Towards social network metrics for supply network circularity

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Abstract

Purpose – Despite the systemic nature of circular economy (CE), theorisation that draws from a supply network perspective is only incipient. Moreover, the operations and supply chain management (OSCM) field has engaged in little dialogue with circularity. This study explores social network analysis (SNA) to depict how the shift from linear to circular not only leads to higher rates of resource economy, repair and recycle, but also reshapes governance dynamics and network structure of supply networks.

Design/methodology/approach – The study departs from a systematic review of the literature, and draws from core concepts in OSCM, CE, and SNA to offer theoretical propositions that articulate how social network metrics can depict supply network circularity. We illustrate the framework with examples from fashion and electronics industries.

Findings – Four theoretical propositions enlighten how betweenness centrality, eigenvector centrality and network density can explain the shift from linear to circular supply networks across the three CE strategies of narrowing, slowing, and closing.

Originality – The combination of biomimicry, CE, the push-pull dichotomy, and social network metrics offer a theory-driven framework for supply network circularity.

Keywords Circular economy; supply network; governance; social network analysis; theory development

1. Introduction

Circular economy (CE) scholarship traces back to 1990 when it first appeared in a book by environmental economists Pearce and Turner (1990). The book has established the connections between the environment and the economy with the former functioning as a resource supplier and as a sink for waste from the latter. The book was inspired by Kenneth Boulding's (1966, pp. 7-8) definition of our planet as a 'Spaceship Earth' where *"man must find his place in a cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs of energy".* In order to transition from the ever-prevalent linear logic of our economy to the circular logic proposed, radical changes are necessary in how products are manufactured, used, and disposed of (Vermunt, Negro, Verweij, Kuppens, & Hekkert, 2019).

CE appears as a counterpoint to the linear take-make-dispose flow that has dominated the economy and that has brought profound negative impacts on the natural environment and the future availability of resources (Korhonen, Honkasalo, & Seppala, 2018; Merli, Preziosi, & Acampora, 2018). The term has been framed as an umbrella concept embracing many fields of disparate knowledge domains and interwoven concepts derived from fields such as industrial ecology, industrial ecosystems and industrial symbiosis, cleaner production, product-service systems, eco-efficiency, cradle-to-cradle design, biomimicry, natural capitalism and others (Hofmann, 2019; Homrich, Galvao, Abadi, & Carvalho, 2018; Merli et al., 2018; Winans, Kendall, & Deng, 2017). CE must thus be viewed as a cross-cutting, unifying perspective, which calls for a systemic/network lens (De Angelis, 2020; Kirchherr, Reike, & Hekkert, 2017). This study borrows De Angelis' (2020) definition of CE:

> *"The circular economy is a transformational and* ***systemic vision*** *for a more ecologically effective economic system that works within planetary limits and thereby maintains and rebuilds natural capital. It is enabled by* ***multiple, cooperative, and simultaneous*** *innovations at different scales in the wider socio-economic context involving regulation, policy and production and consumption systems. Companies in a circular economy can attain a sustained competitive advantage through innovative business models wherein circular principles in offerings and relationships enable the creation, delivery and capture of economic value, whilst ecological and social values are accrued by nature and society." [Note: bold words by the authors]*

The above definition emphasizes the important role of firms as key actors, innovation as the core engine, and systemic cooperation as the soil to circularity. For CE to flourish, one key milestone is a solid theoretical foundation (De Angelis, 2020). And such foundation should be grounded in systemic/network level thinking (Homrich et al., 2018; Korhonen, Honkasalo, et al., 2018; Merli et al., 2018). But a network lens must include micro-analytical tools needed to conduct the changes in operations and supply chain management (OSCM) (Korhonen, Nuur, Feldmann, & Birkie, 2018). Yet, despite the recognition of the importance of business to CE, and the sharp increase of CE research, theorisation is still limited (Jabbour et al., 2019; Korhonen, Nuur, et al., 2018; Leder, Kumar, & Rodrigues, 2020). Moreover, most endeavours do not dive into the core OSCM concepts, with noted exceptions, as discussed by Jabbour et al (2019).

The supply network perspective that has been elaborated in the OSCM field in the last 20 years has been almost absent from the debate in CE studies (Tate, Bals, Bals, & Foerstl, 2019). Conversely, the OSCM has offered little theorisation of circularity. The OSCM core jargon persists with the dichotomy between push and pull strategies which may lose sense in circular loops. And seminal work on social network theory and analysis have been silent on the transition from linear to circular (Borgatti & Li, 2009; Galaskiewicz, 2011; Kim, Choi, Yan, & Dooley, 2011).

We posit that the OSCM field is best positioned to bridge the physical flow dear to the hard sciences and the governance perspective of supply network research, thus combining the needed systemic- and micro-level perspectives. We conduct research to answer the question: *how can social network metrics depict the transition from linear to circular supply networks?*

Our study begins with a systematic review of CE studies that exposes the lack of a network perspective. We next review the foundations of our framework from OSCM, the push versus pull dichotomy; and from CE, biomimicry and the three strategies narrowing, slowing, and closing. We then review social network metrics that can help depict supply network structure. Grounded on these foundations, we develop a conceptual framework with four propositions that we populate with illustrative examples from fashion and electronics. The four propositions enlighten how the shift from linear to circular affects not only physical flows, but governance dynamics and network structure. The framework equips both academia and practice with social network metrics to manage such complexity (Hofmann, 2019) adding clarity to the dynamic factors that need to be tracked during the transition (Sehnem, Campos, Julkovski, & Cazella, 2019).

2. Current theorisation in CE research

2.1. Systematic review of CE studies

Despite the steady increase in CE research, the term has still blurred boundaries. Most importantly, the research front has been led by scholarship in hard sciences (Geissdoerfer, Savaget, Bocken, & Hultink, 2017; Homrich et al., 2018; Korhonen, Nuur, et al., 2018; Merli et al., 2018; Suárez-Eiroa, Fernández, Méndez-Martínez, & Soto-Oñate, 2019) and so far academia has failed to connect the understanding of the shifts in physical flows with the needed reflections in the realm of management and governance (Korhonen, Nuur, et al., 2018). Although the scholarship in operations and supply chain management (OSCM) seems an adequate candidate to theorise the bridge between the physical flows and governance, there is yet much to be done.

In order to assess the stage of theorisation in CE studies and explore the extent that research has addressed the physical-governance bridge, we have employed a systematic review of the literature (Durach, Kembro, & Wieland, 2017). For the sake of brevity, we provide a summary of the systematic review that has been conducted alongside descriptive tables and figures in Appendix A. The final sample of fully scanned articles accounted for 159 articles citing theory-related strings, but only 45% (72 articles) were actually adopting a theoretical lens. Results are discussed next.

2.2. Exposing skewed theorisation

Our review confirms the continued surge of publications in CE (Gregorio, Pie, & Terceno, 2018; Homrich et al., 2018; Merli et al., 2018). Yet, theorisation is still limited to a smaller share of research publications. Even within those articles explicitly naming a theoretical lens, it is often the case that the study does not truly engage with the theory fundamentals and advance theory further. Only a few try to build or elaborate upon the empirical results, providing inferences, unique propositions, or developing new constructs. It is also worth noting that many articles place their emphasis on practical implications rather than contribution to theory. Although we recognize the importance of descriptive mapping in a new research field such as CE, we believe that the field would profit from more theory generating activities that can eventually provide CE its own theoretical lenses. We also understand the urgency for providing short-term practical solutions. Nonetheless, this might represent a short-sighted emphasis. We should not lose sight of the role of theorisation.

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As Table 1 shows, theoretical lenses applied are mostly well-established theories from either management research or social sciences more broadly. Most used theories include institutional theory, resource-based view (RBV), dynamic capabilities and stakeholder theory.

Within the theory-driven studies, it is surprising to see a predominance of inner-looking theoretical lenses, such as RBV and dynamic capabilities, which constitute, by far, the most employed lenses. RBV poses that firm's sustained competitive advantage stems from its internal rare, inimitable, non-substitutable resources. Dynamic capabilities in turn, focus on how firms may leverage internal and external resources in order to address rapidly changing environments. In that way, there is an over emphasis in analysing firms' resources and capabilities that can be leveraged through CE strategies. As exemplars, Prieto-Sandoval et al (2019) investigate what are the resources and capabilities necessary for the implementation of CE principles in SMEs in Spain; while Khan et al (2020) study what micro foundations of dynamic capabilities lead to CE implementation in Italian firms.

CE innovations often appears in association with the resource-based lenses. Kiefer et al (2019) investigate the role of resources, competences and dynamic capabilities as drivers and barriers to different types of eco-innovation. Scarpellini et al (2020) examines formal and informal environmental management systems and how they relate to circular eco-innovation. Ghisetti and Montressor (2020) try to understand what are the best types of financing available for the transition to CE of SMEs enterprises in Europe finding that 'financing as usual' according to pecking-order theory do not support the transition of SMEs to the CE. Núñez-Cacho et al (2018), through the lens of social-emotional wealth theory and by means of a case study of a family owned Spanish food retailer, explains the drivers for family firms transitioning to CE. It seems tough that these studies fail to capture the changes in flow and relationships along the extended supply chain. Moreover, it fails to map the emergence of new actors that arise in the process of shifting from linear to circular systems.

The second and third most prominent theoretical views are respectively institutional theory and stakeholder theory. While RBV and dynamic capabilities are interested in internal resources and capabilities of a firm, institutional and stakeholder theory turn the focus to firm's external environment. Institutional theory posits that external coercive, mimetic, and normative pressures influence organizations in adopting specific behaviours and transforming their practices in order to align corporate practice with external expectations. In stakeholder theory, firms guarantee their survival by taking into account the need of a diverse set of stakeholders (suppliers, employees, customers, government, etc.). As exemplar, Farooque et al (2019) discuss what are the barriers to implementation of circular food supply chains in China. Fischer and Pascucci (2017) investigate how current institutional pressures shape inter-firm collaboration in circular supply chains and how the transition to CE may stimulate new institutional arrangements towards sustainability. Stal and Corvellec (2018) try to understand how Swedish apparel firms deal with institutional pressures by adopting decoupling strategies to implement circularity. Jain et al (2020) investigate if institutional pressures mediated by environmental management systems and organizational flexibility influence reduced environmental impact strategies in oil and gas Indian firms.

While stakeholder and institutional perspectives tend to move from the internal resource orientation to the external, environmental-oriented perspective, they do not capture the physical changes at the heart of the shift from linear to circular systems, such as push versus pull production modes and reverse flows. The fact that CE entails a combined change in both physical flows and governance when emerging new relationships with new actors are incorporated, CE investigation should lead to the exploration of the network perspective. Yet, it highlights the limited exploration of theoretical lenses that can capture changes at the supply-network level.

2.3. Lacking a supply network perspective

One of the most important principles of CE according to the think tank Ellen MacArthur foundation is to “think in systems”, e.g., to acknowledge the interdependencies occurring in our complex world and produce not only economic, but social and environmental value. This relates to aspects of inclusiveness and connectivity, where systems are interconnected and not isolated from each other (De Angelis, 2020). A system-network perspective can unveil co-evolutionary changes in technology, culture, economy and organizational structures (Gorissen, Vrancken, & Manshoven, 2016). The transition to CE entails not only a process shift, but also a governance shift that must breakup the natural inertia (Sarasini & Linder, 2018). The three core strategies of CE – namely narrowing, slowing and closing all have strong impact on OSCM core concepts (Bocken, de Pauw, Bakker, & van der Grinten, 2016).

Yet, our review of the literature exposes the lack of attention to OSCM concepts that can address dynamics tensions across supply network actors. The review identified only three studies employing network-related theory lens. One study using complex adaptive systems (CAS) – a concept used in the OSCM field to capture tensions and co-opetition among supply network actors. One study employing the notion of brokerage from social network analysis (SNA). And a third study using both CAS and SNA to discuss circularity in supply networks.

Chertow and Ehrenfeld (2012) use CAS to theorise industrial symbiosis, bringing probably one the first perspectives of self-organised systems into the CE theorisation realm. The study opens a discussion on governance of circular systems, the coevolution of involved actors while focused on industrial clusters.

Ciulli, Kolk, and Boe-Lillegraven (2019) look at how waste recovery in food supply chains can be increased when ‘circularity brokers’ can bridge ‘circularity holes’, basically digital platforms that link food waste generators to those who can consume it. Their theorisation leads to six different types of brokerage, and provide incipient exploration of SNA to discuss circularity in supply networks.

Finally, Tate et al. (2019) propose a biomimicry lens to frame circular systems. In a natural ecosystem, circularity is ensured as members of the system occupy these four roles:

producers, consumers, scavengers, and decomposers. Exemplary primary producers are plants that capture energy and micronutrients to supply food; consumers process the food and energy generated by the producers. Scavengers are animals such as cockroaches, raccoons, jackals, and hyenas that search and feed on dead plants and carcasses and prepare for the decomposers. Decomposers are the bacteria and fungi that break down material for recycling, helping complete the circularity by providing micronutrients that producers need. The ecosystem is balanced if producers make enough food for consumers that in turn must not deplete resources. The authors explore both CAS and SNA visual diagrams to connect CE to a supply network perspective. They underline the need to foster the development of two new actors - scavengers of discarded goods and decomposers of discarded material in order to boost circularity.

Taken together, the three above articles offer an incipient glance on how a social network perspective can capture both physical and governance flows in the transition from linear to circular systems. Yet, they fall short of some key elements to offer a fully-fledged operationalization of circularity to the OSCM field. We next advance further on the path initiated by these three studies.

3. Conceptual foundations

3.1. Revisiting OSCM push-pull: a circularity perspective

The classification of production systems in terms of push versus pull flows traces back to the initial comparison between Western and Eastern modes of production. While Western systems based on material resource planning have been characterised by the ‘push flow’, the Toyota Production System (TPS) emerged in the East as the ‘pull flow’ alternative. The dissemination of the TPS to other contexts led to the consolidation of the lean and just-in-time approach as a main alternative to the traditional push flow (Slack, 2003). The push-pull dichotomy reached mainstream management research. In fact, it has become part of the management jargon, being used to reflect a wide array of issues, including the push-pull dilemma in theory advancement (Fisher & Aguinis, 2017).

Further advancements have refined – unpacked the pull production flow in terms of lean, agile, and hybrid modes (Christopher, Peck, & Towill, 2006). While the lean mode would fit high volume, low variety/variability production, the agile mode would address challenges of low volume, high variety/variability operations. Fashion has been particularly chosen to discuss these alternatives (Christopher et al., 2006). Yet, resource efficiency have come alongside fierce marketing: ‘fast fashion requires fast marketing’ (Sheridan, Barnes, Moore, & Nobbs, 2006). In fast fashion, production benefits from a pull system to reduce over-stock, but short product life cycles and aggressive and seductive marketing would ensure the constant purchase by final customers, thus accelerating rather than alleviating the system. Ultimately, fast fashion has shifted over-stock from the brands and retailers to the wardrobe of the final customer.

The push-pull dichotomy that grounds most OSCM research has not yet been put against a circular perspective. There is a clear tension between them, as both push and pull go against the tenets of CE, favouring efficiency seeking and output growth. What is most important to CE theorisation, is that despite the evolution of production systems, in common, they have all emerged within a linear mentality. There is thus a need to evolve the OSCM jargon to embrace a circular perspective. How should we reconsider/ reconceptualize the push-pull dichotomy when considering the CE strategies of narrowing, slowing and closing (Bocken et al., 2016)? By the same token, how can CE theorisation benefit from the mature production flow terminology to explain the transition from linear to circular systems?

3.2. Reframing circularity: a supply network perspective

No firm is expected to carry out a circular transition on its own. Firms are part of supply networks therefore they will shape and be shaped by the environment where they are inserted in. Institutions may influence this environment in some form, as in the case of governments through public policy. The structure of the relations and social network ties may be expected to coevolve.

The work of Tate et al. (2019) shows the potential of SNA to capture biomimicry and CE through a OSCM perspective. More specifically, a supply network perspective by reflecting on each of the four biomimicry roles. In business systems, the producer role might be taken by various interlinked actors. Take garment production, for example, primary producers will be at the agricultural stage of cotton farming, while secondary producers will include manufacturers of yarn fabric and the final garment itself. The same goes for consumers: while brands may be considered consumers within the biomimicry lens, if they outsource their full production to suppliers, final customers are primary consumers of the product. Finally, the two roles of scavengers and decomposers are absent in traditional linear systems and emerge as the transition to circular systems evolve. There is limited mapping of scavengers and decomposers and unbalance between traditional actors and such emerging actors (Tate et al., 2019).

Despite the major contribution offered by this study, key questions are left unanswered: how can we identify the level of circularity of a given supply network? How the emergence of decomposers and scavengers affect the push-pull dichotomy? Most importantly, can we still use such terminology within a CE perspective? We intend to advance the field by articulating a set of SNA metrics that can map changes in network structure when systems transition from linear to circular.

3.3. Reviewing social network metrics

Social network analysis (SNA) can examine economic phenomena through two foundational elements: nodes and ties. Nodes are the members that compose the network and interact in many possible ways, and the relationships between the nodes are called ties (Borgatti & Foster, 2003). Network members are thus connected by ties that can represent social interactions, product flows or finance flows, thus forming multiple layers (Borgatti, Everett, & Johnson, 2013). In intra-organisational contexts, network layers represent different types of relationships between members of an organisation, such as formal and informal ties (Krackhardt, 1992) or help/support networks (Doreian & Conti, 2012). In inter-organisational contexts, network layers represent different types of interactions between members of the supply network, such as contracts, product flows, and knowledge sharing (Kim et al., 2011; Marques, Yan, & Matthews, 2020). The analysis of multiple layers fit the reality of OSCM since interactions between supply network actors may be analysed according to the material flow as well as the information flows and power dynamics (Borgatti & Li, 2009).

SNA is the toolbox that can help categorise different networks using metrics at the level of the nodes (supply network actor) and at the level of the network – here the supply network. The SNA toolbox can offer metrics to differentiate supply network structures across the CE strategies. Although CE research has focused so far on the physical shifts, we explore SNA metrics to enlighten governance shifts as well (Chertow & Ehrenfeld, 2012; Ciulli et al., 2019). Such metrics fits well with our goal to produce a framework for circular supply networks as they help in differentiating between supply networks under a traditional strategy – i.e., the linear system, and the alternative strategies based on narrowing, slowing, and closing (Bocken et al., 2016). Differentiation can be produced by both node-level and network-level metrics.

At the node level, the array of measures of centrality can support our goal. Centrality refers to the position of one node (supply network actor) within the network surroundings (Borgatti et al., 2013). Some measures of centrality have been particularly explored within the OSCM context. The most adopted one is degree centrality, which is also the most straightforward, reflecting the total number of ties that one node has within the network. The higher the degree centrality, the higher the visibility of the node in the network (Kim et al., 2011). Despite its clarity and wide adoption, to build our framework we resort to two other centrality measures: betweenness centrality and eigenvector centrality (Yan, Choi, Kim, & Yang, 2015).

Betweenness centrality measures not the number of ties, but rather how often a node lies on the shortest path between all combinations of pairs of other nodes (Borgatti & Li, 2009). When a node lies in such a path, it means that node is connecting nodes that would otherwise be disconnected. As a result, these other nodes are dependent on this one standing at this *bridge* to reach out to the rest of the network. This metric thus reflects the role of a node as an intermediary and posits that this dependence of others makes the node central in the network. As such, the betweenness centrality usually denotes a node's potential control or influence in the network (Kim et al., 2011). A common jargon is to call a node with high betweenness centrality a *broker*.

It is easy to note that focal firms positioned in the middle of a supply chain funnel that connects many suppliers to many customers will exhibit a high betweenness centrality. Fashion brands, electronics brands, and large retail chains are examples of funnel leaders that often manage a large base of weaker suppliers while serving a large base of customers, thus, they exhibit high betweenness centrality (Gereffi & Lee, 2012). Conversely, as circularity increases, scavengers and decomposers emerge, power might be better distributed, and as a result, the betweenness centrality of such funnel leaders should reduce.

The second centrality measure in our framework is *eigenvector centrality*, which indicates a node that is connected to nodes that are themselves well connected (Borgatti & Li, 2009). In other words, eigenvector centrality reflects a node that is connected to other nodes that have high betweenness centrality themselves. The common jargon here is the expression 'it is more important to know people in power than having power yourself'. High eigenvector centrality can indicate nodes that instead of accessing a large base of customers, access other nodes that themselves have access to such a large base. For example, a small service company working for several large firms. Non-traditional supply chain actors may offer education and mobilization, without necessarily achieving the large scale of focal brands (Ciulli et al., 2019).

The two centrality metrics – betweenness and eigenvector – have been used to map innovation diffusion and the role of less obvious suppliers, the nexus suppliers (Yan et al., 2015). We employ the same supply network metrics to map the emergence of the new actors – scavengers and decomposers – in the transition to circularity. In traditional linear systems, major brands will hold power, acting as funnels between suppliers and customers, and exhibit high betweenness centrality. As circularity increases, betweenness centrality should decrease. If power is distributed among new actors particularly alongside the offer of services and educational services, eigenvector centrality might increase to reflect new supply network configurations. Finally, in fully de-centralised solutions, the high number of actors with some level of power and flow control may lead to both metrics achieving low values.

Besides node level metrics, a network level metric can also help comparing different strategies deployed in a supply network. The most adopted metric to classify networks is *network density*. Network density refers to the number of total ties in a network relative to the number of potential ties (i.e., if everyone was connected to everyone). It is thus a measure of the overall connectedness of a network (Kim et al., 2011). While low network density reflects a sparse network, where many nodes are not connected to other nodes, a high network density indicates a dense network where most nodes are connected to all other available nodes.

In the same way that centrality helps to map governance dynamics, network density can help as well. A linear system where the focal firm acts as a major broker between suppliers and customers will exhibit low network density. Conversely, alternative systems where competitors join forces, such as industry clusters (Chertow & Ehrenfeld, 2012) or where decomposers emerge to play a vital role in the system (Tate et al., 2019), new social ties emerge and network density should be higher.

Next, we categorise the three CE strategies in contrast to the baseline of a traditional linear system (Bocken et al., 2016). We illustrate this categorisation with examples of each of the three CE strategies in isolation, and later discuss a blended-strategy perspective.

4. Development of propositions

In this section we develop four theoretical propositions on how social network metrics can depict supply network circularity. The development of propositions is enriched by illustrative examples. We follow a similar path to Gereffi and Lee (2012) and Sodhi and Tang (2016) that have used examples from secondary data, as well as Pathak, Wu, and Johnston (2014) and Yan et al. (2015) that have used examples from previous research when developing their theoretical argument. For two examples, we also resorted to primary data to complement our understanding of the business model, when secondary data was insufficient. Rather than looking for data saturation as seen in empirical research, here we were purposively looking for examples to populate each of the strategies. Rather than grounding our theoretical development on the examples, we use them simply to illustrate our theoretical argument.

As shown in Table 2, the examples cover both fashion and electronics, which are placed among the top six sectors in supply chain emissions (WEF, 2021). Both industries are also dependent on a complex mix of raw materials that makes it harder to recycle disposed products. As such, we use them as extreme challenges for the CE.

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4.1. The narrowing strategy

Narrowing loops refers to reducing the use of material input, increasing resource efficiency, and reducing waste. Although narrowing saves on resource usage, it maintains the linear mentality of traditional businesses. Lean manufacturing, zero waste, and resource efficiency have emerged as linear strategies to narrow resource loops in the CE (Fischer & Pascucci, 2017; Sartal, Ozcelik, & Rodríguez, 2020). For instance, Sartal et al. (2020) investigate how lean practices support the transition to CE through improved water efficiency and labour productivity. Nonetheless, narrowing resource loops is not a sufficient strategy to harmonize with the objective of eternal growth, and it should be treated as a temporary solution as it does not reach full circularity (Fischer & Pascucci, 2017). Yet, it provides changes to the traditional flow of goods as well as less informational advantages.

Drawing from extensive literature on lean and agile that suggest the pull strategy is greener since it is more responsive/efficient than pushing inventory downstream, we elaborate on connections between the OSCM pull strategy and the CE narrowing strategy.

We take a first example in the fashion industry. The Brazilian fashion brand Movin offers a unique way to sell products to customers. The founder Pedro Ruffier is a young entrepreneur born in a countryside family that produces organic vegetables. He has long studied digitalisation, minimalism, and sustainable living. When Pedro decided to venture into a sustainable model, fashion was chosen as the tool to promote products that encompass design, technology, and ethics. Movin originally opened a flagship store in Ipanema, the richest neighbourhood in Rio de Janeiro, but during an economic crisis in 2016, they decided to sell only via the e-commerce channel. In their first years, Movin was awarded a financial grant from an NGO focused on fashion sustainability which gave the brand visibility locally and internationally. In 2018, Movin appearance in the news made a German investor take a plane to visit the store, soon after becoming Movin's largest trader.

The design of his brand, Movin, is minimalist, targeting long-lived garments, but most importantly, inverting the way that price is defined. After years without satisfactory growth in the local market, in 2021, during covid-19, Pedro idealized their 'inverted price model' labelled Movin ZRO®. The inverted price model consists of picturing new products on the website before production occurs. Customers that decide to buy a product enter a crowdfunding scheme, which means that they have to pay in advance and accept that if the minimum threshold of, say, 1,000 pieces is not met, money is returned. Once this threshold is met, the price increases for future purchases. The model is opposite to traditional fashion, where the price decreases as the season progresses and enters sale. The inverted price model offers a truly pull strategy in the sense that production concretely only occurs after sales, reducing inventory. It also is a clear exemplar of the CE narrowing strategy.

Next, we turn our attention to the electronics industry. Users keep their mobile phones for an average of 2-3 years before buying a new one, often banishing their old phone to the back of a drawer. Only 12-15% of discarded phones in Europe are recycled, with only a fraction of material actually being recovered. While the electronics industry ranks top 6 in carbon emissions, e-waste is the world's fastest growing waste stream, with 50 million tons produced per year.

Fairphone started in 2010 as a non-governmental campaign in Amsterdam focused on creating awareness to the general public regarding conflict minerals used in the mobile phone industry (Brix-Asala, Geisbüsch, Sauer, Schöpflin, & Zehendner, 2018). Since the demands of the campaign were not adequately taken up by the industry, the social enterprise, Fairphone, emerged in 2013 as the outcome of a crowd-funding campaign. Their initial business model was based on crowdfunding. The first 25,000 mobile phones were pre-sold – thus a truly pull flow. Since then, Fairphone has accumulated sustainability awards and shifted to the traditional push model, selling in selected retail partners around Europe. Their strong sustainability attributes have led to the emergence of alternative solutions – such as in France – where the platform Commonwn allows you to rent a Fairphone rather than buy one.

The narrowing strategy is a first step towards the sustainability and the CE, focused on resource efficiency beyond what traditional linear systems can offer. Yet, the brand is maintained at the middle of the funnel between suppliers and customers, thus network structure is not affected. This means that betweenness centrality, that reflect the shortest path between two nodes, will be high at the focal brand (Yan et al., 2015). The funnel format also sustains low network density as producers and final customers depend on the brand to reach each other (Kim et al., 2011). In Figure 1 we offer a visual representation of this discussion, and below we theorise our first proposition for the narrowing strategy:

Proposition 1: The narrowing strategy will exhibit a similar network structure to linear supply chains with high betweenness centrality, low eigenvector centrality, and low network density, combined with a truly pull strategy thus improving resource efficiency.

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4.2. The slowing strategy

Slowing resource loops aims to maintain products in use for as long-as-possible through long-life product design and product life-extension services (Bocken et al., 2016). Slowing loops is about keeping products and parts in use for as long as possible through reusing, repairing, and repurposing to preserve the inherent value of manufactured items. This indispensable CE strategy includes the offer of long-lasting designed products, repair services, upcycled products, performance-oriented services (Hofmann, 2019). In fashion, slowing strategy grounded on the upcycling method requires reduced amount of energy and materials to recreate value because the products only need minor alterations (Fischer & Pascucci, 2017; Zacho, Bundgaard, & Mosgaard, 2018). In terms of product flow, the handcraft nature of upcycling techniques may impose brands to engage with new actors – scavengers that can re-work products. Once again, we explore one exemplar in fashion, and another in electronics.

The fashion example is Comas, created by a Uruguayan, and operated in Brazil. Agustina Comas is a Uruguayan fashion designer who started her career in 2004 working for luxury brands. Astonished by the overwhelming amount of overstock generated by the industry, in 2008, she started a side project that later evolved into the service platform Comas. Together with a friend they started producing "clothes from clothes", i.e., upcycling on a small scale to sell at fashion fair markets. In 2015, Comas was officially launched. The business started producing female fashion out of men shirts with small defects. During this period, she won runner-up for the Museum of the Brazilian House design prize. In 2020, Comas partnered with the first brand to upcycle slow selling SKUs. By 2021, Augustina won a financial grant from the C&A foundation to leverage her new business model.

An upcycling fashion platform acts as a scavenger, and it ignites chances on the social network structure beyond mainstream alternatives. First initiatives for upcycling fashion and slowing the product life cycle came from second-hand stores and informal solutions (Gorissen et al., 2016; Levänen, Lyytinen, & Gatica, 2018). These lack scalability and financial support (Marques, 2022). In a structured upcycling platform such as *Comas*, the brand plays the role of a scavenger (Tate et al., 2019). The know-how on handcraft techniques attracts large brands to engage with this new supply chain actor –which characterises eigenvector centrality (being connected to central nodes) (Yan et al., 2015). Yet, de-centralisation is not complete because upcycled products might still flow via the fashion brands channels back to customers.

Our second example is in the electronics industry. Gerrard Street is an Amsterdam based start-up founded in 2015 to provide customers with the possibility to buy or rent (via monthly subscription) a high-quality high-technology headphone. The slowing strategy comes from the fact that repairs are free forever, irrespective of the customer choice, which increases the product lifecycle. This is achieved by a modular design that allows for 85% of the parts to be replaced. After subscribing or buying the phone, customers receive it at their homes. In case headphones are damaged, Gerrard Street sends a replacement part in 24 hours following a customer request. The replacement part comes with a prepaid envelope for customers to ship back the damaged part free of charge. The company prioritizes repairing the returned part. Gerrard Street also engages in the closing strategy – as it has been working on solutions to recycle damaged parts that cannot be reused. Interestingly, in this business model customers act as scavengers themselves, with no need of a scavenger platform/cooperative. Therefore, dispersion is higher than in the previous example, but a similar network structure.

The emergence of scavengers can reshape the network structure. First, it can partially reduce betweenness centrality, while increasing eigenvector centrality as scavengers connect to major brands to offer their repairing/upcycling capacity. Network density can also partially increase as the physical flows are dispersed via a large number of supply chain actors. Figure 2 is a visual summary of these reflections, and below our second proposition frames the slowing strategy:

Proposition 2: The slowing strategy will exhibit semi-circular loops as scavengers emerge, and the network structure will exhibit lower betweenness centrality, higher eigenvector centrality, and higher network density when compared to linear supply chains.

------- Insert Figure 2 here -------

4.3. The closing strategy

Closing resource loops is the third and complementary strategy to narrowing and slowing. Once the flow has been narrowed, and the life cycle has been slowed, and still there is disposal of the good, closing is the third chance to avoid environmental impact. It can also emulate a full circular perspective from source to customer (Bocken et al., 2016). We once again elaborate on illustrative examples from fashion and electronics.

In the fashion industry, the iconic example of the closing strategy is recycled cotton (MacArthurFoundation, 2017). The solution is dependent on both scavengers and decomposers. Recycled cotton begins with the reverse flow of either textile waste (discarded by industry) or disposed clothes (discarded by final customers) (Woolridge, Ward, Phillips, Collins, & Gandy, 2006). While scavengers operationalize the reverse flow, decomposers must master the de-fibrillation technology, that is needed to reuse cotton (Bevilacqua, Ciarapica, Mazzuto, & Paciarotti, 2014). In Brazil, PG Fios was the first company to offer recycled yarn. Although the decomposer is the critical supply chain actor, garment producers also need to adapt to use recycled cotton as input. Producers such as Cocamar had to adapt their process to use recycled yarn, and producers such as Ecosimple were created with the primary purpose of working with recycled yarn. For brands that have long engaged with sustainability, recycled cotton has been a challenge due to lack of preparedness of decomposers, until PG Fios offered a solution (Marques, 2022). Yet, brands adopting recycled cotton also need to adapt their design process as colours are not previously defined any more, but rather accepted as result of the recycling process.

In the above example it becomes clear how new actors emerge, while existing actors in the supply chain had to adapt their process to incorporate recycled cotton in their business model. This profoundly reshapes the network structure.

In the electronics sector, Umicore is a Belgium materials technology and recycling group at the cutting-edge of the CE. The company's origins as a traditional mining company can be traced back to the 19th century. In the 1990's, the company started shifting away from mining to focus on precious metals, but it was in 2000 that the company rebranded itself and started to focus on recycling of precious metals and urban mining. Suppliers provide Umicore with their end-of-life materials, production scrap or by-products for recycling and further refining. Umicore is equipped to recycle e-waste (printed circuit boards, cell phones, CPUs, laptops, etc.). They recover precious metals (e.g. gold, platinum), minor metals (e.g. indium, selenium) and base metals (lead, copper, nickel). The supplier chooses if the recycled materials are sent back to them or Umicore can sell to other parties. Here, there is less change in the network structure, but a shift of centrality. The decomposer can serve both producers and customers directly, reorganizing power dynamics as the solution scales (Levänen et al., 2018).

The dynamics between traditional (producers and consumers) and emerging actors (scavengers and decomposers) dilute power. In addition, limited availability of decomposers and scavengers reduces focal brands' power over their supply chain. Network structure follows. First, the betweenness centrality will decrease as scavengers can engage directly with customers, and decomposers partner with suppliers. Eigenvector centrality will not be as high

as in the slowing strategy because multiple new actors now engage with previously established major players. Network density is thus at its peak, as there is dispersion of both physical flows and contractual relationships (Kim et al., 2011). The model evokes de-centralisation and co-opetition (Pathak et al., 2014). Such challenges add to closing strategy being the least efficient strategy (Fischer & Pascucci, 2017). We align with research proposing it is the de facto circular solution (Bocken et al., 2016), yet the tension highlights the 'chicken-and-egg' challenge of scalability.
While Figure 3 offer visual representation that grounds our third proposition on the impact of the closing strategy:

> *Proposition 3: The closing strategy will exhibit fully closed-loops with scavengers and decomposers, and the network structure will exhibit lower betweenness centrality, lower eigenvector centrality, and higher network density when compared to linear supply chains as well as the narrowing and the slowing strategies.*

------- Insert Figure 3 here -------

4.4. Social network metrics for circularity

------- Insert Table 3 here -------

We offer a comparison between the four supply networks: traditional linear system, followed by narrowing, slowing, and closing strategies. The comparison highlights the changes in the production mode, governance, and network structure operationalized with social network metrics.
As we move from left to right in Table 3, the traditional supply chain funnel evolves into a circular system. The shift is supported by emerging new actors – scavengers and decomposers, as well as changes experienced by traditional actors. The more the system moves towards circularity, betweenness centrality decreases, as brokerage is divided or dispersed. In addition, eigenvector centrality helps to underline the difference between slowing (high eigenvector centrality) and closing (low eigenvector centrality). Co-opetition and dispersed brokerage are present in the slowing strategy, but stronger in the closing strategy. Network density follows the shift in network centrality, ranging from low (traditional and narrowing) to medium (slowing) and finally high density (closing).
It is important to note that all illustrative examples in this study are locally bounded to specific countries as Brazil (Movin, Comas, PG Fios) and Netherlands (Gerrard Street). Previous research also noted locality – see recycling batteries in Chile and Finland (Levänen et al., 2018), food waste in the US, Canada, or specific European countries (Ciulli et al., 2019) or other examples of urban mining in the Netherlands (Tate et al., 2019). In fact, our systematic review revealed over 50% of empirical studies reported examples in European countries, with the Netherlands and Spain leading within that. There are cases of multi-country businesses – the Fairphone as one of the exceptions, although still restricted to Europe.
The Fairphone can also be used to expand our framework for blended strategies. Our framework isolates the strategies to conceptualize their core differences, but CE business models often combine strategies. The Fairphone has been launched as a blend of all three strategies. Their modular design implements the slowing strategy as broken parts can be repaired by customers. With that, they expand the mobile lifecycle from 2-3 years up to 4.5 years. They also recover phones and parts with the higher rate of recyclability in the mobile phone industry targeting to reach 100% circularity in 2023.

The Fairphone might seem a brand-driven business, but we must remind ourselves of their origin as an NGO. We also witness emerging actors such as the rental solution in France that add diversity to the supply network, thus confirming reduction of network centrality and increase of network density. In line with De Angelis' (2020) definition, CE 'is enabled by multiple, cooperative, and simultaneous innovations'. It is never one brand on their own journey, but the joint development of complementary innovations that drives blended strategies as well, as elaborated on our fourth and last proposition:

> *Proposition 4: Blended strategies that combine the closing strategy with other strategies will also exhibit lower betweenness centrality, lower eigenvector centrality, and higher network density when compared to linear supply chains.*

5. Conclusions

5.1. Implications to theory

This piece of research begins by exposing that the extant CE research has been mainly atheoretical. The large majority of studies building or borrowing theory lack a network perspective. This focus may provide a short-sighted conceptualization and understanding of the field given the systematic nature of CE. So far, it seems that enough effort has been put both on CE challenges related to physical material/energy flow, while governance and network structure have been neglected (Korhonen, Nuur, et al., 2018). In addition, we discuss that despite the fact that the push-pull dichotomy became management jargon (Fisher & Aguinis, 2017), we found no OSCM study elaborating on how push and pull related to circularity.

We fill both gaps above by bridging CE and OSCM. From the CE perspective, we take the three strategies of narrowing, slowing, and closing (Bocken et al., 2016). From the OSCM literature we take the push-pull dichotomy for physical flows, and the social network lens for governance and network structure (Kim et al., 2011; Yan et al., 2015). We elaborate on incipient CE taking a network perspective (Chertow & Ehrenfeld, 2012; Ciulli et al., 2019; Tate et al., 2019). The resulting four propositions reconcile CE and OSCM and offer contributions to both sides.

For CE research, we advance beyond metrics of the physical flow – i.e., resource efficiency, resource extended life, and recycling percentage to offer social network metrics. We also advance from qualitative discussions of brokerage (Ciulli et al., 2019; Tate et al., 2019) to specific metrics of network centrality (betweenness and eigenvector) and network density. Our propositions combine these three metrics to differentiate between traditional linear systems and the three strategies of narrowing, slowing, and closing. Our work also highlights how the emergence of the biomimicry roles of scavengers and decomposers induce the changes in social network metrics that reshape the supply network.

For OSCM literature we offer a reconciliation between push, pull and circular terminology. Seminal studies on SNA in the OSCM field have not addressed circularity (Borgatti & Li, 2009; Galaskiewicz, 2011; Kim et al., 2011). We propose how CE shapes the supply network combining CE jargon and network jargon in a structured format based on social network metrics of centrality and density.

5.2.Implications to practice and policy

Our study informs practice by outlining the crucial position of emerging actors on the role of scavengers and decomposers. Entrepreneurs of the CE can learn from the network structures offered in this study to develop their business models. The study describes how scavengers for example can shift from a secondary/informal position to a central position in the supply network. We also show that decomposers can be front-runners on the adoption of specific technologies, reshaping industry sectors.

Our propositions can also inform policy. As previously noted by Tate et al. (2019), less developed supply network actors such as scavengers and decomposers are in need of financial incentives and public awareness for circularity to gain traction and scale. Policy has been key to drive waste management in specific sectors (Gorissen et al., 2016; Marques, 2022). We offer a more fine-grained discussion of how scavengers and decomposers complement each other, as well as metrics to map the transition. Until we take a supply network perspective and foster a healthy economy for all circularity agents, there will be no circular economy.

5.3. Future research agenda

Our framework compares the strategies on equal terms. Scavengers are often low scale such as second-hand markets, and even informal (Gorissen et al., 2016; Levänen et al., 2018). Decomposers are often innovative solutions, one of a kind in their countries (Levänen et al., 2018). Thus, all three strategies still represent a tiny fraction of the volume flowing through traditional linear supply chains. Future research could understand what the scale threshold for a CE innovation is so that it truly reshapes the supply network.

Our illustrative examples have been concentrated in fashion and electronics. The global value chain lens has been used to characterize fashion as buyer-driven, with very low power at the hands of suppliers (Marques, Lontra, Wanke, & Antunes, 2021). Despite some level of upgrading in the East Asia region, most suppliers are still locked in a captive mode. Conversely, in the electronics as well as the automotive industries, innovative suppliers can be disruptive, rebalancing power (Sturgeon, Van Biesebroeck, & Gereffi, 2008; Yan et al., 2015). High-tech industries experience a more intense innovation pace (Nair et al., 2016). Future research could explore the political lens of GVC to understand how power dynamics influence the development of CE innovations in supply chains.

Shifts from linear to circular supply networks may be rather dynamic, with a few cycles of back and forth before stability is reached. Status quo may resist the change inhibiting circular solutions. Future research could explore the social network metrics proposed here with the CAS lens to account for a longitudinal/dynamic view of tensions during the transition to circularity (Chertow & Ehrenfeld, 2012; Choi, Dooley, & Rungtusanatham, 2001).

Further research could also stress test our propositions in other industry sectors. Would there be differences between non-organic products and circular solutions in the food sector? Would our propositions be sustained in FMCG more broadly as well as other industry sectors? Are there other metrics that can help depict circularity? What combination of metrics for both physical flows and network structure could help depict a broader array of configurations for supply network circularity?

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Table 1. Map of theoretical lenses in the sample

Management theories

Theory	**#**	**%**	**Theory**	**#**	**%**
Resource-Based View	17	*24%*	Complex Adaptive Systems	2	*3%*
Dynamic Capabilities	14	*19%*	Natural Resource-Based View	2	*3%*
Stakeholder Theory	11	*15%*	Upper Echelons Theory	2	*3%*
Resource Dependence Theory	4	*6%*	Other theories (one instance each)	11	*15%*

Social Science theories

Theory	**#**	**%**	**Theory**	**#**	**%**
Institutional Theory	18	*25%*	Agency Theory	2	*3%*
Transaction Cost Economics	6	*8%*	Social Network Theory	2	*3%*
Ecological Modernization	4	*6%*			
Transition Management Theory	4	*6%*	Other theories (one instance each)	5	*7%*

Total numbers

Macro-Category	**#**	**%**	**Theory**	**#**	**%**
Management theories	44	*61%*	Grounded Theory/Theory Building	7	*10*
Social science theories	28	*39%*			

Note: The same article may mention multiple theories.

Table 2. Summary of illustrative examples

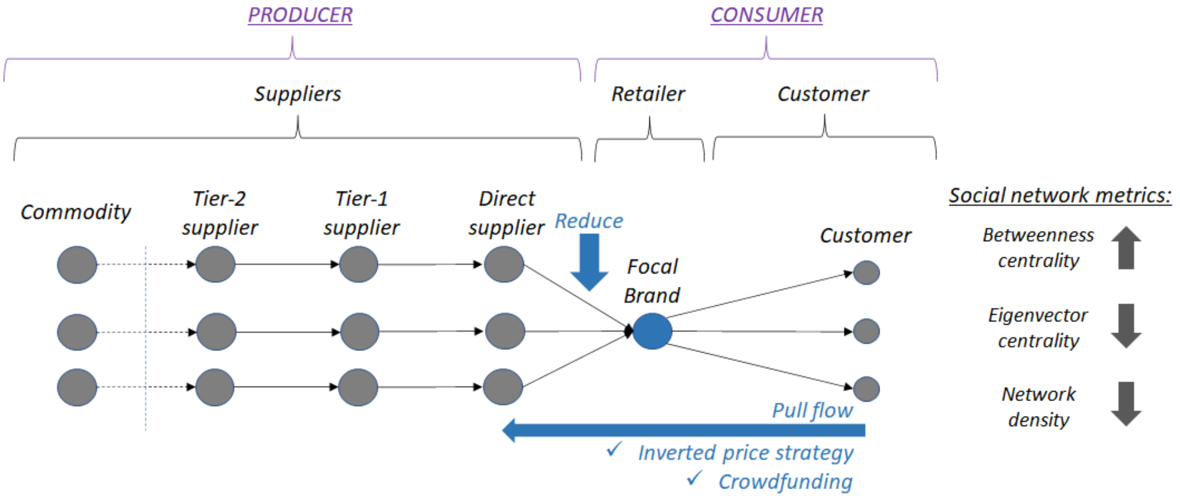
	Narrowing	**Slowing**	**Closing**
Fashion	*Movin* Interviews with the founder in 2020 https://startmovin.com/	*Comas* Interviews with the founder in 2021 https://comas.com.br/	*PG Fios, Cocamar, and Ecosimple* Book chapter (Marques 2022) https://www.cocamar.com.br/ https://ecosimple.com.br/

Electronics	*Fairphone and Commonwn* Article (Brix-Asala et al 2018) https://www.fairphone.com/en/ https://commown.coop/	*Gerrard Street* https://gerrardstreet.nl/en/ https://ellenmacarthurfoundation.org/circular-examples/gerrard-street	*Umicore* https://www.umicore.com/en/ https://pmr.umicore.com/

Table 3. Metrics for supply network circularity

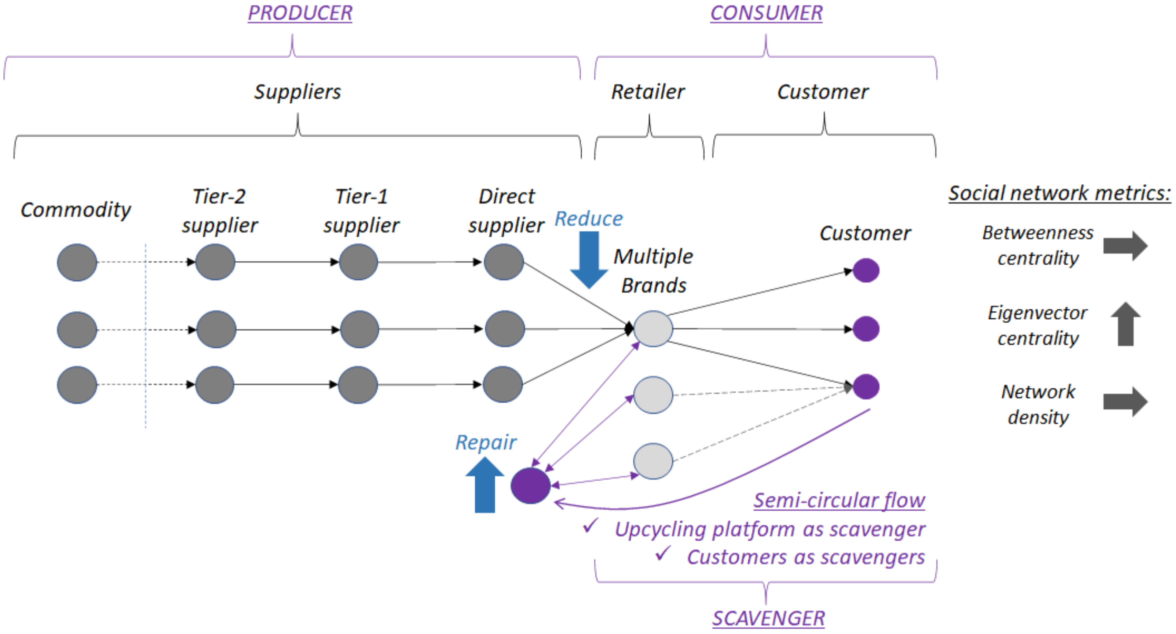
	Linear	Narrowing	Slowing	Closing
Production mode	Push system	Pull system	Semi-circular loop	Closed loop
Physical flow metrics	Output growth	Resource economy + Output reduction	Repair (upcycle, extend life)	Recycle (turning waste into value)
Governance	Brand as supply chain funnel	Brand as supply chain funnel, but higher transparency	New actor: Scavenger as upcycling platform	New actors: Scavengers as recycling cooperatives Decomposers as new industry actor
Network centrality	High betweenness centrality Low eigenvector centrality	High betweenness centrality Low eigenvector centrality	Medium betweenness centrality High eigenvector centrality	Low betweenness centrality Low eigenvector centrality
Network structure	Funnel structure Low network density	Funnel structure Low network density	Upstream funnel, Downstream network Medium network density	Dense network High network density

Figure 1. Narrowing strategy. Still linear supply chain



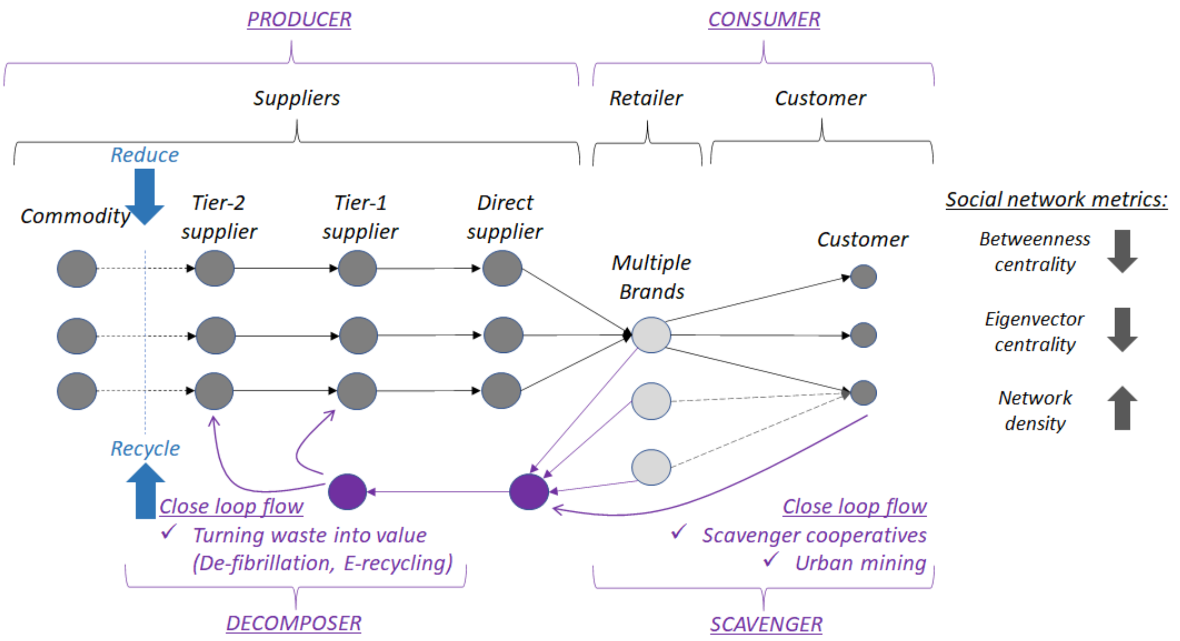
Analytical category	Supply network configuration	Proposed metrics
Production mode / Physical flow	<u>Pull flow</u> - Inverted price strategy - Crowdfunding strategy	Resource economy Output reduction
Governance / Network structure	Brand as supply chain funnel, but higher transparency	High betweenness centrality Low eigenvector centrality Low network density

Figure 2. Slowing strategy. Semi-circular supply network



Analytical category	Supply network configuration	Proposed metrics
Production mode / Physical flow	<u>Semi-circular flow</u> - Upcycling platform as scavenger - Customers as scavengers	Repair rate (Extending lifecycle)
Governance / Network structure	Scavenger connecting to major brands Upstream still funnel, but downstream network density	Medium betweenness centrality High eigenvector centrality Medium network density

Figure 3. Closing strategy. Closed loop supply network



Analytical category	**Supply network configuration**	**Proposed metrics**
Production mode / Physical flow	Close loop flow - Scavengers: cooperatives, urban mining - Decomposers: de-fibrillation, e-recycling	Recycle rate (Turning waste into value)
Governance / Network structure	Fully fledged network structure	Low betweenness centrality Low eigenvector centrality High network density

Appendix A. Systematic review of theory use in CE research

Academia has witnessed a sharp increase in the number of publications devoted to CE since the 2010's, followed by some literature reviews on the topic (Homrich et al., 2018; Merli et al., 2018). Past reviews have mapped the origins of CE and its relation to sustainability and other affiliated concepts (Geissdoerfer et al., 2017; Merli et al., 2018; Murray et al., 2017; Suárez-Eiroa et al., 2019; Winans et al., 2017). Reviews have also sought to define this emergent concept (De Angelis, 2020; Homrich et al., 2018; Kirchherr et al., 2017) and discussed the role of business models in the CE transition (Lahti et al., 2018; Nussholz, 2017), mapping barriers and the needed changes (Bocken et al., 2016; Hofmann, 2019; Kalmykova et al., 2018). Finally, some reviews have highlighted the need of robust theorisation (Korhonen, Honkasalo, et al., 2018; Korhonen, Nuur, et al., 2018). Liu et al (2018) have discussed the overlap of theories between CE and green supply chain management. Lahti et al (2018) have reviewed the management literature in order to provide a range of theoretical perspectives to guide practice and research. Sehnem et al (2019) have conducted mapped management journals to identify organizational theories. Finally, Jabbour et al (2019) have identified the theoretical lenses applied in the intersection between CE and operations and supply chain management (OSCM). Such previous efforts have mapped the status quo, but a robust theoretical framework that connects CE and OSCM is yet to be offered.

The search was conducted using Web of Science (WoS) and Scopus. WoS can reach indexed journals with calculated Impact Factors (IF) and Scopus in the largest database (Hofmann, 2019; Homrich et al., 2018). References from them can be properly imported to reference management software with studies' respective abstracts, keywords, authors, countries, years, etc. During the search, English was selected as the exclusive language and no limitation for the search period was applied. Search strings comprehend CE and theory related expressions. In Scopus the search was inquired into the fields “Title, Author Keywords, Abstract” while in WoS the research criterion is inquired into “Topic” (Title, Author Keywords, Abstract, Keyword Plus®”) – Table A1.

Table A1. Search strings used in the search

Search Strings		
Circular Economy Related		Theory related
"circular econom*"/"circular business model*/ business model* AND circular econom* / closed-loop econom* / circular supply chain	AND	theor* / lens* / transaction cost / dynamic capabilit* / complex adaptive system / resource dependenc* / path-dependenc* / "ecological moderni?ation" / "socio-technical transition" / "endogenous growth" / "decoupling" / "actor network" / "upper echelon" / "contingen*" / "disruptive innovation" / "resource advantage" / "knowledge-based" / "population ecology" / "diffusion of innovation" / "innovation diffusion" / "institutional logic*" / "institutional void" / "organi?ational learning" / "radical innovation/ resource-base*/

Organizational theory related strings were included to delimit the quantity of returned articles as the total mentions to CE has reached over 5,000. Conversely, we have not restricted the search to management journals to avoid the exclusion of, for instance, the journals *Resources, Conservation and Recycling* and *Sustainability* which appear between the most prolific journals in CE research, including publications by management scholars (Geissdoerfer et al., 2017; Homrich et al., 2018; Merli et al., 2018). Theory search strings included “theory”, “lens” and the name of prominent organizational and management theories that may not include the word theory, such as resource-based view, dynamic capabilities, complex adaptive systems, and transaction cost economics. These theory strings were derived from theories found in previous literature reviews on the CE (Lahti et al., 2018; Liu et al., 2018; Sehnem et al., 2019) or related fields, such as sustainable supply chain management (Touboulic & Walker, 2015).

Publication types were restricted to peer-reviewed articles and reviews, including articles in press. Book reviews, conference proceedings and grey literature were excluded from the search to ensure the scientific quality and rigor of the sample. The search process returned 1,264 articles. These results were then transferred to the reference management software EndNote. After removing duplicates, 790 unique articles were left.

Titles and abstracts of the 790 remaining articles were read to guarantee fit with the purposes of this study and eliminate articles considered not relevant. Excluded articles include technical, modelling, macro-oriented articles; articles focused on perspectives of the individual; articles using non-management theories; and articles using the term ‘circular’, but only marginally treating the topic. When necessary, the article was scanned in full to evaluate fit with the study objectives. A final quality assessment was performed excluding articles from journals with no impact factor (IF) or not ranked in the Association of Business Schools (ABS), bringing the sample to 159 articles.

Table A2 summarises inclusion and exclusion criteria.

Table A2. Summary of inclusion and exclusion criteria for selection of relevant articles

Exclusion criteria	Book reviews, letters, conference proceedings; Call for papers; Grey literature; Articles focusing on modelling, simulations or technical aspects. Articles focused on macro perspectives, macro environmental and economic issues, public policy, regional issues, water and waste management. Theoretical or a-theoretical articles focused on individuals, consumers, employees Articles in which circular economy was only a secondary focus (articles that mentioned CE or CBM but treated them *marginally)*

	Papers that have a word of “theory” in the title, abstract or keywords but do not mention specific theories (considered a-theoretical).
Inclusion criteria	Only peer-reviewed English language journals Focus on considering how researchers apply theories and conceptualize circular economy through quantitative, qualitative or conceptual approaches rather than make sense CE mathematically Include paper with theories that have been applied or mentioned as part of propositions and discussion. Theory application includes using theories to build conceptual models, develop analytical models, and completing an explicit theoretical or data analysis. An applied theory indicates that this theory is actually applied for conceptual model development or analysis; or the study seeks to expand the theory. A mentioned theory indicates a theory is included to support some arguments or as potential theories to consider for future studies; but not the central application (Liu et al., 2018) Only articles published in journals with either IF or ranked in ABS

Next, the remaining 159 articles were scanned to map the use of theory, therefore excluding a-theoretical articles. The final sample was reduced to 72 articles. To avoid researcher bias, one researcher conducted the in-depth analysis of all the titles and abstracts, and borderline cases were discussed with the other researcher - see the full scheme in Figure A1 and the 72 articles per year in Figure A2.

Figure A1. Summary of inclusion and exclusion criteria for selection of relevant articles

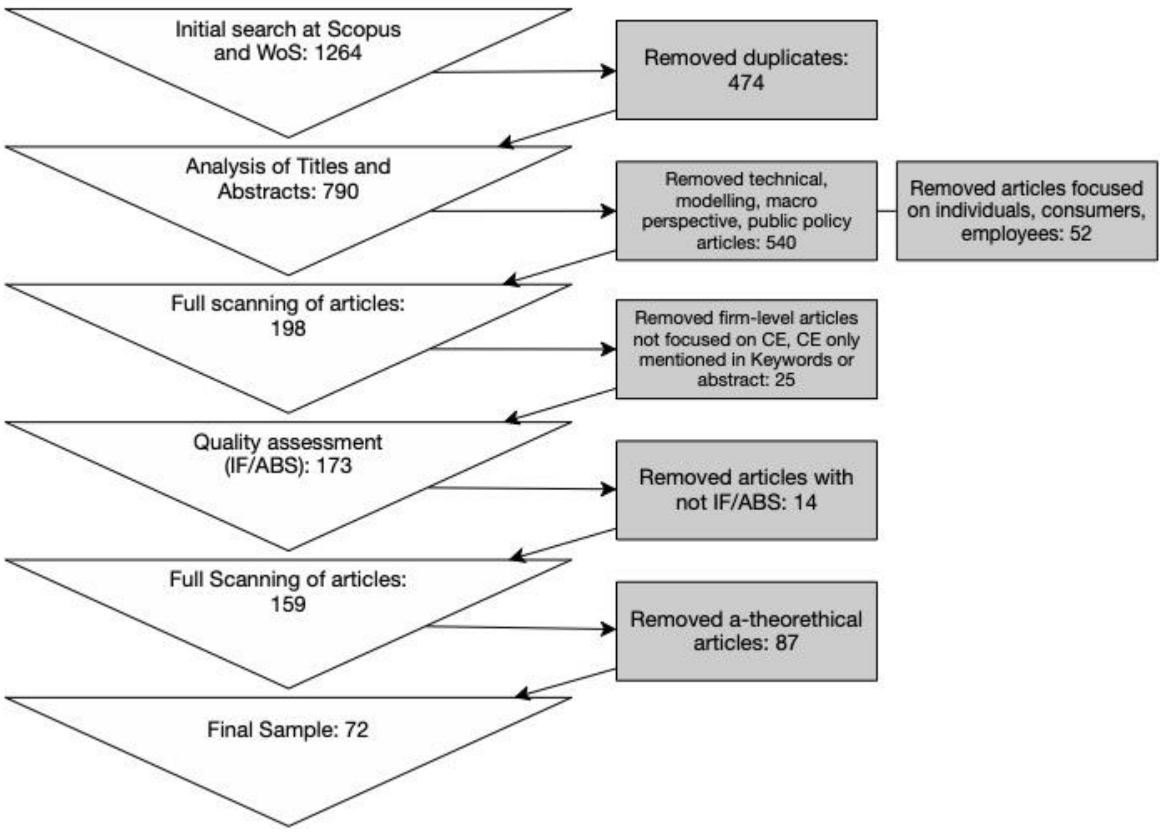
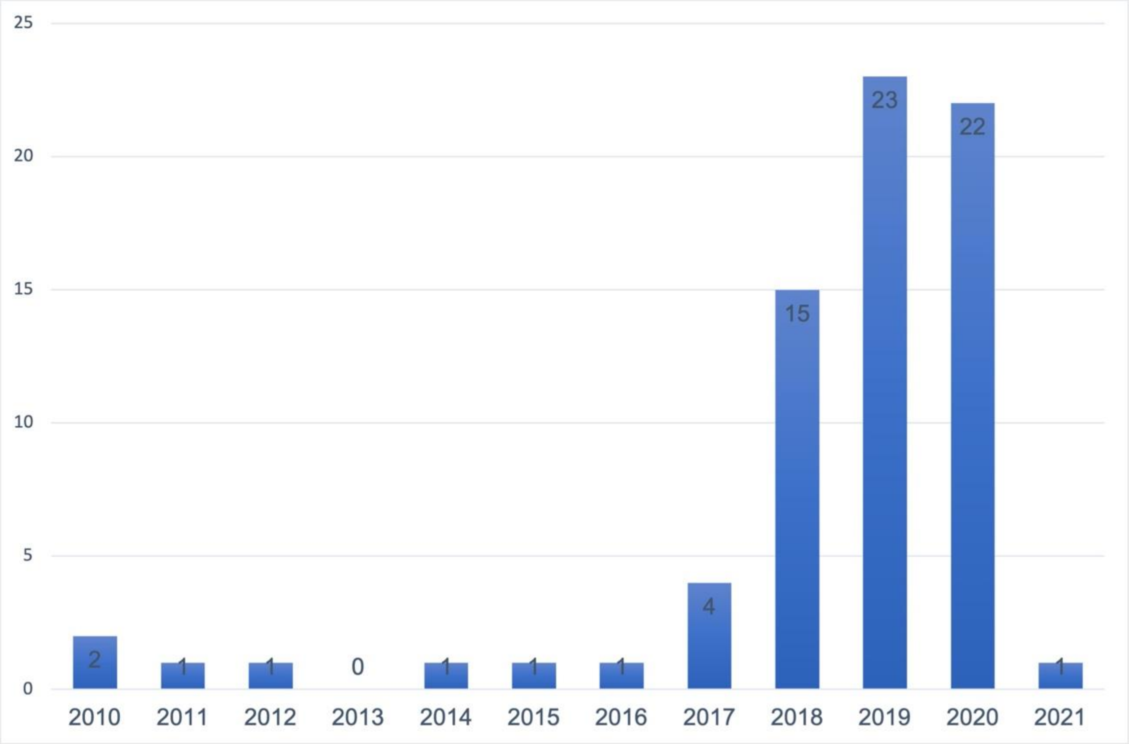


Figure A2. Number of theoretical articles by year



The remaining 72 articles were exported to the software NVivo where they were read coded both in terms of descriptive analysis as well as thematic coding to map use of theory. Table A3 offers the coding structure.

Table A3. Coding structure

Coding Categories	Description
Article Type	One of three possible classes: conceptual, review or empirical
Research Setting	Countries or regions where the study took place
Industry	Industry sector focus of the study, e.g. manufacturing, services, food and agribusiness, construction and infrastructure.
Research Methodology	Primary methodology employed by the study e.g. systematic literature review, survey, case study, focus group
Research Model	Classification of the research model according to Van de Ven (2007): process or variance
Theoretical Framework	The theoretical lenses identified in the study
Circular economy strategy	Classification of the study according to its CE strategy focus. Classes are: narrowing, slowing, closing, a combination of two or all of these dimensions

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