Circular economy: benefits, impacts and overlapping

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Abstract

Purpose – This paper aims to investigate overlaps, complementarities and divergences between the literature on circular economy (CE) models and related literature in non-linear production models and frameworks, including CE, reverse logistics, closed-loop, industrial symbiosis and industrial ecology.

Design/methodology/approach – A systematic literature review was conducted focussing on the benefits of non-linear modes adoption.

Findings – The results show a high degree of convergence in findings, gaps and weaknesses of these literatures. Negative environmental, economic and operational impacts are understudied. There is a scarcity of studies identifying practices resulting in empirically tested benefits. The business and society case for non-linear production is still largely built upon conceptual studies, modelling and a few case studies. Despite a normative focus, there is very little use of theory, in particular, management theories.

Research limitations/implications – First, the authors use only one, albeit highly recognized database, Scopus. This database may have omitted some relevant research, journals such as the *Journal of Cleaner Production and Resources Conservation & Recycling* that are more likely to publish such research and also have a more interdisciplinary approach. This is an important gap and interesting result to claim for more interdisciplinary research. Second, the filtering process used and the focus on Association of Business Schools top journals may have also omitted some relevant research, such as a large stream of literature in specialist journals such *as Resources Conservation and Recycling and the Journal of Cleaner Production*.

Practical implications – There are contradictions, tensions and epistemological ambiguity that needs to be critically addressed. Such tensions may be associated with the knowledge field that gave rise to these different non-linear production approaches. Many of them appeared at the same time, but from different sciences and disciplines with their own perspectives. Then in doing so, they create confusion in the definitions of CE, assumptions underlying modelling and business choices arising from this complexity. This can be minimized through the critical interpretation of knowledge to elucidate epistemological quandaries to improve the understanding of the economic, social and environmental impacts of practices.

Social implications – In some way, this result makes sense, as the authors have limited the search to management, business and accounts journals, especially talking about Operations Management journals. This is an important gap and interesting result to claim for more interdisciplinary research.

Originality/value – In addition to gaps previously described, the authors identified areas of tensions where the literature offers inconclusive – often contradictory – findings requiring further exploration. A better understanding of these tensions is required to understand the impacts of non-linear production and develop policy guidelines for industry and policymakers to scale-up CE.

Keywords Theories, Closed loop supply chains, Agile systems, Circular economy, Systematic literature review, Circularity, Overlaps

Paper type Research paper

The current issue and full text archive of this journal is available on Emerald Insight at: **www.emeraldinsight.com/1359-8546.htm**

Supply Chain Management: An International Journal
24/6 (2019) 784–804

[DOI 10.1108/SCM-06-2018-0213]

The authors would like to thank CNPq (The Brazilian National Council for Scientific and Technological Development) for supporting this research. They also acknowledge financial support from the Spanish Ministry of Economy, Industry and Competitiveness; Agencia Nacional de Investigacion and the European Regional Development Fund, R&D project ECO-2015 –66504 and Excellence project of Junta de Andalucia SEJ-7085.

Received 4 June 2018
Revised 14 August 2018
21 August 2018
Accepted 21 August 2018

1. Introduction

To extend sustainability throughout the supply chain, companies often choose to implement different management practices. In the literature, the practices used to manage resource circularity, efficiency and optimization are referred to as the circular economy (CE). CE proposes to replace wasteful and inefficient linear and open-ended cycles of production (input-output-waste) for a closed-loop where waste is minimized or transformed into inputs and value is created in the process (Blomsma and Brennan, 2017; Homrich *et al.*, 2018). The CE contributes to raising productivity, optimizing the use of natural and human resources (Missemer, 2018) and increasing efficiency in resource management (Linder and Williander, 2017; EEA, 2016). CE ideas have been gaining traction in the past decade in policy formulation, advocacy, consulting and natural sciences (Reike *et al.*, 2018). However, despite some successful examples, scalability remains a major issue and CE practices are still far from being widespread in the industry (Ghisellini *et al.*, 2016). However, Korhonen *et al.* (2018) shows that the concept of CE and its practices have almost exclusively been developed and led by practitioners, i.e. policymakers, businesses, business consultants, business associations, business foundations, etc (EMAF, 2013; CIRAIG, 2015).

Our opaque understanding of interventions and conditions needed to scale-up CE is, perhaps, influenced by the limited discussion of CE benefits in mainstream management literature. An analysis of the articles available in the Scopus database shows that journals belonging to the Association of Business Schools (ABS) Ranking – Rating 3 or higher list, in the period 2007 to August 2017, have published only eight articles on the CE in these 10 years. Related non-linear production models have been investigated by literature in closed-loop processes, reverse logistics, industrial ecology, cradle to cradle and industrial symbiosis. However, it is not known to what extent the findings of these streams of literature converge and can be used to expand our understanding of CE. Table I shows definitions for each of these terms.

To date, scholars conducting literature reviews in CE have adopted a definition of the field and then followed a more or less flexible criterion to include related terminologies/keywords within the scope of that definition; the result crafted is what Homrich *et al.* (2018) calls a CE "umbrella." However, there has been no attempt to compare and contrast literatures conducted under possibly parallel closed-loop/CE terms. As a consequence, it is unclear what gap may still remain in our knowledge. Once tensions have been identified, insights from all non-linear production systems perspectives are consolidated into a unified body of literature.

Therefore, the intention of this study is to analyze what are the overlaps that exist among the CE, reverse logistics, closed-loop, industrial symbiosis, industrial ecology, cradle to cradle and life cycle assessments. We conclude that there is a high level of complementarity among these different approaches. Our results show a high degree of convergence in finding gaps and weaknesses, but some differences can also be identified.

- There is a nested relation where industrial ecology contains industrial symbiosis; industrial symbiosis, in turn, contains closed loop and closed loop contains reverse logistics.

Table I Definitions

CE	In a CE model, wastes become resources to be recovered and reclaimed through recycling and reuse [the value of the resources we extract and produce should be kept in circulation through intentional and integrated productive chains. The final destination of a material is no longer a matter of waste management, but part of the process of designing products and systems (Gregson *et al.*, 2015)]
Cradle to cradle	Design concept to implement industrial ecology ideas, creating products that permit the safe and potentially infinite use of materials in cycles. It focusses on the design of manufactured objects, where disassembly, adaptation and reuse are considered from the outset. It provides for an economy that eliminates waste through reconditioning, remanufacturing and recycling. Circular logic of creation and reuse, where each cycle passage becomes a new cradle for a given material (McDonough and Braungart, 2002)
Reverse logistics	Process of moving back used or unused products or part of products from its typical final destination (i.e. consumer waste) to a producer in a distribution channel, with the aim of regaining value or proper disposal. It advocates collection and restitution of waste to industry so that it can be reintroduced to the production chain or reused (Rogers and Tibben-Lembke, 2001)
Closed-loop	Closed-loop is a logistic process system combining reverse logistic and forward logistics (procurement, production and distribution) with focus on reducing use of raw material and generation of waste by treating effluents and returning them to reuse and/or increasing the durability of products. Closed-loop processes refrain from throwing away used products, components and materials, reorienting them to generate value in other production chains (Morana and Seuring, 2007)
Industrial symbiosis	Industrial ecology-based framework for mutually beneficial cooperation between industries, sharing water resources, energy and by-products and waste materials in all organizations for both environmental and economic benefit. IS designs material flows through industrial ecosystems in which the consumption of energy and material is optimized, the generation of waste is minimized and the effluents from one process serve as material for another (Chertow and Park, 2016)
Industrial ecology	Academic discipline focussed on the study of material and energy flows through industrial systems. It advocates industrial systems, where the actors involved cooperate by using each other's waste material and waste (residual) energy flows (Korhonen, 2002)

- A major difference between CE and the closed-loop is that the former is restorative while the latter is preventive.
- Conceptually, there is a tension between practices that directly extend product life-cycle (durable material design, repair and direct use), practices that extend the life of a product's parts, which start a new cycle of use (remanufacturing, refurbishing), and practices that find use for the materials in a product at the end of its life cycle (recycling). CE conceptualizes the former as better than the latter, but there are no studies comparing its environmental

and economic benefits quantitatively. Although each group of practices requires different strategies, extending the life-cycle and starting a new cycle are often confounded in normative approaches and modelling.
- Current literature is biased towards research into technical cycles at the expense of biological cycles and towards research into multiple new cycles at the expense of extending product life-cycle.
- A majority of the literature in impacts is normative, either through pieces or simulations and mathematical modelling. Empirical studies with primary data collection are less common. They suggest that the benefits of non-linear processes are highly contingent in the type of practice and implementation context.
- Other understudied issues include social impacts, negative environmental, economic and operational impacts (particularly in terms of recovery of fixed costs, the uncertainty of supply and impacts in water use and biodiversity), trade-offs between different types of environmental, social and economic impacts.
- There is very little use of theory, in particular regarding management theories. This is, in part because few studies in non-open-ended production draw on theories of strategy, organizational behaviour, marketing, accounting and innovation.

The article is structured as follows: Section 2 presents the key concepts of CE. Section 3 the method adopted to construct the study. Section 4 presents the results of the analysis. Finally, Section 5 summarizes findings and highlights the implications for future research.

2. Circular economy

CE is a popular concept promoted by the EU (Kirchherr *et al.*, 2018) and by several national governments and many businesses worldwide. However, the scientific and research content of this new concept is superficial and unorganized (Korhonen *et al.*, 2018). There is no clear evidence of the real origin of the CE concept, but contributors include US professor John Lyle, his student William McDonough, the German chemist Michael Braungart, and architect and economist Walter Stahel (Ellen MacArthur Foundation, 2013). The origins trace to Kenneth Boulding's seminal paper:

> The Economics of the Coming Spaceship Earth" (1966) along with major early parallel contributions from Herman Daly and Nicholas Georgescu-Roegen. Importantly, Pearce and Turner's 1990 text book, *Economics of Natural Resources and the Environment*, contains a whole section on the "circular economy (pp. 35-41).

However, the three thematic categories normally used to organize the CE's literature review include:
- policy instruments and approaches (Verger, 2017; Martins, 2016);
- value chains, material flows and product-specific applications (Figge *et al.*, 2018); and
- technological, organizational and social innovation (Winans *et al.*, 2017).

For all these categories, the CE aims to increase the efficiency of resource use (Cracolici *et al.*, 2018) with a special focus on urban and industrial waste, on capability approaches (Martins, 2018) and on renewable resources (Oubraham and Zaccour, 2018) to achieve a better balance and harmony between economy, environment and society (Ghisellini *et al.*, 2016). In the CE, the economic and environmental values of the materials are preserved for the longest possible time through a couple of approaches. They are retained in the economic system either by lengthening the life of products or by returning products and material leftovers in the system to be reused (Huang *et al.*, 2018; Hueso-González *et al.*, 2018; De Jesus and Mendonça, 2018). Design for multiple cycles (Papanek, 1975; Bakker *et al.*, 2014; Moreno *et al.*, 2016) refers to the design of processes and products aimed at enabling the longer circulation of materials and resources in multiple cycles. In turn, design for long-life use of products (Bakker *et al.*, 2014; Chapman, 2005; Lacy and Rutqvist, 2015; Moreno *et al.*, 2016) aims to extend the useful life of a product with increased material durability, enhanced relationships between products and users (emotionally durable design), and availability of services for reuse, repair, maintenance and upgrade. On the other hand, a recent study considers the dematerialization, decoupling and productivity change that is the study of Kemp-Benedict (2018).

CE literature differentiates cycles of technical nutrients from cycles of biological nutrients; the technical nutrients cycle involves the management of finite material stocks. Use replaces consumption. Technical nutrients are recovered and for the most part, restored through processes such as reuse, repair and recycle. This requires product design that facilitates its disassembly into parts to be reused at the end of the product life cycle (eco-design). The cycle of biological nutrients refers to flows of renewable materials. Consumption only occurs in the biological cycle. Renewable (biological) nutrients are, for the most part, regenerated in the biological cycle through processes such as composting and anaerobic digestion (Ellen MacArthur Foundation, 2013, 2017; Moreno *et al.*, 2017). The life-cycle analysis enables the understanding of flows of biological and technical nutrients along the product life-cycle. Table II shows practices for the recovery of technical and biological nutrients.

CE proposes a hierarchy of practices in the order presented in the table, where practices at the top represent initial stages in the cycles. "Collect" refers to the design of recovery inputs, where it is possible to obtain greater efficiency in processes of collection and distribution. "Keep/extend" refers to investment in long circles, that is, extending the useful life of products or time of each cycle. "Cascade" refers to a diversification of reuse throughout the value chain. "Share" identifies changes in ownership, sharing products or providing services rather than selling them (Ellen MacArthur Foundation, 2017). "Reuse and

Table II Practices in cycles of nutrients in the production chain

Technical	Biological
Collect	Collect
Keep/extend	Cascade exploitation
Share	Extraction of biochemical raw materials
Reuse/redistribute	Anaerobic digestion
Remanufacture/refurbish	Biogas generation
Recycle	Biosphere regeneration
	Agriculture/collection

Source: EMAF (Ellen MacArthur Foundation) (2013) remanufacture" aims to maximize the number of cycles of a new use for materials in a product.

Despite all the normative power of the literature, of institutional pressures and conceptually argued benefits for business and society, companies are strongly reluctant to fully implement CE practices (Linder and Williander, 2017). As a consequence, the number of companies truly implementing CE is still relatively small; further, access to these companies is increasingly restricted because these firms receive too many requests. Therefore, empirical evidence of non-linear production benefits is sparse, especially of companies adopting the CE. On the other hand, other practices with a similar focus on non-linear processes, such as reverse logistics and eco-parks (industrial symbiosis) have been gaining traction in industry for decades (UNEP, 2017); there is a larger number of firms implementing them. However, we do not know the extent to which lessons learned from such firms can be used to improve knowledge of CE because currently, our understanding of differences and similarities between CE and other non-linear approaches is not clear enough. Some recent attempts have been made to clarify it. Batista *et al.* (2018, p. 449) developed a systematic literature research of circular supply chain trying to identify overlapping between what they call sustainability narratives: reverse logistics, green supply chain, sustainable supply chain management and closed-loop supply chains. However, these authors claim a need for "a more comprehensive analysis" to capture "the full range of contributions and different perspectives in the area." As CE research is developed throughout different disciplines such as environmental economic and management science (De Angelis *et al.*, 2018).

Can knowledge about benefits of reverse logistics, closed loops, industrial symbiosis and industrial ecology, cradle to cradle and life-cycle assessment be aggregated and applied to expand the social and business case for CE? Some authors simply assume that is the case. If these literatures are aggregated, will they provide enough knowledge about biological and technical cycles for designers to understand how to design circular products and processes? This literature review aims to provide a foundation to address these questions; we seek to analyze in each of the literature's non-linear approaches the extent of research into practices related to CE cycles, impacts of non-linear production, barriers to adoption and implementation enablers.

3. Methodology

To perform the systematic literature review, we followed the three-step procedure of Tranfield *et al.* (2003): planning, execution and reporting. During the planning phase, the objectives of the study were established and the data source identified. The purpose of the research was to identify benefits of non-linear production models and to analyze what are the overlaps between CE, reverse logistics, closed-loop, industrial symbiosis, industrial ecology, cradle to cradle and life-cycle assessment.

We worked with top journals in management available in the Scopus database, which is considered the largest source of abstracts and academic citations (Elsevier, 2016)[1]. Sources were limited to journals ranked 3 or higher in the ABS journals ranking guide[2], in the subject areas of Business, Management or Accounting. This choice was made on the premise that the top journals usually publish high-quality research and have a wider impact on academics and practitioners (Crossan and Apaydin, 2010). The document type selected was "articles published in English," and the search period was from 2007 until October 2017 because the topic in research is recent and other systematic and bibliometric reviews show that the majority of publications have emerged in recent years. See, for example, Ghisellini *et al.* (2016), Ji *et al.* (2018) and Saavedra *et al.* (2018).

In the execution phase, the search terms for initial selection were defined based on discussions. A glossary was compiled during a workshop on resource efficiency and CE funded by the British Council; this workshop was attended by academic experts and policymakers. The search terms used were CE, cradle to cradle, double loop, closed-loop, reverse logistics, life-cycle analysis, industrial ecology, upcycle, spiral economy and industrial symbiosis. Keywords were used as selection criteria for the topic (title, keywords or summary). We decided not to expand the search of articles using derived terms. The 10 search terms defined for this research are specific techniques to implement non-linear systems models, therefore, it was of interest for this analysis to find publications that refer exactly to these terms. Table III shows the number of articles found.

It is noted in Table III that a significant number of articles have been published in the topics under analysis. However, when the filter for the Business, Management and Accounting area of top journals is applied, only 6.62 per cent of publications remain. If we look only at existing publications in top journals listed in the ABS ranking, 151 articles remain, corresponding to 0.34 per cent of the publications on the subject. After reading the full text, 23 articles on double loop and life-cycle assessment (LCA) were not explicitly about non-linear models and were also discarded. We decided that LCA is not a distinct approach to non-linear production. It is an environmental management concept that can be applied to either linear or non-linear

Table III Total of scientific articles mapped

Subject	Total of papers	Articles in the business, management and accounting area	Total articles in journals on the ABS list
"CE"	774	125	8
"Cradle to cradle"	145	31	1
"Double loop"	1,238	103	9
"Closed loop"	31,288	558	39
"Reverse logistic"	1,221	518	41
"Life cycle analysis"	9,432	1,492	32
"Industrial symbiosis"	418	118	10
"Industrial ecology"	1,872	200	11
"Spiral economy"	0	0	0
"Upcycle"	4	0	0
Total	*44,520*	*2,945*	*151*

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Volume 24 · Number 6 · 2019 · 784–804

production. Similar to eco-efficiency, LCA is used by all the approaches analyzed. Finally, 181 papers remained.

The next steps of the research consisted of:

- The collection and organization of data: after reading the full text, we grouped the studies into the non-linear production approaches we aimed to compare (CE, reverse logistics, etc.) [3].
- Data processing and analysis: qualitative content analysis was conducted by two coders each working separately in the whole content of each article. Inter-coder reliability was assessed as satisfactory.

The following codes were used to classify contents in each group of studies:

- practices in cycles of technical AND/OR biological nutrients; and
- environmental, operational AND/OR financial impacts.

4. Results and analysis

4.1 Describing the data set

Table IV shows the journals publishing more research in non-linear production models.

In total, 71 per cent of the analyzed publications are concentrated in three journals. Only seven journals – all but one in the area of operations management and operational research –published 86 per cent of the articles that were analyzed. This finding supplies sufficient evidence that research has been clustered in a narrow range of academic outlets in the field of operations and supply chain management, at least for the journals considered top-notch.

Table V shows the articles reviewed, and each is preceded by a number that refers to the number of articles in subsequent tables.

Table VI classifies the papers according to the type of study: modelling, empirical, conceptual and/or literature review.

The more incremental approaches such as closed-loop and reverse logistics are the most explored topics. The year of the first publication in top management journals for both approaches is 2007. More radical models, such as CE, industrial ecology and industrial symbiosis, only start to be embraced by scholars publishing in top journals in later years. For example, our sample cites Liu *et al.* (2012), Linder and Williander (2017), Wang and Hansen (2016), Nassit *et al.* (2016), Spring and Araujo (2017) and others. If we look at the total number of empirical and theoretical papers considering all techniques, we can see that there is a relative balance of theory, empirics and mathematical models in the aggregated body of knowledge. However, very little has been done to collate and integrate findings using literature reviews and meta-analysis. None of the papers published has attempted to integrate the theory and empirical evidence generated by all the approaches. CE research itself is a recent development with the first paper published in 2015 in a top management journal. Most papers do not draw in-depth in the body of knowledge previously generated on closed loops and related concepts, and this observation suggests that currently there is not a maturity of knowledge on the subject.

Table IV Top journals with relevant publications in the systematic literature review

Journal	No.	(%)	R.*
International Journal of Production Economics	48	33.80	3
International Journal of Production Research	34	23.94	3
Business Strategy and the Environment	19	13.38	3
Supply Chain Management: An International Journal	6	4.23	3
Production Planning and Control	6	4.23	3
International Journal of Operations & Production Management	5	3.52	3
Transportation Research Part E	4	2.82	4
Industrial Marketing Management	2	1.41	3
Omega	2	1.41	3
Long Range Planning	2	1.41	3
Journal of Business Ethics	1	0.70	3
Critical Perspectives on Accounting	1	0.70	3
Journal of Operations Management	1	0.70	4*
IEEE Transactions on Engineering Management	1	0.70	3
Journal of Supply Chain Management	1	0.70	3
Journal of the Operational Research Society	1	0.70	3
Manufacturing and Service Operations Management	1	0.70	3
Corporate Governance	1	0.70	3
Organization Studies	1	0.70	4
Production and Operations Management	1	0.70	4
British Accounting Review	1	0.70	3
Journal of Sustainable Tourism	1	0.70	3
Corporate Governance: An International Review	1	0.70	3
Entrepreneurship Theory and Practice	1	0.70	4

Note: *Ratings

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Table V Articles reviewed

1: Aitken and Harrison (2013)	47: De Jesus and Mendonça (2018)	92: Jin *et al.* (2011)	137: Raabe *et al.* (2017)
2: Akanbi *et al.* (2018)	48: Almeida *et al.* (2017)	93: Kabongo and Boiral (2011)	138: Raz *et al.* (2013)
3: Alblas *et al.* (2014)	49: DeCroix *et al.* (2009)	94: Kaenzig *et al.* (2011)	139: Reike *et al.* (2018)
4: Anctil and Le Blanc (2015)	50: Defee *et al.* (2009)	95: Kähkönen *et al.* (2015)	140: Rex and Baumann (2008)
5: Ashton (2011)	51: Desrochers and Sautet (2008)	96: Kannan *et al.* (2009)	141: Sasikumar and Haq (2011)
6: Ashton (2008)	52: Doménech and Davies (2011)	97: Kenne *et al.* (2012)	142: Seager (2008)
7: Awasthi *et al.* (2018)	53: Dupont-Inglis and Borg (2018)	98: Khor *et al.* (2016)	143: Sgarbossa and Russo (2017)
8: Ayres (1994)	54: EEA (European Environment Agency) (2016)	99: Kim *et al.* (2013)	144: Shin *et al.* (2014)
9: Baas (2011)	55: Ellen MacArthur Foundation (2013)	100: Kim *et al.* (2010)	145: Simpson (2010)
10: Badri *et al.* (2017)	56: Ellen MacArthur Foundation (2017)	101: Kralj *et al.* (2017)	146: Smirnov and Gerchak (2016)
11: Bakker *et al.* (2014)	57: Elsevier (2016)	102: Kumar and Chan (2011)	147: Song *et al.* (2017)
12: Balkau and Sonnemann (2010)	58: Esmaeili *et al.* (2015)	103: Kumar and Putnam (2008)	148: Spring and Araujo (2017)
13: Bansal and McKnight (2009)	59: Esposito *et al.* (2018)	104: Lacy and Rutqvist (2015)	149: Stahel (2016)
14: Akanbi *et al.* (2018)	60: Fraccascia *et al.* (2017)	105: Lake *et al.* (2014)	150: Stahel (1994)
15: Benyus (2002)	61: Franco (2017)	106: Lehr *et al.* (2013)	151: Stahel (2010)
16: Blomsma and Brennan (2017)	62: Frota Neto *et al.* (2010)	107: Lifset and Graedel (2002)	152: Strothman and Sonnemann (2017)
17: Bocken *et al.* (2016)	63: Fuente *et al.* (2008)	108: Linder and Williander (2017)	153: Swain (2017)
18: Bolks and Stevel (2007)	64: Gallego-Schmid *et al.* (2018)	109: Liu *et al.* (2012)	154: Szekely and Strebel (2013)
19: Boons and Howard-Grenville (2009)	65: Garza-Reyes *et al.* (2016)	110: Lu *et al.* (2007)	155: Sun (2017)
20: Bovea and Wang (2007)	66: Geissdoerfer *et al.* (2017)	111: Luthe *et al.* (2017)	156: Tagaras and Zikopoulos (2008)
21: Butzer *et al.* (2017)	67: Genç and Bada (2010)	112: McDonough and Braungart (2002)	157: Peiró *et al.* (2017a, 2017b)
22: Chapman (2005)	68: Genovese *et al.* (2017)	113: Mandolini *et al.* (2018)	158: Todeschini *et al.* (2017)
23: Chaabane *et al.* (2012)	69: Ghisellini *et al.* (2016)	114: Matos and Hall (2007)	159: Tognetti *et al.* (2015)
24: Chan *et al.* (2014)	70: Govindan *et al.* (2015)	115: Minner and Kiesmüller (2012)	160: Topi and Bilinska (2017)
25: Chan (2013)	71: Gregson *et al.* (2015)	116: Mondragon *et al.* (2011)	161: Tranfield *et al.* (2003)
26: Chan (2014)	72: Han *et al.* (2016)	117: Mora *et al.* (2014)	162: Tsai and Hung (2009)
27: Chen and Chang (2013)	73: Hasani *et al.* (2014)	118: Morana and Seuring (2007)	163: Tsai *et al.* (2015)
28: Chen *et al.* (2010)	74: Hazen *et al.* (2016)	119: Moreno *et al.* (2016)	164: Tukker (2015)
29: Chertow and Miyata (2011)	75: He (2015)	120: Murray *et al.* (2015)	165: Ueberschaar *et al.* (2017)
30: Chertow (2007)	76: Heidrich and Tiwary (2013)	121: Nasir *et al.* (2017)	166: Urbinati *et al.* (2017)
31: Chertow *et al.* (2008)	77: Hey (2017)	122: Nurjanni *et al.* (2017)	167: Wang *et al.* (2015)
32: Chiarini (2014)	78: Hollander *et al.* (2017)	123: Olorunniwo and Li (2010)	168: Wang and Hanzen (2016)
33: Choi *et al.* (2013)	79: Hong *et al.* (2015)	124: O'Shea *et al.* (2012)	169: Weeks *et al.* (2010)
34: Choudhary *et al.* (2015)	80: Hoogmartens *et al.* (2018)	125: Ostlin *et al.* (2008)	170: Wolf *et al.* (2007)
35: Chouinard *et al.* (2010)	81: Hsu *et al.* (2013)	126: Paquin *et al.* (2015)	171: Wu (2015)
36: Chouinard *et al.* (2008)	82: Huang and Wang (2017)	127: Papanek (1975)	172: Xing *et al.* (2013)
37: Ciliberti *et al.* (2008) and Coelho *et al.* (2015)	83: Huang *et al.* (2009)	128: Patala *et al.* (2016)	173: Xiong et al. (2016)
38: Coob (2016)	84: Huang *et al.* (2011)	129: Pauliuk (2018)	174: Xu *et al.* (2012)
39: Cong *et al.* (2017)	85: Huang *et al.* (2018)	130: Pearce (2009)	175: Xu *et al.* (2017)
40: Cong *et al.* (2017)	86: Huang *et al.* (2009)	131: Peters *et al.* (2007)	176: Yuan and Gao (2010)
41: Crossan and Apaydin (2010)	87: Hueso-González *et al.* (2018)	132: Pialot *et al.* (2017)	177: Yung *et al.* (2012)
42: Curkovic *et al.* (2008)	88: Jabbour *et al.* (2018)	133: Pishvaee *et al.* (2014)	178: Zhalechian *et al.* (2016)
43: Dadhich *et al.* (2015)	89: Jabbour *et al.* (2015)	134: Pistol *et al.* (2017)	179: Zhong and Pearce (2018)
44: Das and Chowdhury (2012)	90: Jayaram and Avittathur (2015)	135: Popa and Popa (2017)	180: Zhu and Tian (2016)
45: Despeisse *et al.* (2017)	91: Jiménez-Rivero and García-Navarro (2018)	136: Pullman and Wikoff (2017)	181: Michaud and Llerena (2011)
46: Díaz *et al.* (2017)			

4.2 Coding

Having described the data, we now present the results of the coding. Our starting point was to investigate the extent of research available about each of the practices in the technical and biological cycles. Tables VII and VIII summarize research into the different techniques and elements of the technical and biological cycle of nutrients (Ellen MacArthur Foundation, 2017).

By each grouping of literature, the table indicates papers addressing each practice in CE cycles. Table VII shows that all

Table VI Types of studies analysed

Types	CE	Closed-loop	Cradle to cradle	Reverse logistics	Industrial symbiosis	Industrial ecology
Modelling/simulation	3	22	–	14	2	–
Empirical (primary data)	3	3	–	14	6	8
Meta-analysis	–	–	–	1	–	–
Literature review	–	–	1	–	–	–
Conceptual	2	14	–	12	2	3

Table VII Interfaces between the different techniques and the technical cycle of CE

	Technical cycle				
Techniques	Collect (recovery)	Keep/extend	To share	Reuse/redistribute	Remanufactured/ refurbished
CE	– (147) and (75)	– (121)	– (147)	– (108), (1,210), (75) and – (103)	– (108), (121), (147), (75), (120), (70) and – (103)
Closed loop	– (53), (45) and (61) – (166)	– (140) and (142)	– (83)	– (78), (76), (80), (125) and (175)	– (97), (103), (102), (106) and (174)
Reverse logistic	– (1), (26), Chileshe et al. (2016) and (45)	– (66)		(1), (35), (96), (103) and (102)	(103), (102), (106), (125), (155), (173), (179) and (28)
Industrial symbiosis	– (55), (63) and (126)		– (5)	– (9) and (13)	– (29)
Industrial ecology		– (55), (121), (141) and (153)	– (4), (5) and (169)	– (9), (55) and (93)	– (29)

Table VIII Interfaces between the different techniques and the technical determinants of CE

	Biological cycle							
Techniques	Collect	Cascade	Extraction of biochemical raw materials	Anaerobic digestion	Biogas	Biosphere regeneration	Biochemical raw materials	Agriculture/ collecting
CE	– Spring and Araujo (2017) and – (75)	– (108), (75) and (70)					– (121), (120) and (70)	
Closed loop	– (53), (45), (61) and (166)	– (78), (97), (102), (106), (140) and (142)						
Reverse logistic	– (1), (26), Chileshe et al. (2016) and (45)	– (66)						
Industrial symbiosis		– (9), (13), (55), (63) and – (126)				– (4) and (5)	– (29)	
Industrial ecology		– (9), (55), (93), (141) and – (169)				– (4), (5) and (153)	– (29) and (121)	

CE practices have been researched by previous literature in non-linear approaches. However, existing knowledge provides more guidance for the design of multiple cycles of use of materials than for the design of extended product life cycles. Practices related to keep/extend and share products are understudied by all approaches except for industrial ecology.

Table VIII shows that research in biological cycles is scarcer and fragmented. Several practices have yet to be studied in the biological cycle. The studies analyzed consider a limited spectrum of biological cycle practices where materials are reclaimed and restored and nutrients (e.g. materials, energy and water) regenerated. Little guidance and clarity is provided about how designers should design for new circular business models. These new business models pertain not only to industries in which biological cycles are dominant, such as food and beverages but also to industries such as the chemical industry. The chemical industry offers new research that identifies the potential for the renewed chemical stock to serve as a replacement for petrochemicals (Srai *et al.*, 2018). Our findings reinforce Winans *et al.* (2017) identification of critical research gaps when analyzing the CE concept application to and assessment of the biological systems (e.g. agricultural industries) and the chemical/biochemical industry products and value chains. De Angelis *et al.* (2018) further emphasize that better understanding of material loops in biological cycles will be needed to scale up circular business models.

In summary, if knowledge from different approaches is aggregated it will be biased towards a model of non-linear production that prioritizes technical cycles at the expense of biological cycles, while also prioritizing the design of multiple cycles of use at the expense of design of extended life cycles. Therefore, subsequent sections analyzing the impacts of non-linear approaches reflect mainly impacts of these types of production models, as they dominate the literature reviewed.

With this caveat in mind, we next analyze environmental, financial, operational and social impacts of non-linear production models.

4.3 Environmental benefits

Table IX summarizes research investigating environmental impacts of CE, industrial symbiosis, industrial ecology, closed-loop and reverse logistics.

Our analysis suggests that the focus of non-linear production literatures has been in conceptualizing and testing resource efficiency, in particular, regarding materials. Most cited benefits for all the practices include reduction in use of raw materials (Linder and Williander, 2017; Esmaeili *et al.*, 2015; Choudhary *et al.*, 2015; Chertow and Miyata, 2011; Domenseh and Davies, 2011; Fraccascia *et al.*, 2017; Paquin *et al.*, 2015) and the minimization of waste (Kähkönen *et al.*, 2015; Chileshe *et al.*, 2016; Garza-Reyes *et al.*, 2016; Hsu *et al.*, 2013; Fuente *et al.*, 2008; Lu *et al.*, 2007; Minner and Kiesmüller, 2012).

Reductions in carbon and greenhouse gases emissions are also claimed (Choudhary *et al.*, 2015; Defee *et al.*, 2009; Esmaeili *et al.*, 2015), with several mathematical models showing that products from non-linear production processes have significantly lower carbon emissions during their life-cycle than products made with linear production (Hazen *et al.*, 2016; Zhalechian *et al.*, 2016; Nassir *et al.*, 2017).

Studies in energy use reduction are also frequent. Positive impacts have been found for closed-loop (Defee *et al.*, 2009; Zhalechian *et al.*, 2016), industrial ecology (Chertow and Miyata, 2011; Wolf *et al.*, 2007) and industrial symbioses practices (Fraccascia *et al.*, 2017; Paquin *et al.*, 2015). However, they are not mentioned in reverse logistics and CE research. Positive impacts in water quality are less studied. They have been described for industrial symbiosis and industrial ecology practices (Anctil and Le Blanc, 2015; Ashton, 2011) but do not feature centrally in articles reviewed in CE, closed-loop or reverse logistics. Impacts on water use have been even less researched across all streams; water use is neither accounted in modelling nor measured in case studies (a notable exception is Chertow and Miyata, 2011). An unfortunate consequence of this gap is the lack of knowledge about the impacts of potential trade-offs between water use efficiency and material efficiency. For instance, there is a potential increase in water use associated with cleaning parts for reuse and remanufacturing.

A further problem with the literature in environmental impacts is that it is largely normative and aspirational, relying on comparative mathematical modelling of impacts of linear and circular productions chains. Empiric papers using primary data tend to rely on single company case studies and they generally focus on a particular environmental issue. A case study involving more companies and issues was conducted by Chertow and Miyata (2011) in Hawaii. The authors analyzed the environmental performance of eight companies exchanging six materials using price and quantity data collected during interviews. In addition to significant reductions in landfilling, they quantified savings of primary materials, including 40 million gallons of freshwater and approximately 17,800 tons of coal annually.

Table IX Impact on environmental performance

Aspects	CE	Closed-loop	Reverse logistics	Industrial symbiosis	Industrial ecology
Raw materials reduction	(108) and (75)	(61), (174) and (97)	(34) and (146)	(29), (55), (63), (126) and (13)	(9), (29), (5), (55) and (169)
Waste reduction	(108), (121) and (70)	(65), (53), (61), (177) and (103)	(95), (Chileshe *et al.*, 2016), (67), (82), (66), (110), (115) and (66)	(63), (126) and (13)	(9), (29), (5) and (55)
Energy reduction		(53) and (177)		(63) and (126)	(5), (55), (29) and (169)
Air emissions reduction	(121), (70) and (75)	(53), (61) and (177)	(23) and (34)	(26)	(5)
Water effluents reduction				(13)	(4)
Land use reduction		(61)			
Hazardous waste		(61)			
Pollution		(122)	(82)	(126)	
Eco-efficiency (increase of profitability and environmental performance)	(75)		(33), (34) and (146)		(4), (9), (29), (55), (93) and (153)
Water use reduction					(5) and (55)
Biodiversity/ecosystems					(9)
Ecological footprint		(65)	(13) and (126)		(5), (55) and (93)
Sustainable innovation					(153)
Regulation compliance	(121)	(103)	(33), (34), (102) and (162)	(126)	(5)

Although a majority of the cases analyzed are success stories, the literature also identifies failures to achieve environmental benefits, as is in the case of industrial symbioses practices in Puerto Rico investigated by Ashton (2011). Longitudinal cases are scarce (Linder and Williander, 2017; Chiarini, 2014), therefore, there is little conclusive evidence supporting sustained environmental benefits in the medium- and long-term. Trade-offs between a comprehensive range of environmental impact dimensions are not systematically analyzed, not even in mathematical models. Many case studies are based on small numbers of interviews or even on one interview, which casts doubts on the extent of theoretical saturation achieved. Very few qualitative studies analyzed use double-coding, and the absence of that technique raises reliability concerns.

In terms of quantitative studies, two studies using cross-sectorial surveys support a positive influence of reverse logistics in resource efficiency and environmental performance (Chiarini, 2014; Khor *et al.*, 2016). Paquin *et al.* (2015) use secondary data from 313 waste exchanges in the UK to show positive results in terms of total waste divested from landfill and reduced amount of emissions. Chiarini (2014) conducted a longitudinal survey with 800 large companies in Europe and found that reverse logistics is needed to improve environmental performance in manufacturing but not in services. From a small sample of 89 industries in Malaysia, Khor *et al.* (2016) found that environmental performance is improved by practices extending the life of products through repair and reconditioning. Performance is further improved by strong regulatory and shareholder pressures. On the other hand, recycling and remanufacturing do not improve environmental performance.

4.4 Economic benefits

Table X presents research in financial benefits of non-linear production models.

The literature in all the approaches under analysis claims substantive financial profits when moving from linear to circular production (Linder and Williander, 2017; Liu *et al.*, 2012; Garza-Reyes *et al.*, 2016; Lehr *et al.*, 2013; Ostlin *et al.*, 2008). This is an unanimously claimed result of value creation (Kabongo and Boiral, 2011; Aitken and Harrison, 2013; Ciliberti *et al.*, 2008; Nassir *et al.*, 2017). Value creation results from, on the one hand, reducing costs. Those costs may be lessened from reduced marginal costs (Liu *et al.*, 2012); reduced costs of buying virgin materials (Kummar and Putnam, 2008; Lehr *et al.*, 2013); reduced waste disposal (Esmaeili *et al.*, 2015); or from lower environmental taxes (Anctil and Le Blanc, 2015; Paquin *et al.*, 2015). Value creation can also be addressed from the other perspective of enhancing profits. Increased revenues result from exchange flows, selling waste as input for another industry (Lehr *et al.*, 2013), generating energy out of waste (Chaabane *et al.*, 2012) or increasing brand and reputation effects (Tognetti *et al.*, 2015). An increase in market share and reduced risks is also mentioned by the literature in closed loops (Alblas *et al.*, 2014).

Conceptually, the literature differs from the traditional "business case for environmental management" in its emphasis on collaboration and revenue generation from inter-industry exchanges. However, Paquin *et al.* (2015) observes that industrial symbiosis production has a higher intensity use of services than linear production; Linder and Williander (2017) note that the CE model has higher fixed costs because of the logistics and infrastructure required for exchange flows. Similarly, RL, CL, IE and IS also require higher fixed costs and intensity of services. Transport costs can also be substantial; therefore, close geographical proximity between firms involved in flows of resources seems critical to reduce variable transport costs (Baas, 2011). The additional profitability of closed models in comparison with linear models depends on the extent to which revenues and reductions in marginal costs (Liu *et al.*, 2012) offset

Table X Impact on financial performance

Aspects	CE	Closed-loop	Reverse logistics	Industrial symbiosis	Industrial ecology
Profitability	(108)–	(10), (78) and (96)	(33), (102), (110), (67), (106) and (125)	(13)	(4) and (5)
Variable costs reduction	(108), (75) and (109)	(72), (174), (174), (177) (116) (85) (96), (140), (142), (145) and (170)	(23), (38) and (168)	(126)	(93), (5) and (153)
Higher fixed costs	(108)				
Shorter return in investment				(9)	
End-of-life product benefits		(65)			
Increased revenues	(109)			(126)	(153)
Increased market share		(142)			
Value generation		(1) and (37)	(95) and (123)	(63) and (126)	(93)
Brand and reputation/reduced risks	(120) and (121)		(3)		
Win-win	(120) and (121)				
Economic efficiency		(76), (92), (102), (106) and (118)	(72), (102), (168) and (179)		(93)
Decrease in sales		(180)	(98)		

increase in fixed costs and use of services. This suggests that circular models are more sensitive to fluctuations in demand and are riskier in volatile economic contexts. More longitudinal studies are needed to analyze to what extent higher fixed costs affect long-term economic viability and whether the minimum efficient scale (share of the market needed to benefit from economies of scale) is higher than in linear models.

The literature on CE, CL, IS and IE examined in this paper does not provide examples of surveys large enough to provide statistically significant relations. For instance, Desroches and Sautet (2008) noted that in most cases of industrial symbiosis, what matters is the context in which non-linear production takes place. Quantitative studies in reverse logistics also suggest that benefits are strongly contingent on the context in which the company operates and the type of practice implemented.

Khor *et al.* (2016) found that recycling, repair, reconditioning and remanufacturing improve profitability but only reconditioning and remanufacturing improve sales growth. The presence of strong stakeholder pressures improves the profitability of manufacturing and recondition. Strong stakeholder pressures increase the impact of manufacturing in sales but lead to reduce sales of repaired products. Weeks *et al.* (2010) analyzed the scrap industry in the USA. He found that reverse logistics practices for transport partially mediate the relation between reverse logistics in operations management and profitability, but reverse logistics practices for product mix do not impact in profitability. Paquin *et al.* (2015) use secondary data from 313 waste exchanges in the UK to show positive results in terms of eco-efficiency, as a reduction in waste also increased firm-level value through additional income and cost reductions. Value created, however, depended on the experience of the firm with industrial symbiosis, the volume of waste transacted, and the involvement of waste dedicated firms. When specialist firms were involved, the environmental benefits were higher but the value captured by the firm was lower.

4.5 Operational benefits

Table XI shows that all non-linear production approaches share similar operational benefits in terms of productivity and efficiency. A difference between CE and other approaches is the attitude towards recycling. Recycling is considered a lower value practice by the CE model, but it is endorsed by all non-linear approaches. Research in reverse logistics has identified improvements in product quality, reduced inventory, lead time and incineration and higher levels of services. As in previous sections, the foundations of these claims are conceptual and/or supported by mathematical models and case studies. Research studies analyzing negative operational impacts are less abundant, but literature in CE (Linder and Williander, 2017), closed-loop (Pishvaee *et al.*, 2014; Kenne *et al.*, 2012) and reverse logistics (Chouinard *et al.*, 2008; Hey, 2017) converge in pointing out towards increased uncertainty when operations depend in the supply of waste from other companies. This can result in reduced operational resilience or increase in stocks to compensate potential fluctuations in supply. A different type of uncertainty refers to customers' purchasing intentions. Hazen *et al.* (2016) finds that customers have a poor opinion of remanufactured products and are not prepared to buy them. A closed-loop strategy to address this uncertainty is a transference of a part of the value captured to customers. Through marketing segmentation, remanufactured products are marketed at lower prices (Huang *et al.*, 2011). As a result, customers see value in buying remanufactured products but still consider them a risky purchase (Wang and Hanzen, 2016). Research in closed-loop and reverse logistic agrees with this finding. However, Linder and Williander (2017) show how companies can overcome this hurdle by designing circular products with increased quality and attractiveness for customers.

4.6 Social benefits

Murray *et al.* (2015) observe "of the three pillars of sustainability (social, economic and environmental) it is the

Table XI Impact on operational performance

Aspects	CE	Closed-loop	Reverse logistics	Industrial symbiosis	Industrial ecology
Productivity	(108)	(53), (10), (97), (103), (106), (125), (172) and (175)	(67), (23), (36), (35), (45), (86), (66), (97), (103), (102), (106), (168), (173), (179) and (28)		
Efficiency	(108)	(76), (174) and (97)	(67)		(93)
Reduced inventory			(67)		
Reduced lead time			(67)		
Reduced incineration			(23)		
Higher level of services			(34)		
Product quality/ attractiveness	(108) and (167)		(3)		
Increased uncertainty/ unpredictable return flow	(108)	(132) and (97)	(36) and (125)		
Recycling		(76), (103) and (106)	(23), (1), (36), (66), (103), (97), (140), (144), (162), (168), (173) and (28)	(5)	(126)

former that is least expanded in most of the conceptualizations and applications of the CE." Accordingly, we can see in Table XII just 12 papers addressing social sustainability issues, six of them tangentially. Murray *et al.* (2105) is the outstanding theoretical work integrating an analysis of social impacts of non-linear production. They theorize how a full-on CE will create value-enabling investments in social equity (intra-generational and inter-generational).

Employment and community development are the main social impacts analyzed. Three papers factor in social welfare in closed-loop and reverse logistics modelling (Pishvae *et al.*, 2014; Wang *et al.*, 2016; Zhalechian *et al.*, 2016). Wang *et al.* (2016) finds that increasing government incentives and penalties over the closed-loop supply chain leader – either the manufacturer or the waste collector – enhances social welfare. Zhalechian *et al.* (2016) present a model to assess the impact of reverse logistics chains in job creation and community development. Interestingly, they predict that social impacts increase with higher transports costs and decrease with higher inventory costs. Pishvaee *et al.* (2014) compared the environmental and social impacts of supply chains with the recycling of waste and supply chains with landfilling. They evaluated social impact considering local development, created job opportunities, consumer risk and worker health and safety. They found that supply chains with recycling not only have higher costs but also higher environmental and social benefits. However, they did not analyze more advanced non-linear production options such as remanufacturing.

Paquin *et al.* (2015) use secondary data from 313 waste exchanges in the UK to show positive results in terms of eco-development, defined as an increase in employment with a decrease in carbon emissions. They observe that the involvement of waste specialists (green logistics firms) in closed-loop supply chains significantly increases the social benefits of industrial symbiosis but at the expense of decreasing the economic gains of manufacturers. Examples of empirical research analyzing social benefits are scarce. Sgarbossa and Russo (2017) include a qualitative evaluation of social impacts in their case study of closed-loop strategies in the meat industry in Italy. Their proposed social benefits are employment creation, food security and better health and safety conditions for workers; however, their evaluation is purely speculative.

Literature in closed loops suggests that increased benefits and reduced costs to consumers area social benefit (Morana and Seuring, 2007). Indeed, most of the social impacts claimed are side-effects rather than the intended benefits (Hong *et al.*, 2015). Improvements in human health result from less polluting closed loops (Sgarbossa and Russo, 2017), reverse logistic models (Mora *et al.*, 2014) and from the marketing of organic products (Kabongo and Boiral, 2011). In the same vein, Baas (2011) argues that flows between firms in industrial symbiosis make organizations more transparent and more engaged with communities. With the exception of Murray *et al.* (2015), there is no literature investigating the impacts of non-linear production systems on social issues such as human rights (modern slavery), gender, fair-trade, social inequality, food scarcity or welfare of vulnerable populations. A starting point for the development of a research agenda on social impacts of non-linear production models is found in the Ciliberti *et al.* (2008) index of Logistics Social Responsibility, which takes on board many of the issues above-mentioned.

4.7 Discussion

Although some processes have been researched at length (recycling and remanufacturing), there is a gap in terms of literature linking each of the processes in these cycles to theoretical and empirical research. Table XIII presents the management theories used to frame studies analyzed.

Table XIII Theories used in studies

Techniques	Theories and approaches
CE	Theory of perspective (147)
Closed-loop	Game theory (61)-utility theory (174)-transaction costs theory (174)
	Market sign theory (174)-theory of complexity (114)-stakeholder theory (114)-transformational leadership (53)
Reverse logistic	Institutional theory (82) and (90)-resource based view (98)-leadership
Industrial ecology	Industrial ecology (93), (9) and (153)-sustainability science (141), behavioural theories: trust and cooperative behaviour (9)-embeddedness (9) and (152)-radical innovation (153)-leadership (153)
Industrial symbiosis	Industrial ecology (169), (55) and (29)-embeddedness theory (55)-social network analysis (55)-behavioural theories (trust, collective action and reciprocity) (29) and (55)-externalities (54)-network theory (63)
	Urban economics/economies of agglomeration (54)
LCA	Nothing
Cradle to cradle	Nothing

Table XII Impacts on social sustainability

Aspects	CE	Closed-loop	Reverse logistics	Industrial symbiosis	Industrial ecology
Value gained allows investment in social equity	(120)				
Increased benefits to customers	(108)	(85)			
Engaged employees	(120)				
Positive impact on health		(142) and (132)	(52) and (146)		(93)
Increased employment		(142), (165) and (132)	(166)		
Eco-development	(121)			(13)	
Food security		(142)			
Transparency				(9)	
Community development	(120)	(132)	(177) and (166)	(9)	

It is noteworthy that there are relatively few studies that adopt a management theory as a basis to perform empirical data analyses and/or to propose theoretical frameworks. The theories used include some theories frequently discussed in the literature of organizations and natural environment: institutional theory, stakeholder theory and resource-based theory. These theories are applied to theorize drivers for adoption (Hsu *et al.*, 2013; Jarayan and Ayittathur, 2013; Khor *et al.*, 2016). Theoretical propositions mirror those of literature in environmental management in linear systems. Companies implement non-open-ended production processes in response to institutional isomorphism (Hsu *et al.*, 2013; Jin *et al.*, 2011) or because they want to develop a competitive advantage adding value through closed loops (Khor *et al.*, 2016) or to send signals to markets (Xu *et al.*, 2017) and stakeholders (Matos and Hall, 2007). It is worth noticing the limited use of innovation theories, which is also related to the low presence of non-linear production research in innovation journals. There are differences in terms of the theoretical field most commonly used in each stream of non-linear research.

4.7.1 Overlaps

Despite differences in theoretical framings used to interpret phenomena, our analysis shows not only a high degree of conceptual convergence between the terms but also some differences, which suggests that concepts are nested in each other. In the inner cycle of nested concepts sits reverse logistics. Closed loops and reverse logistics are both focussed on flows of resources and the exchange of by-products (the sale of by-products of one company to be used as input by another). Closed loops include reverse logistic concepts but add on forward logistics (Chen and Chang, 2013). At Batista *et al.* (2018, p. 444) show the state that "[...] closed-loop supply chain combines forward and reverse supply chain to cover entire product life cycles from cradle to grave" The following circle is CE. CE concepts include closed loops concepts but take it further with a broader perspective looking at flows of resources and wastes within and across supply chains (Genovese *et al.*, 2017). The outer circles are industrial symbiosis and industrial ecology. The definitions in Table I demonstrate the specific concepts of all the mapped aspects: for instance, IS includes IE. These embrace not only CE concepts but also emphasize energy flows and social embeddedness (Baas, 2011). In addition to the exchange of by-products, activities include utility sharing (shared management and/or utility provision – electricity, water and wastewater – by a group of companies) and service sharing: the shared provision of ancillary services with explicit environmental benefits by a third party (Ashton, 2009).

Practices such as eco-design, disassembly and life-cycle analysis are shared by all approaches. However, Bocken *et al.* (2016) argues that the terminology around the CE has been diverting rather than diverging, and closed-loop ideas originating in different epistemological fields are used in parallel with often contradictory aims. Therefore, we should expect differences and even tensions between approaches originating in economy, business and management (closed-loop, reverse logistics and CE) and approaches originating in ecology (industrial ecology, industrial symbiosis and cradle to cradle).

Closed-loop and reverse logistics share a proactive focus on preventive process redesign. They aim to prevent further environmental damage improving eco-efficiency through non-linear production. The CE, industrial symbiosis, cradle to cradle and industrial ecology go a step further. They share a restorative system focus. They aim to repair previous environmental damage by designing better production systems. The CE aims to increase the efficiency of resource use, with a special focus on urban and industrial waste, to achieve a better balance and harmony between economy, environment and society (Ghisellini *et al.*, 2016). Yang *et al.* (2018) state that shifting of supply chains from linear to closed-loop models is an important step towards an increase in the CE.

Literature from all these approaches can be integrated to provide knowledge about practices in the technological and biological cycles of the CE. The caveat is that knowledge generated is biased towards technological cycles at the expense of biological cycles and towards multiple life cycles at the expense of longer life cycles. A recent systematic literature review about circular supply chain (Batista *et al.*, 2018) confirmed that the focus of studies on "technical materials." Research studies in the biological and technical cycles of circular economies are still fragmented and in need of substantial development. We have a very limited understanding of how these cycles are being implemented and integrated with business models and strategies. A recent study from Hansen *et al.* (2018) claims to be the first attempt to adopt strategic alignment approach to analyze the reverse supply chain. In the databases accessed, only two studies were found that deal simultaneously with practices in the biological cycle and practices in the technical cycle of the CE (Kralj *et al.*, 2017; Moreno *et al.*, 2016). Both papers only investigate a few aspects of the biological cycle. A more comprehensive analysis may uncover trade-offs in the implementation of technical and biological cycles. Therefore, there is a distinct need for new studies that can address all the dimensions of the technical cycles and biological cycles of the CE. Research is needed to explore diverse sectors of production that meet the fundamental principles and characteristics of the CE by promoting sources of value creation. We conclude that, as approaches are nested into each other, each approach adds incrementally and knowledge from the literatures discussed can be aggregated to understand CE challenges, with the proviso that tensions and biases also need to be critically considered.

4.7.2 Impacts

The literature review has identified consensus in the potential of non-linear production economy as a source of competitive advantage through the optimization of resources used in production processes (Reike *et al.*, 2018). Non-linear business models based on remanufacturing and reuse promise significant cost savings and revenues, as well as radical reductions in environmental impact (Linder and Williander, 2017).

The literature analyzed allows us to conceptualize two main potential impacts of non-linear production: eco-efficiency and eco-development. Eco-efficiency refers to the simultaneous attainment of positive environmental impacts and increased value for the firm. Eco-development refers to the simultaneous

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attainment of economic development and restorative environmental action. There is not enough literature to conceptualize trade-offs between different types of environmental impacts (water use, emissions, waste and biodiversity) and between types of environmental impacts and types of value.

Overall, all the literatures analyzed emphasize similar environmental benefits, use similar approaches and display similar methodological weaknesses and conceptual omissions. Mathematical models and single case studies offer a very positive picture of environmental benefits, but these are often restricted to waste, materials and emissions. The literature in closed-loop and reverse logistics offers more insights in reductions in hazardous waste and effluents than the rest, while the literature in industrial ecology includes research studying a broader range of issues, including water use, impacts on biodiversity and ecosystems. Despite these promising efforts, there is still a lack of quantitative studies evaluating environmental impacts and qualitative studies systematically exploring trade-offs, and the impacts of non-linear processes in water use and biodiversity remains unexplored.

The positive economic effects claimed in the literature are again, just as in the case of environmental benefits, largely conceptual (Defee *et al.*, 2009) or supported by mathematical modelling (Fraccascia *et al.*, 2017; Nurjanni *et al.*, 2017), case studies (Wolf *et al.*, 2007) and old success stories. For instance, several authors (Das and Chowdhury, 2012; Linder and Williander, 2017; Han *et al.*, 2016) build into their arguments how during the 1980s Xerox reduced manufacturing costs by approximately 40-65 per cent through reusing parts and materials and saved almost $200m in material costs in less than five years. Issues such as uncertainty of supply and the impacts of high fixed costs in long-term economic viability are still understudied. Modelling assumptions tend to be overoptimistic. For example, modelling tends to assume limited cycles of remanufacturing; however, in practice remanufacturing becomes unviable after only a short number of cycles (UNEP, 2017). The limited evidence found in this review suggests that positive economic effects are highly contextual. There is a need for primary data collection and for studies that investigate contextual determinants of economic benefits.

In addition to gaps previously described, we identified areas of tensions where the literature offers inconclusive, and often contradictory, findings that demand further exploration. A better understanding of these tensions is required to understand the impacts of non-linear production and to develop policy guidelines for industry and policymakers to scale-up CE.

Tension 1 design: extended versus *new cycle*. While industrial ecology sees an extended life cycle of products as a primary pathway to reduce waste, long product life cycle is not cited as a priority in closed-loop literature. This tension has been backgrounded in many of the articles reviewed but has important implications for policy. An extended life-cycle is achieved with more durable material, simple repairs and direct reuse (Sasikumar and Haq, 2011; Seager, 2008; Sgarbossa and Russo, 2017). Remanufacturing and refurbishment do not extend the life of a product; they extend the life of its parts by starting a new cycle. Hence, designing for remanufacturing often implies products with short life-cycle, designed to be easily disassembled and remanufactured again and again, but materials become unusable after a number of circles (Tagaras and Zikopoulos, 2008; Xiong *et al.*, 2016; UNEP, 2017). To date, there is no comparative study of the impacts of extended versus new cycles.

Tension 2 impacts: social versus *economic/environmental*. Social impacts have been largely omitted from modelling and case studies. When included, however, the models showcased trade-offs between social indicators and financial indicators or environmental indicators (Pishvaee *et al.*, 2014; Wang *et al.*, 2016; Zhalechian *et al.*, 2016).

Tension 3: *technical* versus *biological cycles*. A central consideration is to what extent principles developed for cycles of durable materials may be applied to technical cycles. What are the social and ethical implications of recycling, reusing, cascading or remanufacturing food?

Overall, our findings provide tentative directions for a research agenda responding to Batista *et al.* (2018) views. In the editorial introduction to a special issue on the CE, these authors question how extant research discourses concerning the sustainability of supply chains contribute to understanding about circularity in supply chain configurations that also support restorative and regenerative processes, as espoused by the CE ideal.

5. Final remarks

This study has analyzed the overlaps among CE, reverse logistics, closed loops, industrial symbiosis, industrial ecology, cradle to cradle and life-cycle assessments. We conclude that there are similar purposes among the different approaches, especially in terms of operational, environmental and financial performance, and therefore, knowledge generated can be aggregated to better understand CE challenges. However, there are also contradictions, tensions and epistemological ambiguities that need to be critically addressed. Such tensions may be associated with the knowledge field that gave rise to these different non-linear production approaches. Many of them appeared at the same time, but from different sciences (economics, biology, operations, management, etc.) and disciplines with their own perspectives. In doing so, they create confusion in the definitions of CE; assumptions underlying modelling and business choices arise from this complexity. These abstractions can be minimized through a critical interpretation of knowledge to elucidate epistemological quandaries and a more comprehensive research design to improve our understanding of the economic, social and environmental impacts. Practices that attend to the technical cycle and the biological cycle of the CE allow diverse options of reutilization of the resources in the companies. In some way, these results make sense, as we have limited the search to management, business and accounting journals and to Operations Management journals in particular. This is an important gap and interesting results should encourage more interdisciplinary research.

In the context of sustainable supply chain management, collaborative mechanisms would be relevant to facilitate sustainable practices, especially those focussed on CE. Specifically, mechanisms are implemented by means of more direct actions (hands-on), with active involvement of the companies or by more indirect (hands-off), with less active involvement of the companies.

Our review has acknowledged limitations. First, we use only one, albeit highly recognized database, Scopus. This database may have omitted some relevant research, Journals such as *Journal of Cleaner Production and Resources Conservation & Recycling* are more likely to publish such research and they have a more interdisciplinary approach. Second, the filtering process used and the focus on ABS top journals may have omitted some relevant research, such as a large stream of literature in specialist journals. However, our additional review of recent publications in all business, management and accounting journals reduced the probability that the omitted research would have contained information that would critically alter our conclusion. Finally, as our aim was to integrate prior research, we have not presented detailed propositions linking the elements, which would be a necessary next step.

Above all, our review highlights that there is an opportunity to advance a research agenda for CE more strongly based on theory. Management theories, in particular, can contribute to deep analyses of existing tensions and can identify how to address barriers to scale up a model of CE. The objective is to create value for companies and for society at large, which is restorative and regenerative, and which focusses on the maintenance of products, components and materials at its highest level of value.

Notes

1 Results from the year of 2016 collected 1.4 billion references, having 22 million and 618,000 titles, 5,000 publishers and 12 million profiles of authors and 70,000 of institutions.

2 The ABS ranking guide is based on peer evaluation, editorial judgements and experts after the evaluation of many hundreds of publications, and it is informed by statistical information related to the citation (CABS, 2015).

3 In addition, following Crossan and Apaydin (2010), we extracted two groups of publications from articles in CE published in management, business and accounting journals, namely, reviews and meta-analyses and more recent articles (2015-2018). We used these sources for the section on CE and the discussion.

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