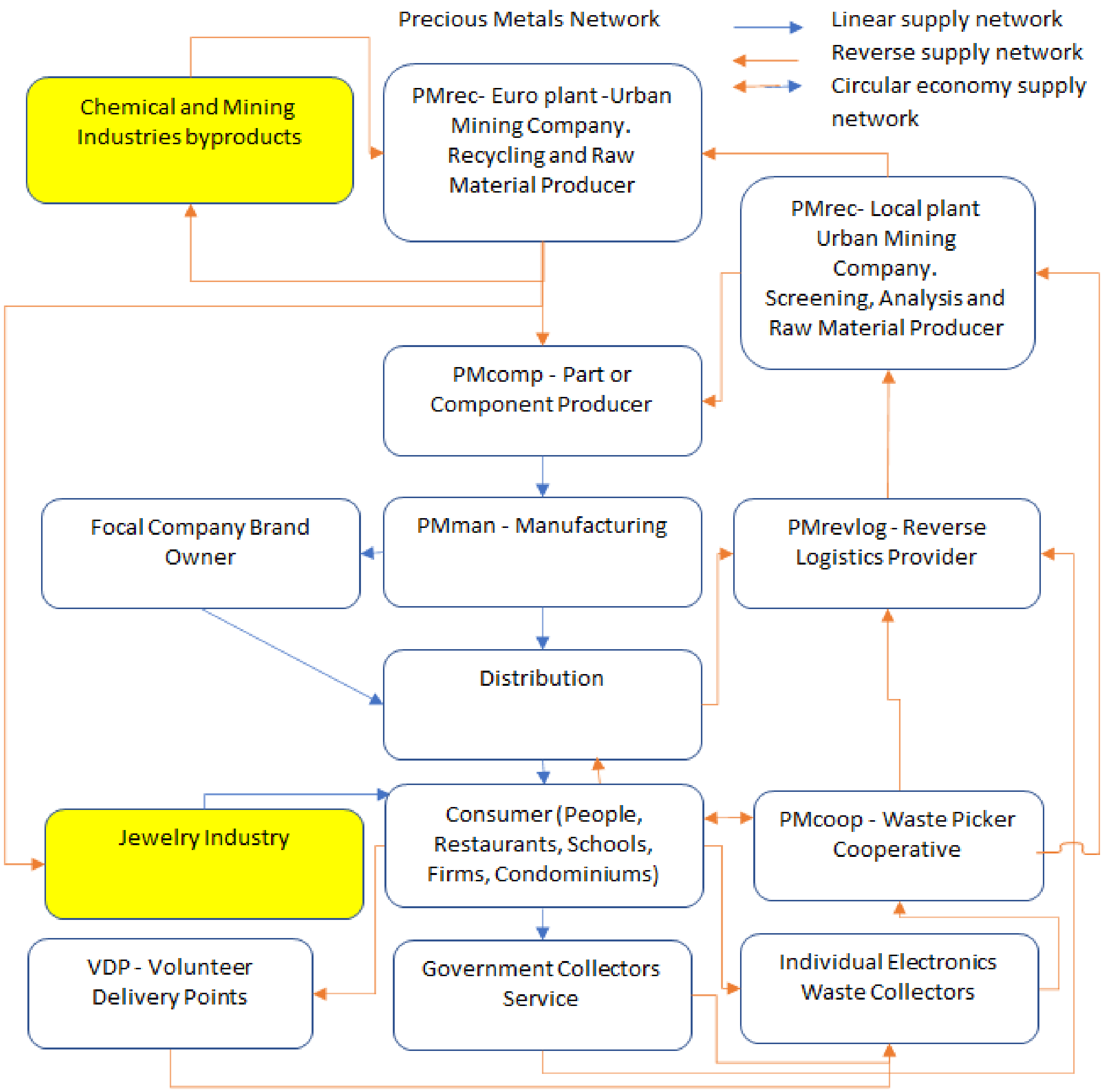
APPENDIX 9 – Article 2 - Case 2 - Printers Network Structure



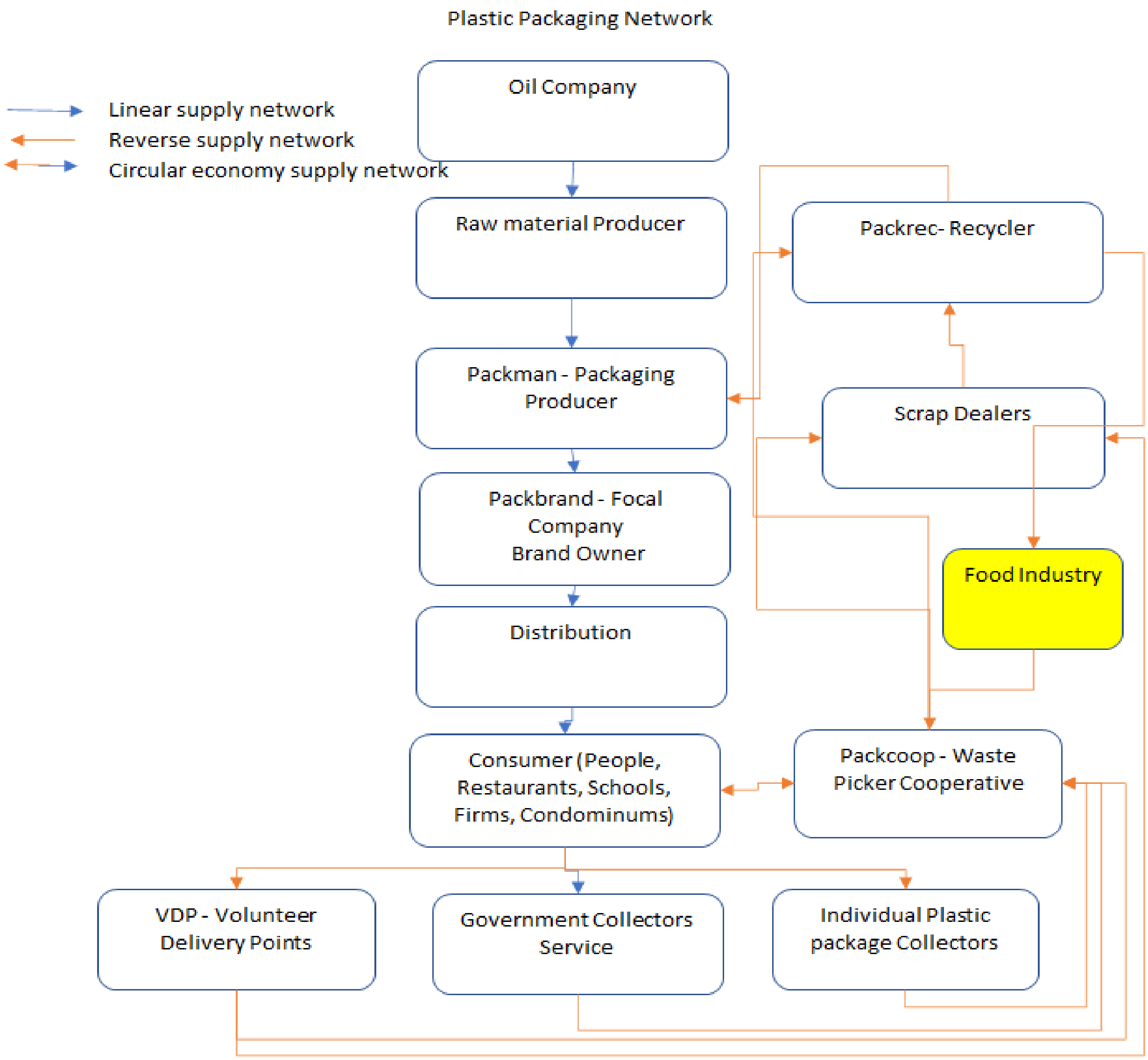
APPENDIX 10 – Article 2- Case 3- Electronics Network Structure



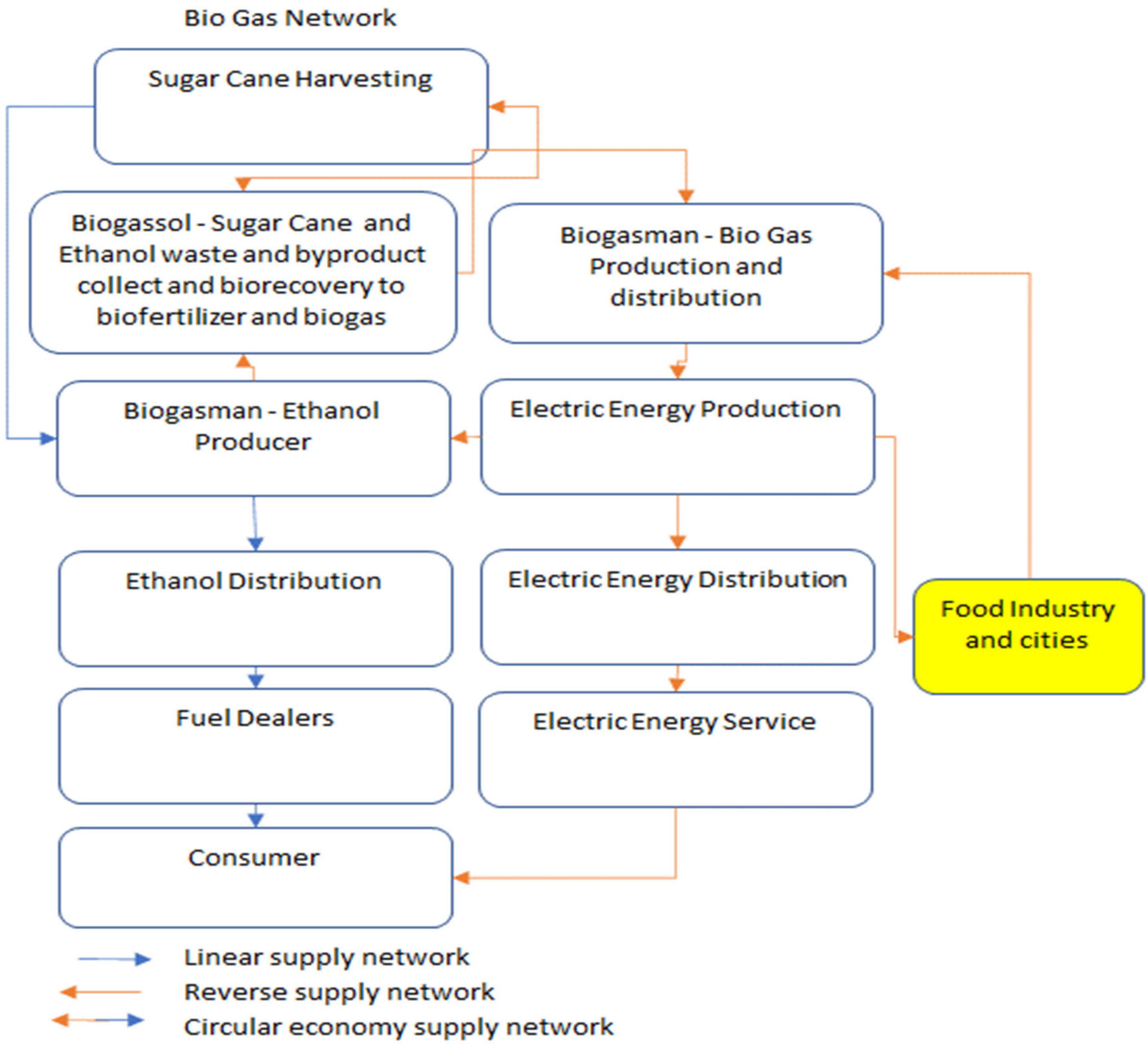
APPENDIX 11 – Article 2 - Case 4 – Precious Metals Network Structure



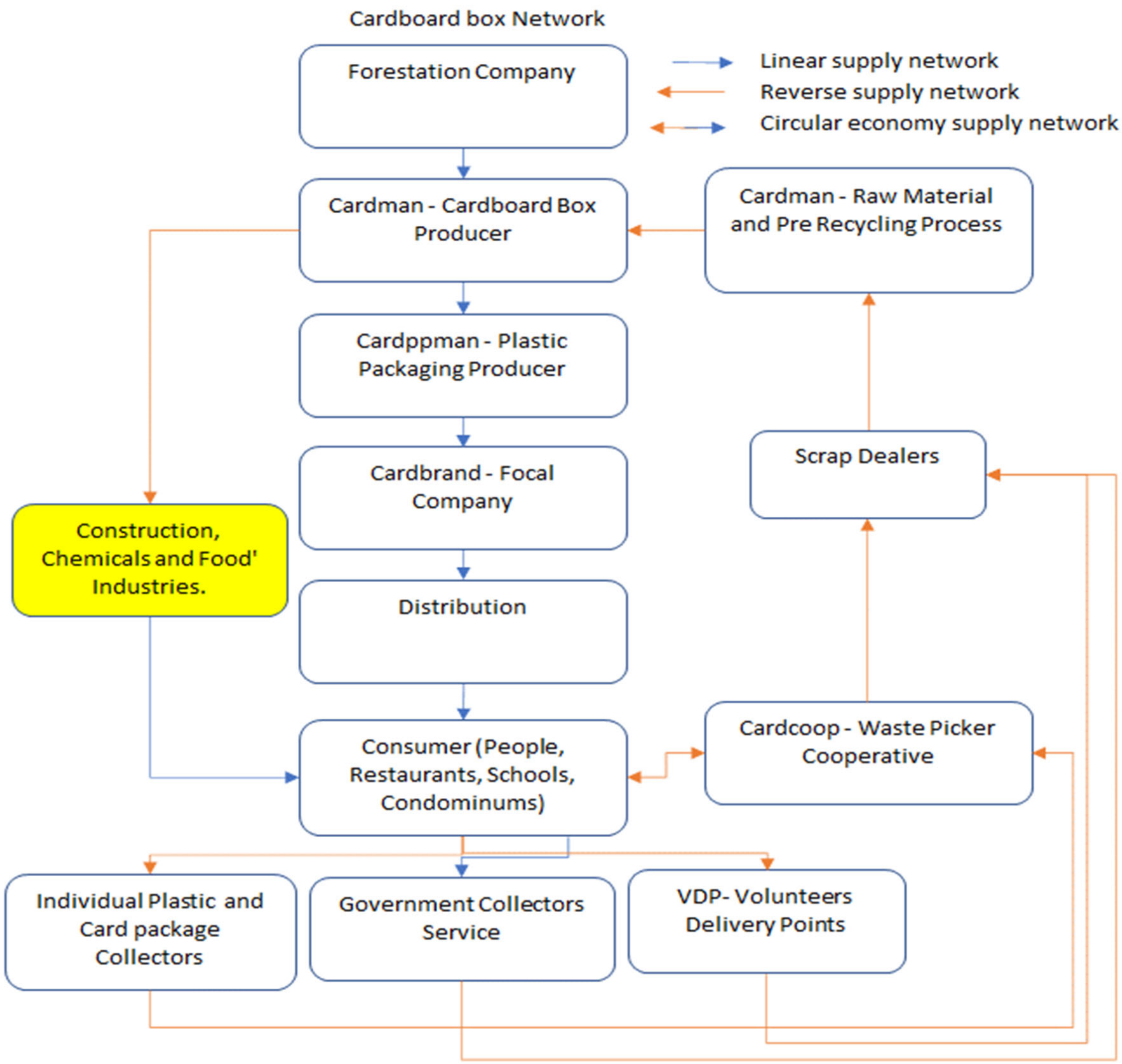
APPENDIX 12 – Article 2 - Case 5- Plastic Packaging Network Structure



APPENDIX 13 – Article 2 Case 6 – Bioproducts Network Structure



APPENDIX 14 – Article 2 - Case 7 – Cardboard Box Network Structure



APPENDIX 15 – Article 2 - Management mechanisms, emergent properties, internal and external environment across the seven cases.

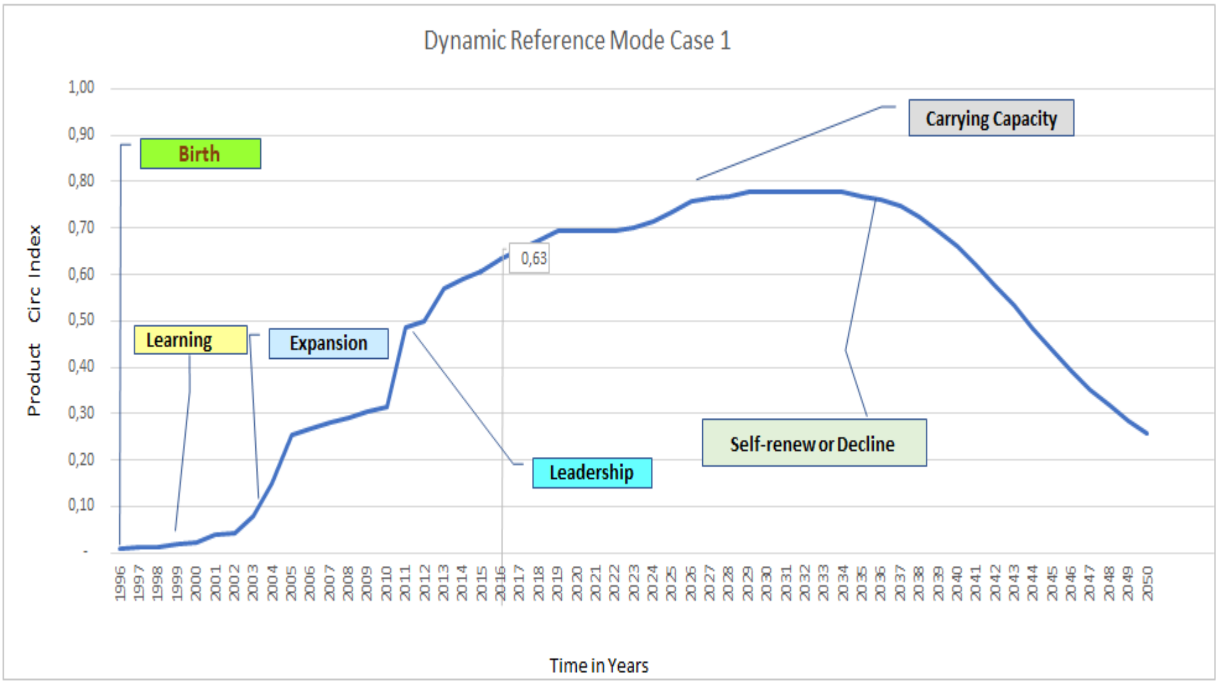
Categories	Subcategories and Codes	Case1	Case2	Case3	Case4	Case5	Case6	Case7
Management Mechanisms	**Agents**	☒	☒	☒	☒	☒	☒	☒
	Agents Reverse Schemata	☒	☒	☒	☒	☒	☒	☒
	Agent Role	☒	☒	☒	☒	☒	☒	☒
	Coordination Mechanisms	☒	☒	☒	☒	☒	☒	☒
	Combine product and byproduct recycl w renewable						☒	☒
	Manage value creation	☒	☒	☒	☒	☒	☒	☒
	Manage value capture	☒	☒	☒	☒	☒	☒	☒
	Sustainability Measurement Management	☒	☒	☒	☒	☒	☒	☒
	Supplier Selection	☒	☒	☒	☒	☒	☒	☒
	Mixed commodity and customer strategy			☒		☒	☒	☒
	Commodity strategy	☒	☒	☒	☒	☒		☒
	Multi-tier	☒	☒	☒	☒	☒	☒	☒
	Multi tier supplier development	☒	☒	☒	☒	☒	☒	☒
	SN Transactional Leadership	☒	☒	☒	☒	☒	☒	☒
	Manage the same agent relationship as supplier and customer			☒		☒	☒	☒
	supplier self-assessment	☒	☒	☒	☒	☒	☒	☒
	SN Transformational Leadership	☒	☒	☒	☒	☒	☒	☒
	Sustainable entrepreneuship	☒			☒	☒	☒	
	Increase competitiveness recycled versus virgin		☒			☒	☒	☒
	Hybrid = Transactional and Transformational	☒	☒	☒	☒	☒	☒	☒
	Manage collection process	☒	☒	☒	☒	☒	☒	☒
	Sustainable management measurements	☒	☒	☒	☒	☒	☒	☒
Emergent Properties	**Non-Linear Change**	☒	☒	☒	☒	☒	☒	☒
	Lack of brand owner and final consumer involvement	☒	☒	☒				
	Lack of competitiveness of recycled versus virgin		☒			☒		☒
	Non-Random Future	☒	☒	☒	☒	☒	☒	☒
	Cooperative business model		☒			☒		☒
	Operations spin off	☒	☒		☒		☒	☒
	Hybrid Loop	☒			☒	☒		☒
	Open Loop			☒				
	Closed Loop		☒				☒	
Internal and External Environment	**SN External Stakeholders**	☒	☒	☒	☒	☒	☒	☒
	Increase society and government involvement				☒	☒		☒
	Agents that influence SN	☒	☒	☒	☒	☒	☒	☒
	Natural Resource Scarcity							
	NRS as factor to start a CESN	☒	☒		☒			☒
	SN Internal Stakeholders	☒	☒	☒	☒	☒	☒	☒
	Lack of quality	☒						☒
	Main agents in the SC	☒	☒	☒	☒	☒	☒	☒
	Regulation	☒	☒	☒	☒	☒	☒	☒
	Regulation incentive and brand owner involvement	☒		☒	☒	☒	☒	
	Regulation complexity should be reduced	☒	☒		☒	☒	☒	☒

APPENDIX 16 – Article 2 Representative quotations for propositions support and causality.

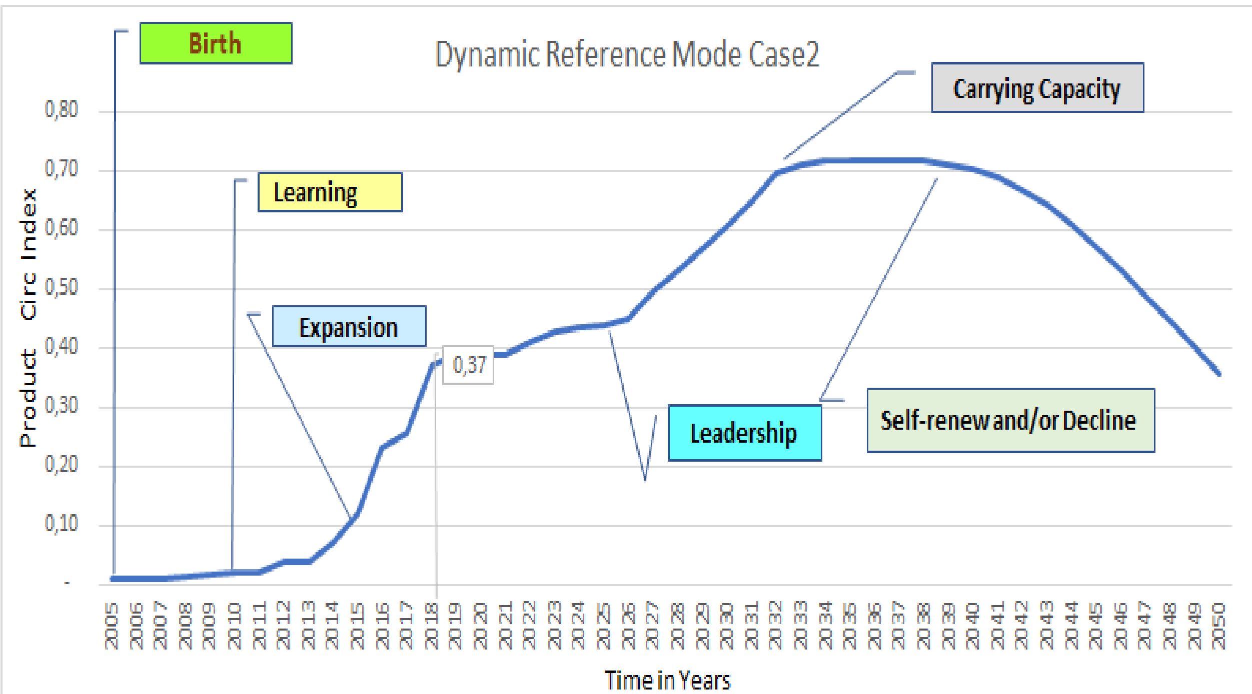
Proposition Support	Causality	Representative Quotations	Cases
P1. CESN has inflection points, in that agents with different role and position might be responsible for initiating or coordinating post consumption' product or byproduct physical reverse flow.	Agents with different role, position and coordination mechanisms leads to a SN configuration that can influence internal and external environment to create and improve the post consumption product and byproduct recovery rate.	"We coordinate battery returns process with Batman from Batdis". "We coordinate Batdis to send used batteries to Batrec". "We coordinate electronic's products return from PMrevlog and PMcoop".	Case1, Batrec Batman Case4 PMec
P1a. CESN agents' role and position also might indicate supply network leadership type it should play, agents in extreme upstream or downstream position could play hybrid leadership, combining transformational and transactional leaderships.	Agents in extreme upstream position as mining, oil, reforestation, recycler, primary raw material extraction, and in extreme downstream position as waste picker cooperatives could play CESN hybrid leadership.	"Every year our team visits current and new suppliers to re-validate their process capacity and guide them to improve quality and productivity". "Learning about bio digestors to find a solution to use high quantity of byproducts, lead us to develop partnership with a small solution firm ".	Case 7 Cardman Case 6 Biogasman
P1b. New supplier selection process, merging sourcing and customer strategy is influenced by the lack of quality and supply due to high variability in quantity of post consumption products and byproducts.	Managing agent's relationship as supplier and costumer at same time in buyer-supplier and supplier-buyer relationship leads merged sourcing and customer strategy.	"We have no difference between supplier and customer because the main suppliers are customers too, they buy our waste management service". "The same agent is the buyer of our products and the supplier of our supplies".	Case7 Cardcoop Case3 Eledist
1c. Agents in CESN extreme upstream or downstream positions might apply multi-tier CESN management strategy to increase post consumption product return rate.	Agents in CESN extreme upstream position as mining, oil, reforestation and primary raw material extraction starting multi-tier CESN relationship management in triad relationship or more, with waste picker cooperatives, reverse logistics providers and scrap dealers.	"Coordination process is done by our plants with scrap dealers, however to improve post consumption product quantity and quality, we manage waste picker cooperatives and individual waste picker relationship, teaching them production process and business management". "We supply to scrap dealers; however, we support post consumption products approval process with Packrec and Packbrand".	Case 7 Cardman Case5 Packcoop
P2. CESN configuration - agents, stakeholders and their relationships - dynamically adapts to internal and external environment changes.	The byproducts and recycled material is circulating to other SC even in other industries.	"We supply recovered acid to acid recycler that recycles and can supply to Batman or chemical industry besides that we buy lead scrap from sinker fish or bullets industries, and also we supply recycled lead to them". "We supply corrugated cardboard to several industries such as food, chemical and construction".	Case 1 Batrec Case7 Cardman
P2a. Internal and external stakeholders are influenced or influence regulations and taxes.	SN external stakeholders can influence the relationship and flow of products, materials, information, knowledge, finance between SN agents	"Society pressures on government and firms are leading us to embed sustainability strategy in our SC relationship". "Regulation helped us in the beginning to start, although our small suppliers still pay duplicate taxes, and we help them to avoid this understanding the regulation".	Case5 Packbrand Case7 Cardbrand
P2b. Natural resource scarcity may be a trigger to start a CESN.	NRS is a restriction that can be trigger to start CESN, agents in the role and position of mining, oil, reforestation and primary raw material extraction companies and recycler, create an intellectual stimulation, have a greater influence and also have a contingent reward with others direct agents in SN to overcome NRS.	"We developed reforestation operations combining this renewable resource with recycled from our operation, scrap dealers and cooperatives". "We develop partners to supply electronic waste and increase the returns rate, becoming urban mining company".	Case7 Cardman Case4 PMrec
P3. Multi-tier CESN management and external stakeholders may lead to CESN hybrid loop configuration open and closed loop combined.	The need for increase post consumption' products and byproducts return rate, and recycled product demand may lead to relationships with others SC even in other industries.	"We get byproducts from our operations and others reforestation suppliers, and waste from scrap dealers, that get from our customers in our SN or in others like food, chemicals, construction, and so on. We are developing cooperatives to increase volume and quality, so in the future, maybe supply direct to us but for now they are supplying to the scrap dealers". "We buy scrap from reverse logistics suppliers; besides we work close to some cooperatives to teach them product separation process for example plastic parts from PCB".	Case7 Cardman Case4 PMrec

P3a. The lack of competitivity, and an agent to recover post consumption products and byproducts may lead to emerge small agents generating large outcomes.	The waste and byproduct growing quantity can lead to emerge small agents in SN to solve that in feasible way.	"The biggest barrier was to find a company to develop sugar cane byproducts recovery process to us in a competitive way". "The recovered cost to get the post consumption products is still not competitive compared to the virgin". "The quantity of product returned still is small" "We need to increase the collection points of post consumption products".	Case6, Biogasman Case2 Prbrand Prman Prrec
P3b. The properties that emerge in different CESN in meso level, may have common patterns of behavior, once the agents follow similar reverse schemas in a SN self-organization.	The emergent properties of these interactions between the agents in these SN configurations can be result of CESN self-organization.	"We started getting together several individual waste pickers collectors into cooperative" "We wanted cleaning up our community/neighborhood, after sometime we decided to start a waste picker cooperative to make money".	Case5 Packcoop Case2 Prcoop

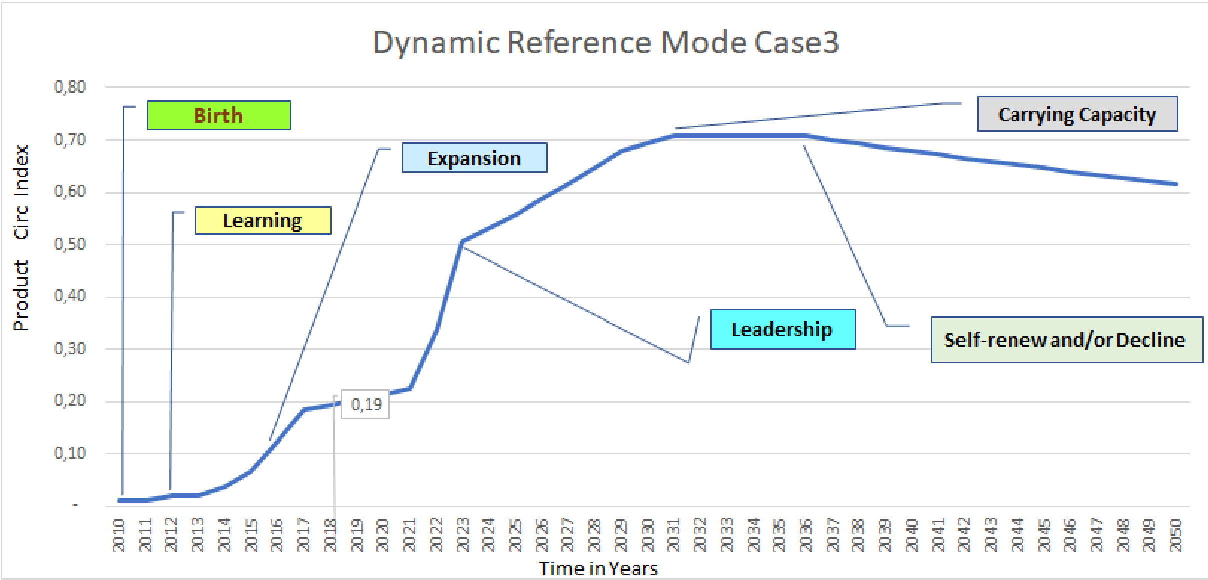
APPENDIX 17 – Article 3 -Dynamic Reference Mode for Circularity Index: Case 1 Batteries (Data collection between 2016 and 2018)



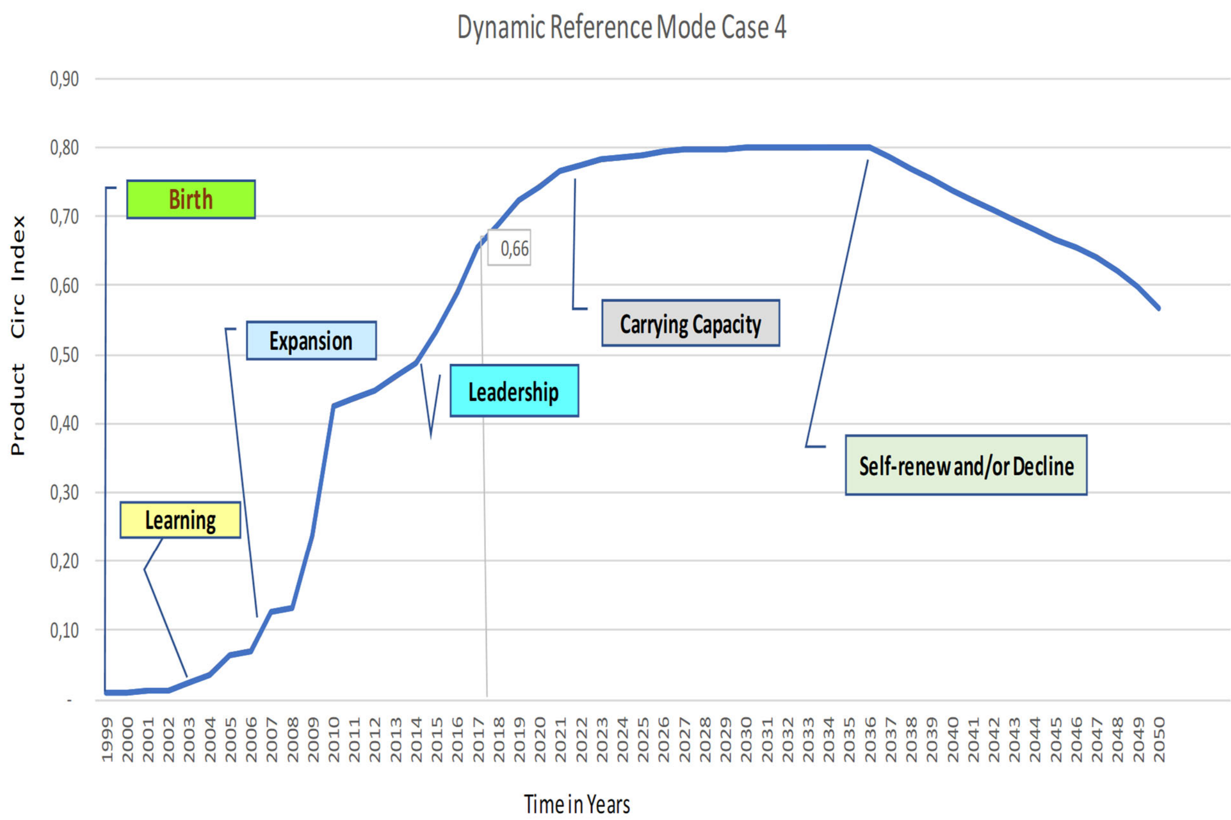
APPENDIX 18 – Article 3- Dynamic Reference Mode: Case 2 Printers (Data collection between 2018 and 2019)



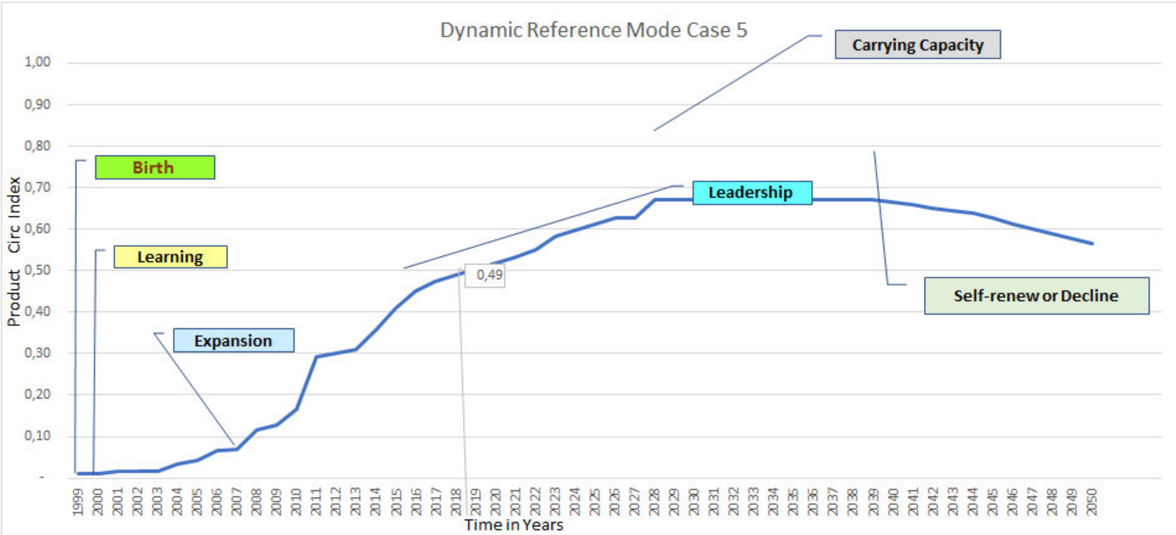
APPENDIX 19 – Article 3 - Dynamic Reference Mode: Case 3 Electronics (Data collection between 2018 and 2019)



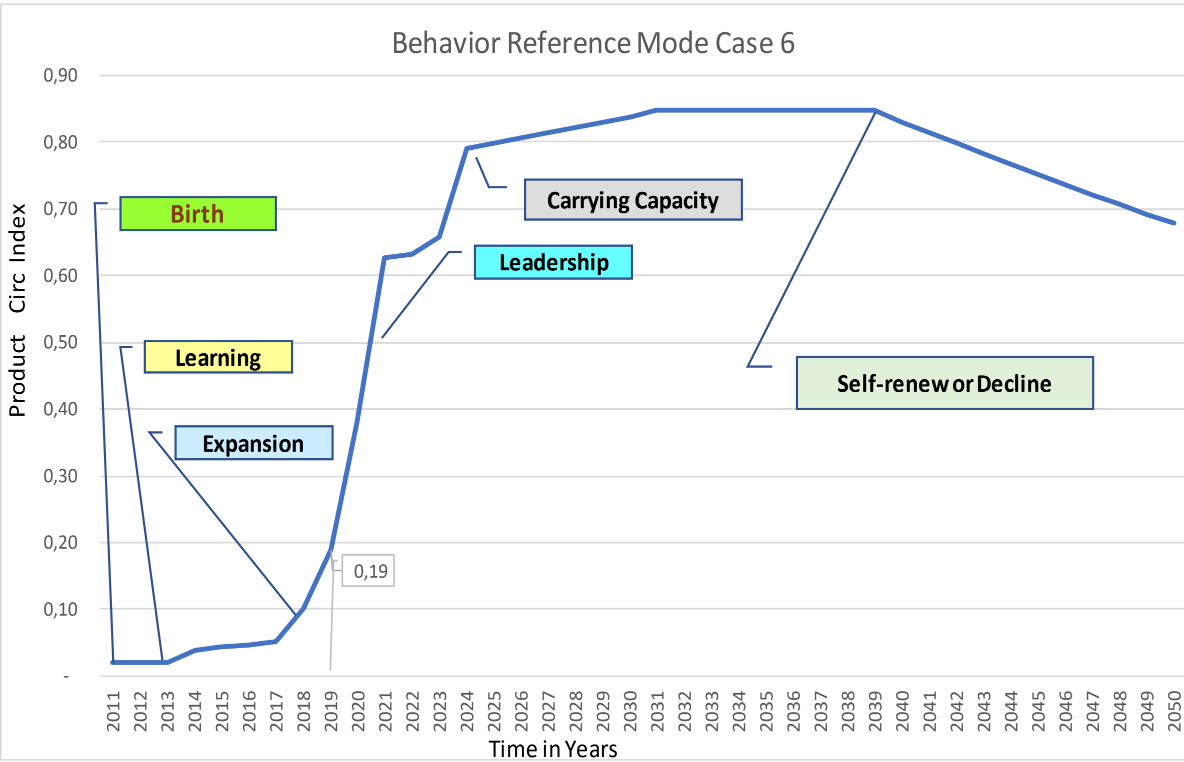
APPENDIX 20 – Article 3- Dynamic Reference Mode: Case 4 Electronics (Data collection between 2018 and 2019)



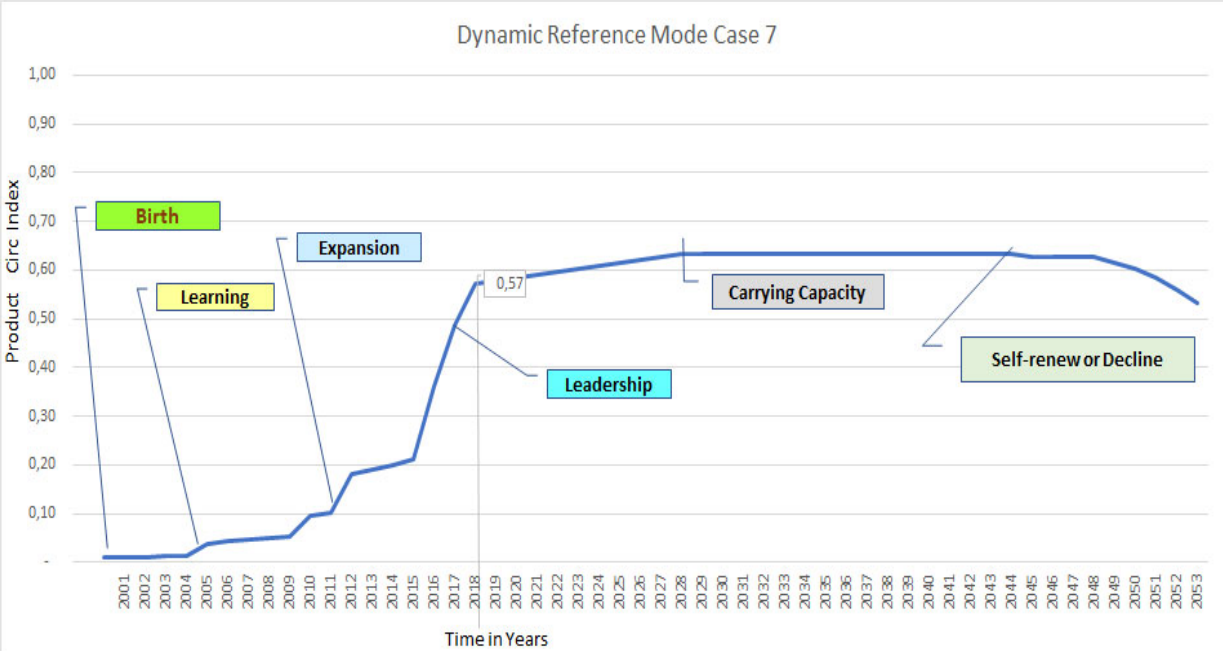
APPENDIX 21 – Article 3 - Dynamic Reference Mode: Case 5 Plastic Packaging (Data collection 2019)



APPENDIX 22- Article 3 - Dynamic Reference Mode: Case 6 Bioproducts such as: biofuel/ethanol, biogas and biofertilizer (Data collection between 2019 and 2021)

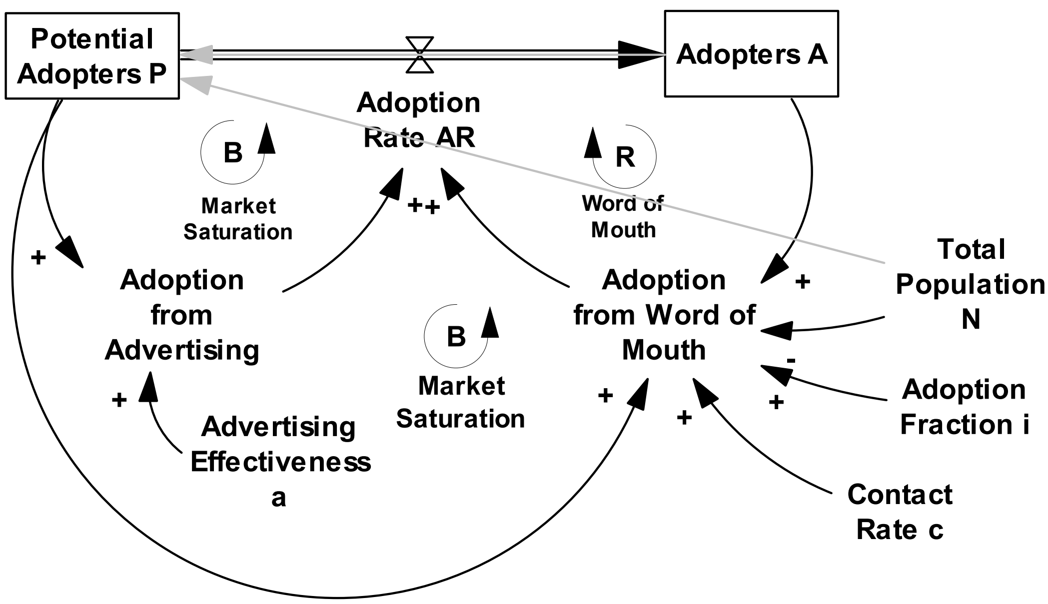


APPENDIX 23 – Article 3 - Dynamic Reference Mode: Case 7 Cardboard box (Data collection 2019)

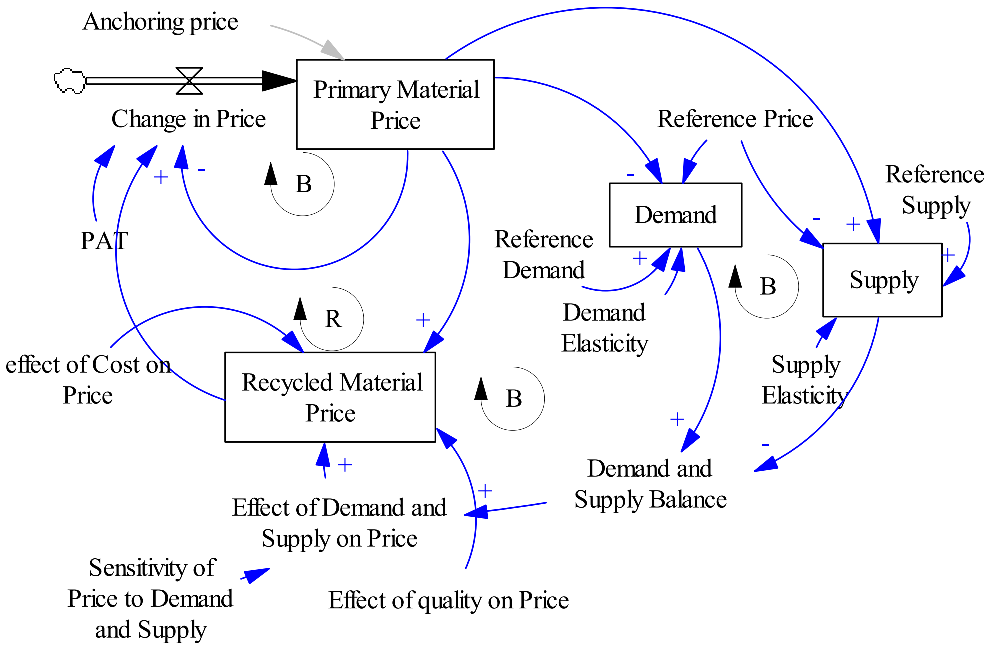


APPENDIX 24 – Article 3 – Innovation Diffusion Model: Bass (1969), Morecroft (2015) and Making Decision Model (Sterman, 2000)

Innovation Diffusion Causal loop and Flow and Stock Diagram



Making Decision Causal loop and Flow and Stock Diagram



APPENDIX 25 – Article 3 - Description of system dynamics validation process gradually building confidence in the model.

Test category: Structural	
Purpose of Test	Tools and Procedures
1-Integration Error Test	In the first test suggested by Lohmann and Meyers, (2015) and Sterman, (2000) the results of our models should not be sensitive to the choice of time step or integration method; the wrong time step or integration method can introduce spurious dynamics into our model. The test for such "DT error" cutting the time step from 0.125 in half to 0.0625 and running the model again, shows no matter change. We also duplicate the time step in double to 0.25 and running the model again, no matter change either, as in Fig. 3. If the results change in ways that matter, the time step was too large, so we should continue until the results are no longer sensitive to the choice of time step. Likewise, we run the model with alternate integration methods from Euler to RK4auto, as in Fig. 4, shows no matter change either.
2-Extreme Condition Test	Extreme condition tests ask whether models behave appropriately when the inputs take on extreme values such as zero or max. value. We carried out in two main ways: by direct inspection of the model equations and by simulation. We examine each decision rule (rate equation) in the model and ask whether the output of the rule is feasible and reasonable even when each input to the equation takes on its maximum and minimum values. Results are in Figure 5.
3-Boundary Adequacy	We used model boundary charts, causal diagrams, stock and flow maps as Figure 6 and direct inspection of model equations. Data source were interviews, observation, archival materials, review of literature, direct inspection /participation in system process, etc. We modify model to include plausible additional structure in each supply network position repeating sensitive analysis.
4-Structure Examination/Assessment	We conduct partial model tests of the intended rationality of decision rules. We develop disaggregate sub-models and compare to aggregate formulations (Figs. 7, ,8 and 9). Disaggregate suspect structures, repeating sensitivity analysis. We tested physical law that stocks can't become negative, outcomes could approach zero. All variables have measure units.
5-Dimensional Adequacy and Consistency	We use real world units of measure got from case studies, besides we check each sub-model variables units, to understand the structure or decision process we are trying to model (Fig. 10).
6-Parameter assessment	We make examination to evaluate model's parameters against evidence or knowledge about the real system. The test utilizes both empirical, from cases BOM and theoretical information according to Haas et al., (2015). Hence, the test is conceptual and numerical. The conceptual parameter examination test is about construct validity. Numerical from cases bill of materials based on knowledge of the real system constrains is about real-world validity (detailed in set of Appendix from 17 to 23).
7-Mass-balance Check	We procedure accumulating all the inflows and outflows over time for each resource being modeled and then use the following balance or checksum equation: (Sum of all inflows-Sum o all outflows+initial values of stocks-current values of stocks) *dt=0 (Dangerfield, 2014; Lohmann & Meyers, 2015). No sub-model has gain mass (Figs 7,8 and 9).

Continue	
Test category: Behavioral	
8- Reproduction and symptom tests. Theil Inequality Statistic Test breakdown the mean square error in three components, bias, unequal variation and unequal covariation	The mean-square error (MSE) for Circularity is 0.02 and the root mean-square error (RMSE) is 0.14. The individual components of the inequality statistics are UM = 0.05 bias, US= 0.03 unequal variation, UC= 0.92 unequal covariation (Fig. 11). The decomposition shows that the major part of the error is due to the unequal covariation component, while the other two sources of error are small. This signifies that the point-by-point values of the simulated and the historical data do not perfect match, even though the model captures the dominant trend and the average values in the historical data. Such a situation indicates that the major part of the error is probably unsystematic and therefore that the model should not be rejected for failing to match the noise component of the data. The residuals of the historic and simulated time series show no significant trend. This strengthens the assessment that the model comprises of a structure that captures the fundamental dynamics of the issue under study. According to Sterman, (2000) many systems, including the supply chains and commodity markets, selectively amplify certain frequencies in the random shocks that constantly perturb them. Since no model can capture all the random variations in the environment.
9-Family Member and Multiple Modes Test	The family member test asks whether the model can generate the behavior of other instances in the same class (CESN) as the system the model was built to mimic. Our model of CESN implementation and growth can explain why some other circular networks, with different policies and parameters, experience growth, this test permits a repeat of the other tests of the model in the context of different special cases that fall within the general theory covered by the model. The general theory is embodied in the structure of the model. The mode is a pattern of observed behavior. The multiple mode test considers whether a model is able to generate more than one mode of observed behavior. We replicate our model to Case 4 parameters and policies as shown in Fig. 12.
Test category: Contextual	
10-Model Framing and Issue Identification	Model has orientative purpose and clear goal defined in problem articulation. Besides recurrently tested during model building.
11-Issue identification and Adequacy of Methodology Test	System Dynamics methodology is best-suited for dealing with the issue under study. Once the issue is characterized by dynamic complexity, feedback loop mechanisms, nonlinear interdependency of structural elements, and delays between causes and effects. Besides CESN management to foster CE system must be studied in a dynamic way understanding the process over time.
12-System Improvement	Finished model compared to real world reference mode was tested in base case scenario Fig 12.
13-System configuration	CESN management developed framework focused on recycling process in that a hybrid loop configuration adding several industries chains in a network was the best choice Fig. 13.
All figures Location:	https://github.com/Acbraz/Transition-to-circular-economy-The-role-of-CESN-management-variables-and-its-dynamic-evolutionary

APPENDIX 26- Article 3 -System Dynamics Model Equations

Model Equations:

- INTEGR STOCK: Internal and External Environment have CE Potential Adopters (t) = [Internal and External Environment have CE Potential Adopters(t-dt)] – [Management Mechanisms CE Adoption Rate (*dt)].
- Initial CE Potential Adopters = Int and Ext Stakeholders Total N-Emergent Circularity has the CE Active Adopters {products}.
- DIFER. FLOW: Management Mechanisms Influence CE Adoption Rate = Natural Resource Lifespan + Circular Supplier Development and Selection {products / year}.
- INTEGR STOCK: Emergent Circularity has the CE Active Adopters (t) = [Emergent Circularity has the CE Active Adopters (t-dt)] + [Management Mechanisms Influence CE Adoption Rate(*dt)].
- Initial CE Active Adopters = 0 {products}.
- Circular Supplier Development and Selection = Multitier Supplier Management*Hybrid Leadership*Internal and External Environment have CE Potential Adopters*Emergent Circularity has the CE Active Adopters*(Coordination Mechanisms + Initiating Mechanisms)/Int and Ext Stakeholders Total N {circularity / year}.
- Natural Resource Lifespan = (Internal and External Environment have CE Potential Adopters + Circular Supplier Development and Selection) * Regulation Effectiveness {products / year}.
- Int and Ext Stakeholders Total N = RANDOM TRIANGULAR (5, 90, 3, 90, 90, 0) {products}.

Constants:

- Regulation Effectiveness = 0.015 {1/year}.
- Contact rate and adoption fraction sum are direct related to the new program buyer resource time = 1.
- Multitier Supplier Management = 0.28 {1/ year}- definition: Contact rate multi-tier supply development influencing SDS. The rate at which CE adopters come into contact with potential adopters.
- Hybrid Leadership = 0.28 {1 / year}.
- Initiating Mechanisms = 0.22 {dimensionless}.
- Coordination Mechanisms = 0.22 {dimensionless}- definition: Adoption fraction influenced by coordinating mechanisms such as providing by trade -in. The fraction of times a contact between an CE adopter and a potential adopter result in adoption.

Growth and Limiting Engines (Feedback loop): As the stock of CE potential adopters decline while CE active adopters stock grows, the regulation effectiveness rate contribution falls, resulting in a negative (limiting) feedback loop, while the contribution of circular supplier development and selection and CE active adopters rises, resulting in a positive (growth).

Sub-model: Management Mechanisms Influence CE Adoption Rate (Flow)

Key variable: Coordination mechanisms.
Type: endogenous and auxiliary.
Theoretical background: Act of managing interdependencies between activities performed to achieve a goal for value creation (Simatupang et al., 2002). The relations through which key actors create, maintain, and potentially transform network activities (Gosling et al., 2016; Raynolds, 2004) leading with a landscape more or less rugged depending on the distribution of fitness values and interdependences among the parts, developing a tool to integrate sustainable development pillars (Husgafvel et al., 2017; Matos & Hall, 2007).
Characteristics: Agents interact in the CESN to overcome a lack of government incentives and develop new capabilities to increase value creation and capture. Buyers have two economic criteria to define a source a: buyer perspective in that they buy from the most competitive supplier and a supplier perspective in that they try to monitor how much value is captured by the supplier and when they need improve it and increase its own sales price to compensate the cost increase (Braz & Mello, 2022).
Propositions: P1. A CESN has inflection points in that agents with different roles and positions might be responsible for initiating or coordinating postconsumption product or byproduct physical reverse flow(Braz & Mello, 2022).

Key variable: Initiating mechanisms.
Type: endogenous and auxiliary.
Theoretical background: Act of managing interdependencies between activities performed to achieve a goal for capturing most possible part of created value without expense of supply ecosystem (Ketchen et al., 2014; Moore, 1993). Inflection points to start the reverse post consumption products or materials physical flow (Braz and Mello, 2022).
Characteristics: Buyers buy from the most competitive suppliers, that try to value capture increase by its own sales price to compensate the cost increase.
Proposition: P1. A CESN has inflection points in that agents with different roles and positions might be responsible for initiating or coordinating postconsumption product or byproduct physical reverse flow (Braz & Mello, 2022).

Key variable: Multi-tier supply network management
Type: endogenous and auxiliary.
Theoretical background: Focal companies work with Tier 1 and Tier 2 suppliers, in three types of multi-tier supply chain structures: open triad, transitional triad and closed triad, the forms of triad are linked with management resources (Mena et al., 2013). In a multi-tier supply chain, focal companies can apply four approaches on their lower tier suppliers: “Direct”, “Indirect” (via Tier 1 suppliers), “Work with third parties” and “Don’t bother” and "a combined and dynamic manner of them" (Jia et al., 2019).
Characteristics: Agents in the CESN extreme upstream positions as mining, oil, reforestation and primary raw material extraction companies, plays multi-tiered management in triad or

larger relationships with waste picker cooperatives, reverse logistics providers and scrap dealers.
Proposition: P1c. Agents in extreme upstream or downstream positions of a CESN might apply a multi-tiered CESN management strategy to increase the postconsumption product return rate (Braz & Mello, 2022).

Key variable: Supply network hybrid leadership.
Type: endogenous and auxiliary.
Theoretical background: Supply chain leader is characterized as the organization that demonstrates higher levels of the four elements of leadership in relation to other member organizations (the organization capable of greater influence, readily identifiable by its behaviors, creator of the vision, and that establishes a relationship with other supply chain organizations. Transformational leadership exhibits inspiration, intellectual stimulation and individualized consideration more frequently. Transformational leaders focus on developing longterm relationships in a more holistic way. Inspiration behaviour as a mission and vision of a desirable future and the definition of the path to achieve the vision; intellectual stimulation indicates leaders calling on followers to be more innovative and creative to provide better solutions to problems; individualized consideration means a leader's ability to recognize each individual follower's unique skills and development needs .Transformational and transactional combined, demonstrate contingent reward, is capable of greater influence, creator of the vision and establishes a relationship with other supply chain organizations (Jia et al. 2019).
Characteristics: Agents closer to CESN downstream positions in role as distributors or retailers and play transactional leadership.
Proposition: P1a. CESN agents' role and position might also indicate the types of supply network leadership they should play, agents in extreme upstream or downstream position could playing hybrid leadership,

Key variable: Circular Supplier development and selection.
Type: endogenous and auxiliary
Theoretical background: This is one of the most fundamental, important and critical decision that a buyer makes. Mainly due to the increased levels of complexity involved in considering various supplier performance and relationship factors. Such as quality, process capability, cost, financial and regulation issues (Ellram et al., 2008; Sarkis & Talluri, 2002). Even though for small and startups suppliers (Kurpjuweit et al., 2020).
Characteristics: Agents in the CESN adopt a systemic supplier selection process approach, and agents responsible for initiating physical reverse flow use merged sourcing and customer strategies.
Proposition: P1b. The new supplier selection process merging sourcing and customer strategies is influenced by a lack of quality and supply due to high variability in the quantity of postconsumption products and Byproducts types (Braz and Mello, 2022).

Sub-model: Internal and External Environment have CE Potential Adopters (Stock)

Key variable: Supply network external stakeholders.
Type: exogenous and auxiliary

Theoretical background: Stakeholders that do not belong to the SN in terms of materials, products or byproducts flow (Gong et al., 2018).
Characteristics: People, governments, nongovernmental organizations, competitors, universities and companies outside of an CESN can influence relationships and flows of products, materials, information, knowledge and finance among CESN agents.
Propositions: P2. CESN configuration - agents, stakeholders and their relationships - dynamically adapts to internal and external environmental changes.
P2a. Internal and external stakeholders influence or are influenced by regulations and taxes (Braz & Mello, 2022).

Key variable: Supply network internal stakeholders.
Type: exogenous and auxiliary
Theoretical background: Stakeholders that belong to the SN in terms of the flow of materials, information, products or byproducts and finance (Gong et al., 2018).
Characteristics: Major agents in the CESN can influence postconsumption product or byproduct quality and quantity variability, preferred suppliers and new agents in performing new roles in the CESN.
Propositions: P2. CESN configuration - agents, stakeholders and their relationships - dynamically adapts to internal and external environmental changes.
P2a. Internal and external stakeholders influence or are influenced by regulations and taxes (Braz & Mello, 2022).

Key variable: Natural resource.
Type: exogenous and auxiliary
Theoretical background: Natural resource extraction and scarcity (Kalaitzi et al., 2018).
Characteristics: Natural resource scarcity or extraction economic unviability is a restriction that can initiate a CESN.
Proposition: P2b. Natural resource scarcity may trigger CESN formation (Braz & Mello, 2022).

Key variable: Regulation.
Type: exogenous and auxiliary
Theoretical background: Regulation regarding reverse supply chains in each city, state, region or country (Kalverkamp, 2018).
Characteristics: Regulation impacts the CESN positively by incentivizing brand owner involvement or negatively by increasing costs through high tax complexity.
Propositions: P2. CESN configuration - agents, stakeholders and their relationships - dynamically adapts to internal and external environmental changes.
P2a. Internal and external stakeholders influence or are influenced by regulations and taxes (Braz & Mello, 2022).

Sub-model: Emergent Circularity has the CE Adopters (Stock)

Key variable: Non-linear change
Type: exogenous and not included in the model, only to explain the model behavior
Theoretical background: In a non-linear system, large changes in input may lead to small changes in outcome, and small changes in input may lead to large changes in outcomes (Choi,

et al, 2001). Most relevant nonlinear dynamics are those that emerge as system properties from the underlying interactions, not those coded into the initial specifications (Nair and Tsoshas, 2019). Complex systems change inputs to outputs in a nonlinear way because their components interact with one another via a web of feedback loops (Anderson, 1999).
Characteristics: Small emergent agents as cooperatives can cause major changes in the CESN by increasing postconsumption product and byproduct competitiveness and brand owner and final consumer involvement.
Proposition: P3a. The lack of competitivity and an agent to recover post consumption products and byproducts may lead to emerging small agents generating major outcomes.(Braz and Mello, 2022).

Key variable - Non-random future
Type: exogenous and not included in the model, only to explain the model behavior
Theoretical background: Small changes may lead to large different future paths; however, the same characteristic pattern of behavior emerges despite the change. One finds that systems will tend to be involved in certain prototypical ways and, thus, our predictive capacity, although limited to the exact prediction at a future point in time, can benefit from the knowledge of these patterns. Common patterns of behavior are observable (Choi et al,2001).
Characteristics: Future CESN trends show common patterns of behavior such as cooperative business models and business spinoffs, and through self-organization a lack of government incentives and companies' corporate strategies can be overcome to explore sustainable development.
Proposition: P3b. Properties that emerge in different CESNs at a meso level may show common patterns of behavior once agents follow similar reverse schemas in SN self-organization (Braz & Mello, 2022).

Key variable: Supply chain configuration hybrid loop.
Positions: upstream, midstream and downstream.
Type exogenous and not included in the model, only to explain the model behavior.
Theoretical background: SC type is defined regarding the characteristics, such as the type and level of SC integration, the type of process (Lejeune and Yakova, 2005) the type of issues faced (Vonderembse et al., 2006) and structure (de Kok et al., 2018).
Characteristics: The CESN flows of recovered products and byproducts can be governed by the same or new agents "with (in a closed loop) or without (in an open and/or slow loop) brand owner direct" involvement. Moreover, the CESN expands to others SNs even in other industries (Braz & Mello, 2022).

Propositions: P3. A multi-tier CESN management and external stakeholders may lead to CESN hybrid loop configuration, an open and closed loop combined.

APPENDIX 27 – Data Management Template available on: https://dmptool.org/plans/60182 and Supplementary Material

Following University of Sao Paulo Resolution number 7900, of 11/19, I have created a data management plan using DMPTool based on USP Template DCC:

Details of data collected or created:

What data will be collected or created?

The data of involved companies that represent circular supply chains with their characteristics in the case studies should be used to set up a database. Companies already have these data; we will make a selection and analysis of the data needed to create a management and modeling framework with systems dynamics. Their customer data, suppliers, management systems, management of sustainability indicators, circularity and which reports are issued, mapping the upstream and downstream supply network, how the coordination of post-consumption products and byproducts flow work reverse and direct, how is the value creation and capture in these flows, how is the innovation process in the company if it exists, what can be improved.

How will the data be collected or created?

The primary data collection tool was a semi-structured questionnaire for the interviews, as well as the observations of the visits were recorded in spreadsheets and secondary data were collected on companies' websites, industry associations, business fairs and government websites and NGOs.

Documentation and Metadata Information:

What documentation and metadata will accompany the data?

Transcribed interviews, indexes of sustainability and circularity indicators collected, input data and results of simulations generated by the Vensim software all in .pdf

Ethical and Legal Compliance Information on Ethical and Legal Compliance:

How will ethical and legal issues be handled?

Permission to preserve data was obtained with the guarantee of protecting the identity of companies and interviewees through the anonymization of them with the use of pseudonyms guaranteeing their confidentiality.

How will the author's rights and intellectual property issues be handled?
In addition, if accepted for publication, data sharing will be postponed.

Storage, Backup, Responsibility and Resources Storage and Backup Information:
How will the data be stored and how will it be backed up during the search?
The data is being stored in a notebook, must be stored in the Google drive of autor@usp.br, doing a backup every week with flash drive or external HD.

How will access and security issues be handled?
In Google drive the author will allow access to some researchers who participated in the research
Liability and Resource Information.

Who will be responsible for data management?
The author abraz@usp.br

What resources will be needed to maintain this plan?
Notebook, USB stick, external hard drive and Google drive

Selection, Preservation and Sharing Data Selection and Preservation Information:
What data is long term and will need to be maintained, shared and / or preserved?
All data that will be made available
What is the plan for long-term preservation for the data set?
Keep on external HD and Google Drive

Data Sharing Information:
How will the data be shared?
The author will be aligning with his advisor.
Are there any restrictions on data sharing?
First: the author must prepare the primary data removing companies and interviews identification.
Second: If a paper is going to be accepted before thesis publication, author will need to understanding what is the Journal guidelines regarding quarantine period.

APPENDIX 28 – CESN transition phases management Cases main events

Phases	Cases main events	CI	G. Rate	Time (Years)	Circular Factors (CF)
Pre-development	Cases 1 and 4 (CF1)- Natural resource extraction economic unviability, starts batteries and precious metals recycling; Case2 (CF5)- Prbrand was facing an economic disadvantage due to clandestine companies that, without its approval, refilled used and discarded ink cartridges produced by Prman. Since these competitors did not have the costs for developing product or legalizing their own operations, they were able to sell both the refilled cartridges and the recharge service at prices not feasible for Prbrand. Cases 3,4,5 and 7 (CF2and 4)- Take advantage from waste management policy, supply and governance regulation incentives to start electronics device recommerce, plastics pack and cardboard recycling, besides corporate strategy to use sustainability and biodiversity as competitive advantage. Cases 6 and 7 (CF3)- Due to large amount of by-products' sugarcane harvesting, ethanol production, reforestation companies and corrugated cardboard production.	0-0.01	0%	1	1-Natural resource extraction economic unviability; 2- Regulation pressures (incentives or barriers); 3- Large quantity of by-products; 4- Corporate strategy to use sustainability and biodiversity as competitive advantage; 5- Reduce clandestine competitors.
Learning	Cases 1 and 2 (CF 6,7,8) –Circular product design, local recycling mass production technology development and product manufacturer spin-off, reducing primary raw material dependency. Cases 3, 5, 6 and 7 (CF 6,7) - Partnership development and new technologies. Cases 1, 4 and 7 (CF7)- Reducing primary raw material dependency, technology owner acquisition, carbon credits usage.	0.02 - 0.09	28%	5	6- Circular Product Design, Mass production technology development; 7- New partnerships development or acquisition; 8- Reduce primary raw material dependency.
Expansion	Cases 1, 2 and 3 (CF9)- Implement trade-in with distributors or retails to increase postconsumption products and by-products recovery. Cases 1, 2, 4, 5 and 7 (CF9)- Implement high capillarity reverse logistics network adding new external stakeholders. Cases 1,2,3,4, 5 and 7 (CF10). Waste Management Law and policy industries agreements. Cases 5 and 6 (CF9)- Getting other industries National and International recycled product certification and develop postconsumption products and by-products recovery solutions partnership.	0.10 - 0.49	32%	9	9- Strategies to increase postconsumption product and by-product recovery rate; 10- Regulation fine tuning.
Leadership	Cases 1, 4 and 7 (CF 11,12,13) - Mass production technology fine tuning, overseas operations expansion. Adding new actors and networks in the circular system even from others industries. Focus in increase the BOM circularity of the less weighted parts. Influencing partners to take UN SDG goals to all network positions. Influencing external stakeholders through social programs.	0.50 - 0.79	3%	10	11- Overseas operations expansion; 12- Adding new networks and industries; 13- Mass production technology fine tuning.
Stabilization	No case yet (CF14). Assumptions made by the authors	0.80 - 0.84	<1%	11	14- Incremental improvements every year
Self-renewal or decline	No case yet (CF15), Assumptions made by the authors	> 0.85	< 0%	36	15-Product or service replaced by a radical innovation

APPENDIX 29 – Data Management Plan Tool available on: https://dmptool.org/