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The Role and Value of Data in Realising Circular Business Models – a Systematic Literature Review

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Abstract

Purpose: A systematic review of the literature on circular business models was performed, for synthesis of what it reveals about the role and value of data in those models. The increasing quantity of supply-chain and life-cycle data available has potential to be a significant driver of circular business models. The paper describes the current state of knowledge and identifies avenues for further research related to use of various forms of data in the models.

Design: A systematic review of literature on the use of data in circular business models was carried out, to inform understanding of the state of knowledge and provide a firm foundation for further research.

Findings: The literature reviewed points to fragmented understanding of the role and value of data in circular business models. Nonetheless, scholars and practitioners commonly see data as a driver and enabler of circular economy. The article identifies two distinct approaches to value for data as presented in the corpus and discusses what types of data seem to be valuable in a circular business-model context. Among the further research opportunities are work on data as a source of business-model innovation and on collaboration in capturing the value of data in circular business models.

Value: The study provides new insight on the nexus of circular business models and data, and it represents one of the first comprehensive reviews addressing data's value in a networked circular-economy context.

Keywords: business models, circular economy, value of data, data-driven, sustainability

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Introduction

Scarcity of natural resources is among the most significant factors defining the landscape where today's companies do business and create value. Population growth and climate change create rising pressure related to the use of natural resources (IPCC, 2019) and call for intelligent decisions for efficient allocation, use, and conservation of valuable resources. For companies, resource scarcity is not only a source of risk and concern (e.g., Gaustad *et al.*, 2018) but, through circular business models, also an opportunity to pursue new revenue streams and market segments, along with enhanced customer experience (e.g., Lüdeke-Freund *et al.*, 2019; Stahel, 2016; Tukker, 2015).

In the context of circular economy, new innovative business models are needed for closing resource loops, slowing the cycle, and narrowing the loops, by such means as extended customer experience, long-life goods, product-life extension, recycling, reuse of materials, and resource-efficiency (e.g., Bocken *et al.*, 2016). Circular business models are aimed at resolving environmental sustainability challenges by turning linear resource flows into loops (Stahel, 1997). The goal is to get more value from the resources and simultaneously improve the sustainability of production and consumption.

At the same time, the burgeoning availability of data is transforming how businesses operate, and data's utility in generating knowledge and insight to improve decision-making is seen as a potentially powerful source of creation of both economic and social value (Grover *et al.*, 2018). More efficient use of data can serve as a significant driver and enabler of circular economy (Frishammar and Parida, 2019; Gupta *et al.*, 2018; Stahel, 2016), and interesting examples of data-driven circular business models, such as performance contracts, sharing models, and digital marketplaces for resources and waste streams, are already emerging (Ellen MacArthur Foundation, 2019; World Economic Forum, 2016). Circular economy requires better understanding of (often complex) flows and loops of resources, their value, and environmental impacts in contexts of complex value chains and networks. At the same time, these phenomena extend across borders between technologies, actors, and industries and over the full lifetime of products and services. Particularly in light of this complexity, data might be of help in considering how to realise circular economy.

Recent years have witnessed growing interest in sustainable business models and related innovations (e.g., Dentchev *et al.*, 2018; Wirtz *et al.*, 2016), with circular business models being no exception (e.g., Brown, 2019; Lüdeke-Freund *et al.*, 2019; Manninen *et al.*, 2018; Pieroni *et al.*, 2019). However, previous studies have not specifically considered the role and value that the wealth of data can have at the core of circular business models and related decision-making. Research on the intersection of data and circular business models has remained scarce (for exceptions, see Bressanelli *et al.*, 2018; Tseng *et al.*, 2018), and more insight into this nexus is needed, for understanding of how data can support creation of sustainable business.

Accordingly, we identified two research questions, formulated thus: 1) In what ways does literature on circular business models inform about the role and value of data in this set of models? 2) Through a review, can one identify possible paths for further research related to the use of various forms of data in circular business models?

The presentation of the systematic review begins in Section 2, laying out the conceptual background with regard to circular business models and the value of data therein. Then, Section 3 describes the research design and Section 4 presents the findings from the literature review. We conclude the paper by offering final thoughts and identifying further research opportunities.

Conceptual Background

Circular Business Models

The aim in employing circular business models is to address environmental sustainability challenges by transforming linear resource flows into loops, giving them circular form (Bocken *et al.*, 2016; Stahel, 2016; Tukker, 2015). The goal is to obtain greater value from the resource use and increase the sustainability of production and consumption. In circular business models, value is created in three ways: closing resource loops through reuse and recycling of materials, slowing the loops by designing long-life goods and extending products' service life, and narrowing the resource flows via resource-efficiency (Bocken *et al.*, 2016). To move from linear business models to circular ones, companies must redesign their value-creation logic, covering value propositions, the value-creation infrastructure, and the value-capture models (Hofmann, 2019).

For this paper, a business model is defined as describing the logic or design of how a business creates value and delivers it to the customers while also outlining the architecture of the revenues, costs, and profits associated with the company delivering that value (Teece, 2010). It is seen to include the following components: the value offered to customers (the value proposition), how the value is created and delivered to customers (value's creation and delivery), and how profit is generated (value capture) (Bocken *et al.*, 2014; Richardson, 2008; Teece, 2010). However, the concept of the business model is versatile, and it is defined and conceptualised in numerous ways (e.g., Al-Debei and Avison, 2010; Lüdeke-Freund *et al.,* 2019; Zott *et al.,* 2011). At base, such a model provides an abstract understanding of the relevant organisation's business logic in a somewhat descriptive manner (Al-Debei and Avison, 2010). In practice, business models are systems that exhibit complex interdependencies among these elements (Massa *et al.*, 2018). They are often industry-specific and depend also on the company context and business maturity in how they are designed to yield competitive advantage for the organisation in question.

In this paper, a circular business model is defined as a business model that helps companies to create value by means of using resources in multiple cycles, thus reducing both waste and consumption (Lüdeke-Freund *et al.*, 2019). In the context of circular business models, several approaches have been taken to apprehend the core of the model, with reasoning based on various taxonomies of the value-creation rationale (Ellen MacArthur Foundation, 2015), strategies (Bocken *et al.*, 2016), and patterns (Lüdeke-Freund *et al.*, 2019) represented by the business models. For this paper, the classification of circular business patterns developed by Lüdeke-Freund *et al.* (2019) was used for categorisation of the literature in the circular business model context. In this classification, the following six patterns are considered: repair and maintenance, reuse and redistribution, refurbishment and remanufacturing, recycling, cascading and repurposing, and organic feedstock.

The value expected to arise via circular business models encompasses not just economic value and direct value created for the customer (through means such as savings on production costs and materials and greater 'value-in-use') but also societal value (Lüdeke-Freund *et al.*, 2019; Stahel, 2016). As a concept, circular economy has strong connections with sustainability, and this concept is evolving, manifesting various definitions, boundaries, principles, and associated practices as it does so (Merli *et al.*, 2018). That said, from a sustainability point of view, the concept has, in general, been claimed to be more environmentally driven, with only a tenuous link to social sustainability (e.g., D'Amato *et al.*, 2017). Likewise, the value is characterised as created primarily on foundations of an environmental value proposition (Manninen *et al.*, 2018), and some have argued that circular business models might not always be able to capture the full scale of sustainability (Geissdoerfer *et al.*, 2018). In these models, the value is often co-created over the entire supply chain: customers, suppliers, manufacturers, retailers, etc. (Manninen *et al.*, 2018; Urbinati *et al.*, 2017).

Although not unambiguously defined or conceptualised, circular business models facilitate reflection on how companies can reach sustainability objectives in a way that makes good business sense. Hence, the insights from the review presented here are clearly relevant not only for academia but also for companies striving for circular-economy objectives.

Business models and innovation in them have been subject to increasing research efforts in recent years (e.g., Foss and Saebi, 2017; Massa *et al.*, 2018; Nielsen *et al.*, 2018), and, their conceptual fuzziness notwithstanding, they have turned out to be a helpful tool for understanding how companies do business and create value. Paying attention to business models can aid in rethinking and redesigning how companies reach their goals, understanding new types of innovation, and drawing attention to creation of social and environmental value alongside the economic (Massa *et al.*, 2018). There is a growing body of research on sustainable business models and related innovations (e.g., Dentchev *et al.*, 2018; Wirtz *et al.*, 2016) – of which examination of circular business models forms a key part (e.g., Brown, 2019; Lüdeke-Freund *et al.*, 2019; Manninen *et al.*, 2018; Pieroni *et al.*, 2019) – and on what kinds of inherent uncertainties these entail (Linder and Williander, 2017). While a few authors have cited data as a potential driver and enabler of circular economy and related business models (e.g., Frishammar and Parida, 2019; Gupta *et al.*, 2018), the role and value of data in circular business models remains largely uncharted territory.

Understanding the Value of Data

Growth in the volume of data is changing how businesses operate, and the power of data in generating insight to support better decision-making is seen as a potentially vast source of customer, economic, and social value (Grover *et al.*, 2018), where one can define data as objective facts about events and observations about the state of the world (Davenport and Prusak, 1998) or as symbols that represent properties of objects, events, and their environments (Ackoff, 1989). Said data may be either structured or unstructured, although the application of analytics to extract value from data usually assumes availability of sufficiently structured data – normalised records in a database with a rigid and regular structure (Abiteboul, 1997; McCallum, 2005). However, vast volumes of data are being generated in unstructured form, such as human-generated e-mail messages and their attachment files, photos, videos, voice recordings, and social-media content. This limits the direct applicability of traditional analytics.

Through data's integration, discovery, and exploitation (e.g., Miller and Mork, 2013), one can turn data into valuable information and knowledge. That insight holds promise for improving decisions and yielding such results as better utilisation of assets, greater operation efficiency, cost savings, and extended customer experience (e.g., Chen *et al.*, 2015; Günther *et al.*, 2017). Through data's potential contribution to uncovering hidden patterns and heretofore unknown correlations (Chen *et al.*, 2015), this resource could aid in increasing understanding of circular phenomena and in realising circular economy.

In this paper, we focus on which circular business models and strategies are seen as specifically benefiting from data and how the data may be conceptualised as a source of value under circular business models. More efficient use of data may help to turn the visions behind these models into reality by refining the value-creation logic, including decisions on how value is created, offered, and delivered to customers and how profit is generated. Those classes of business models that rely on data may be termed data-driven business models (Hartmann, 2016).

However, data might not always represent the world accurately, as it is easier to capture data from readily quantifiable phenomena (Jones, 2018). Structured and quantifiable data might be more readily available, as well as more attractive to use, than unstructured and non-quantifiable data. Data that could yield understanding of often complex circular phenomena might not be available, at least in relevant form, and a less accurate view of the phenomena might be produced. Such a picture may have much less value in decision-making. In addition, value may be lost through delays in extracting data, transforming the data into usable information, and deciding how to act on the information (Pigni, 2016). For example, either the absence of data indicating a need for maintenance or non-response to such data can lead to equipment breakdowns, production downtime, and other waste. Also, some use of data can have adverse impacts, which may run counter to circular-economy objectives. Even if handled responsibly and well, exploitation of data often requires extensive investments in management, technology, and other capabilities (Akter *et al.*, 2016).

General rationales related to data-driven value creation may be applicable in circular business models. More efficient use of data can add value by affording transparency of information and greater access to it, discovery and experimentation, prediction and optimisation, rapid adaptation and learning, customisation of products and services, and deeper understanding of customers (Chen *et al.*, 2015). Value can be extracted from data streams through initiation of action on the basis of real-time data or via merging of multiple data streams (Pigni, 2016). For example, real-time data on products' use and performance can prompt initiation of predictive maintenance measures, and demand for ride-sharing services can be forecast from considering weather data in combination with details of mobility demands. Data can be accumulated for information services, refined into insights and decision support, aggregated to inform existing services and enable new ones, and utilised for tracking and optimising operations and performance (Pigni, 2016). Better use of data can lead to innovation in product, service, and business models and thereby transform businesses' operations (Grover *et al.*, 2018; Hartmann, 2016). Reaping the full benefits of data often demands a change in business model, however (Buhl *et al.*, 2013).

Prior research offers insight pertaining to data-driven business models and the benefits and value of data in general (e.g., Chen *et al.*, 2015; Grover *et al.*, 2018; Hartmann, 2016). Yet, while some authors have identified data as a potential driver and enabler of circular economy (de Mattos and de Albuquerque, 2018; Frishammar and Parida, 2019; Gupta *et al.*, 2018; Tura *et al.*, 2019), little work has addressed the role and value of data specifically in relation to circular business models (for exceptions, see Bressanelli *et al.*, 2018; Tseng *et al.*, 2018). Nonetheless, further research addressing it is seen as important (Alcayaga *et al.*, 2019; Rajala *et al.*, 2018). This area represents a significant gap in scholarly understanding of data's potential to support development of circular economy.

The Research Design

To understand what the existing body of research indicates about the role and value of data in realisation of circular business models, we identified, reviewed, and formed a synthesis of the relevant literature. The literature review represents a method suited to systematic understanding of an existing body of knowledge and to providing a firm foundation for further research (Levy and Ellis, 2006). The search was limited to peer-reviewed scholarly articles found in academic databases (Scopus and EBSCO Business Source Complete) and published in this millennium.

For emphasis on the business context, the search used the term 'circular' in combination with either 'business model' or 'value creation', in the title, abstract, key words, or subject (stemming and Boolean operators were used thus: 'circular' AND 'business model*' OR 'value creat*'), where 'data' was used in any of the text. These search terms had been identified as having appropriate breadth and depth for answering our first research question (Levy and Ellis, 2006; Okoli, 2015). Additional criteria were used to screen the literature: publication language (English) and publication date (1.1.2000–30.8.2019).

After removal of duplicates, the total number of articles was 147, and 39 papers from this set were identified as relevant for understanding the role and value of data in circular business models. To be deemed relevant, the content had to speak to the research questions. There were no criteria related to research design or the context of the research. This search was complemented with forward and backward searches because the key words taken as search terms might have a limited 'lifetime' and alternative terms may have been used (Levy and Ellis, 2006). The forward and backward search yielded five further articles. Therefore, the final sample consisted of 44 articles.

The full text of each article selected was systematically reviewed with regard to the theoretical, conceptual, and empirical contribution to answering research question 1. Relevant material was collected manually and documented systematically in Excel sheets. The perspective of the articles on data and data's value was assessed and the link to circular business models identified. The type and sources of data dealt with, the nature of the data-driven activities considered, and the benefits and impacts of data identified as expected and/or realised were identified as the main themes in the course of the analysis. This enabled classifying and comparing the content of the articles and systematically synthesising the findings within a conceptual framework.

The development of our conceptual framework was based on the results of the literature review and reflects the conceptual background for our work also. Finally, further research opportunities were identified on the basis of the outcomes from the literature review. Figure 1 summarises the research design.

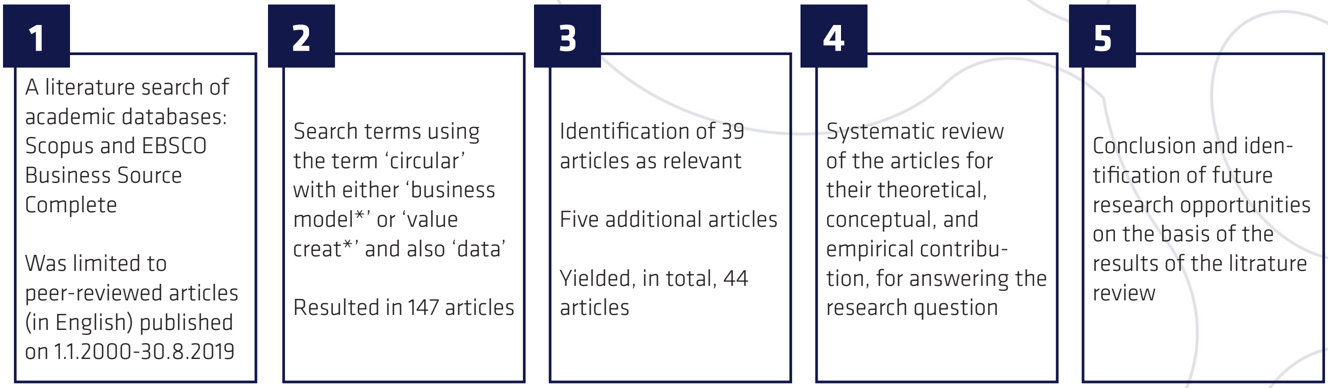

Figure 1: The research design for the literature review

Results of the Literature Review

In the corpus, data and related information technologies, services, and platforms are commonly presented as drivers and enablers of circular economy (e.g., de Mattos and de Albuquerque, 2018; Tura *et al.*, 2019), and lack of data is often cited as a barrier to circular business models (e.g., Saidani *et al.*, 2018; Vermunt *et al.*, 2019). A summary table covering all 44 articles is presented in Annex 1, and Annex 2 lists the context of each piece, its perspective on the relevant data, and the business models and strategies discussed.

All the articles matching the criteria used for our review are quite recent, published between 2016 and 2019. This attests to a strong upswing of attention to the subject, with growing interest in understanding the nexus of circular business models and digital technologies. In total, the sources feature 340 articles published on circular business models and value creation during the time span considered, so about 10% of the model-related papers deal with the role of data in one way or another.

As a whole, the body of literature reviewed indicates that the state of understanding of the intersection of circular business models and data is highly fragmented. The articles show wide variety in the circular business models addressed. In addition, diverse contexts and industries, among them manufacturing, waste management, and digitalisation, are covered. In some articles, the data or related factors are at the core of the discussion, while they are presented as a minor issue in others. Perspectives on the data were found to vary too, from perceiving the data as input to modelling, through applying life-cycle assessment of information flows in the supply chain, to expressing more general views on unlocking the potential of circular economy.

Below, we discuss the ways in which the literature on circular business models informs us about circular business models' relationship with data (including the associated strategies for exploitation of data) and what specific use data may have in circular business models. In addition, we identify two approaches to value of data that were articulated in the corpus and discuss which sorts of data seem the most valuable in this context.

Connecting circular business models to the role and value of data

The articles reviewed cover a broad spectrum of circular business models. Table 1 presents examples of this breadth with regard to the potential role and value of data, reflecting the various circular business model patterns introduced by Lüdeke-Freund *et al.* (2019). Many of the articles show connections with several business-model patterns, not least because roughly half of the papers express a general perspective on circular business models, without considering any specific ones. Many of the models discussed in the literature represent a high-level strategy or approach rather than a ready-to-apply model that could easily be classified as a specific business-model pattern.

Several articles cite opportunities in servitization and product–service systems, providing customers with service and performance rather than products (Alcayaga *et al.*, 2019; Bressanelli *et al.*, 2018; Frishammar and Parida, 2019; Khan *et al.*, 2018; Pialot *et al.*, 2017; Spring and Araujo, 2017). While this prominence might

Circular business model pattern (Lüdeke-Freund *et al.*, 2019)	Potential role and value of data	Examples from the literature
Repair and maintenance Through repair and maintenance services, companies can extend product life. This necessitates customer-centred services, expertise in the products, ability to solve problems 'on the fly', and corresponding forward and reverse logistics.	• End-to-end product and service data, real-time and historical, are needed for design support and for provision of long-life products and their repair and maintenance. Both understanding of customers' behaviour and preferences and the real-time visibility of the usage of a product seem crucial for increasing value for the customer. • There is potential value in data on the use, status, condition, location, and operation of products and services. Both real-time and historical data for the products or services' full service life and on customers' behaviour and preferences could be relevant. The data may be either user- or product-generated. • Several articles point to opportunities for product–service systems to provide customers with service and performance instead of products. These can extend companies' ownership of products over the full service life. This potential encourages companies to optimise the design, maintenance, and service-life management. Product–service systems' creation requires good understanding and evidence of customer behaviour and preferences.	Alcayaga *et al.* (2019) Bressanelli *et al.* (2018) Pialot *et al.* (2017) Spring and Araujo (2017) Zhang *et al.* (2017)
Reuse and redistribution Through reuse and redistribution, customers can be given access to used products, possibly with minor enhancement or modifications. This might require evaluating the products' market value and creating suitable marketplaces.	• Product lifetime data is a prerequisite for supporting the design and provision of long-life products that can be reused and redistributed. Digital platforms could serve as marketplaces. Both understanding of customers' behaviour and preferences and clarity as to the usage of a product seem crucial. • Data on the use, status, condition, location, and operation of products and services may be of value. Both real-time and historical data for their full lifetime and details on customers' behaviour and preferences may be relevant. The data may be either user- or product-generated.	Alcayaga *et al.* (2019) Nascimento *et al.* (2019) Saidani *et al.* (2018)
Refurbishment and remanufacturing Refurbishing and remanufacturing products – e.g., repairing or replacing components – can extend product life. This requires combining repair and maintenance capacity with reuse and redistribution capabilities in various ways, including reverse and forward logistics and applying technical expertise about products and their refurbishment and remanufacturing.	• Data for the products' full lifetime performance can be used to adjust design, operation, and disposal strategies for refurbishment and remanufacturing. Tools for product design can assist with assessing refurbishment and remanufacturing potential but might demand prohibitive quantities of product data. For a summary of potentially valuable data, see 'Repair and maintenance' and 'Reuse and redistribution', above.	Favi *et al.* (2019) Jensen *et al.* (2019) Khan *et al.* (2018) Matsumoto *et al.* (2016)

Table1: The potential role and value of data in circular business models

Circular business model pattern (Lüdeke-Freund ***et al.***, 2019)	Potential role and value of data	Examples from the literature
Recycling Used materials can be converted into materials of lower value or into higher-quality materials for improved functionality. This requires knowledge of product design, material sciences, and the materials' physical and chemical properties, along with solid ability to arrange reverse logistics.	• Data on material flows and on waste streams are of potential value. In addition, product-design data and data covering the entire service life (from the materials used to end-of-life contamination) are of importance for understanding recyclability and the recovery options.	Alcayaga *et al.* (2019) de Mattos and de Albuquerque (2018) Favi *et al.* (2019) Mishra *et al.* (2018) Niero and Olsen (2016)
Cascading and repurposing Organisations can apply iterative use of the energy and materials within physical objects, including biological nutrients. Exploiting this pattern demands facilitating material flows and supporting industrial symbiosis networks.	• Real-time and historical data on the whole life cycle and details of material flows, environmental impact, performance, etc. are seen as relevant. Valuable data may pertain to condition, operation, status, location, use, and the surrounding system. Information flows in the supply chain appear crucial. • Articles referring to closed-loop systems and industrial symbiosis are classified as articulating a cascading and repurposing business model, as they often focus on facilitating material flows and supporting industrial symbiosis networks. However, they may be crucial for any of the models in enabling forward and reverse logistics.	Aid *et al.* (2017) Fisher *et al.* (2018) Rajala *et al.* (2018) Tseng *et al.* (2018)
Organic feedstock This pattern involves processing organic residuals, via biomass conversion or anaerobic digestion, for use as production inputs or safe disposal in the biosphere. Corresponding reverse flows, alongside conversion, must be arranged and managed. Material compositions might be complex and the residues contaminated.	• The articles reviewed do not specifically address a business model based on organic feedstock. However, some do focus on cloud manufacturing, the sharing of manufacturing capabilities and resources on a cloud platform, which might be valuable in this context. Among the potential benefits are greater process resilience and improved waste reduction, reuse, and recovery.	Fisher *et al.* (2018) Lindström *et al.* (2018)

Table1: The potential role and value of data in circular business models *(Continued)*

be connected with the popularity of these models in writings on circular business models, it also ties in with the role that data could take specifically in such systems. Product–service systems of this nature show links to several business models (repair and maintenance, reuse and redistribution, refurbishment and remanufacturing, and recycling). Exploiting data for product–service systems should encourage companies to optimise their products' design, maintenance, and lifetime management to support a long service life, easy reuse, and recyclability, alongside other circular-economy-related objectives.

Several articles refer to closed-loop supply chains and product systems (Aid *et al.*, 2017; de Mattos and de Albuquerque, 2018; Mishra *et al.*, 2018; Niero and Olsen, 2016; Rajala *et al.*, 2018; Tseng *et al.*, 2018), bringing in discussion of cross-industry networks needed for reverse logistics, with links to many of the business models. Said articles are classified as representing a cascading and repurposing business model (just as the articles dealing with industrial symbiosis are), although networks of this sort may offer value under any of the models presented. These papers indicate that data could be of particular value with regard to orchestrating resources and activities in circular business ecosystems. Since flows and loops of resources often cross boundaries among a host of actors in complex value chains, there is good reason to deem associated data valuable for this component of circular business models.

Most of the papers reviewed place emphasis on manufacturing, the goods domain, and related issues such as product design and managing the supply chain or waste, while the corpus concentrates less on some other sets of businesses (such as companies in the service industry). The material points also to an uneven spread of attention across the various families of circular business models and strategies. For instance, there is relatively little focus on extending product value via such mechanisms as sharing-oriented platforms and collaborative consumption (for further details, see, for instance, Moreno *et al.*, 2016), even though use of data holds potential for significant contributions in these contexts too.

It appears that the role/value of data varies less from one business-model pattern to another than it does with the activity those data can support. This makes sense in that several models may incorporate a given general activity, whether that is orchestrating the necessary resources and activities, extending product lifetime through the product design, enabling effective forward and reverse logistics, or providing a service instead of products.

Collaboration in collecting and sharing data is portrayed as crucial for capturing the value of data in a networked circular-economy context, as is efficient flow of information along the supply chain (e.g., Brown, 2019; Gupta *et al.*, 2018; Rajala *et al.*, 2018). While existing circular business models vary in their degree of openness (Frishammar and Parida, 2019), a shift over time seems evident: toward a more collaborative approach to data-sharing (Rajala *et al.*, 2018). Nonetheless, data discrepancies, gaps, and confidentiality issues still hamper collaboration somewhat (Tseng *et al.*, 2018), and sharing of data requires ample trust (Gupta *et al.*, 2018; Rajala *et al.*, 2018). The possibility of lock-in to unproductive partnership relationships is to be considered also, since it may be difficult for a company to shift to employing circular business models if its partners are 'unwilling to make the required investments and adjustments' (Lahti *et al.*, 2018). In circular-economy-driven collaboration, collection and sharing of data could be the first joint step (Brown *et al.*, 2019) and a way to align the value chains' actors at the outset (Lopes de Sousa Jabbour *et al.*, 2018). Also highlighted in the corpus is that service providers specialising in software or data analytics might be needed, to boost the total value of the offer, provide access to knowledge resources, and render the solutions more innovative (Frishammar and Parida, 2019). At the same time, companies may find their data to exceed their own needs and be more valuable to others (Spring and Araujo, 2017), thereby opening collaboration opportunities and possibly representing sources of additional revenue.

The specific use of data in circular business models

Numerous types of data, such as product, service, and system data of various sorts (from design to disposal), can be valuable in the context of circular business models. More precisely, the data may represent the volume, characteristics, use, transactions, location, state and operation, condition, history, and surroundings related to products, services, systems, and associated material flows (Lopes de Sousa Jabbour *et al.*, 2018; Rajala *et al.*, 2018). Whether real-time or historical, user-generated or product-generated, structured or unstructured in form, said data holds potential to offer insight into, for example, how customers are actually using the products (Bressanelli *et al.*, 2018) or how supply-chain logistics could be optimised (Hopkinson *et al.*, 2018). There are limitations, though. Details for the entire service life are not always accessible (Alcayaga *et al.*, 2019), so more general material-flow data (e.g., on waste streams) may be used in their stead for mapping the current state and baseline (Gupta *et al.*, 2018) or identifying circular-economy opportunities (Aid *et al.*, 2017). Also, the data type and collection frequency demanded by any given use vary; for example, continuous flow of data may be needed for maintenance purposes while irregular input might suffice for other purposes (Alcayaga *et al.*, 2019).

In circular business models, as characterised by the literature reviewed, data can be used for product design, extension of products' life span, product and service innovation, and enhancement of customer experience. In product design, both user- and product-generated data may hold value (Zheng *et al.*, 2018) in affording insights into customers' usage patterns (Spring and Araujo, 2017). One can use data to extend product life (Bressanelli *et al.*, 2018); evaluate the life-cycle performance of products (Matsumoto *et al.*, 2016); improve recyclability (Favi *et al.*, 2019); and adjust the design, operation, and disposal strategies over the life cycle in line with said data (Khan *et al.*, 2018). The importance of data for better product design is emphasised by several articles specifically in the case of product–service systems and long-life products. Product-design tools can be used to assess product-specific disassembly and recycling potential and to provide redesign suggestions (Favi *et al.*, 2019). Data-mining tools can be employed to uncover hidden patterns and knowledge via real-time and historical life-cycle data for improving the product design, optimising the production process, and honing the recovery strategy (Zhang *et al.*, 2017). However, many design tools require significant quantities of technical data on the products (Matsumoto *et al.*, 2016) such as material and mass for each component and the contamination potential of all the materials, down to the coatings and adhesives (Favi *et al.*, 2019). Through the notion of digital identity introduced by Rajala *et al.* (2018), information could be made available on each product's composition, the process parameters used by all actors involved, and the instructions for processing and sorting – preferably without a need for add-on sensors or monitoring devices. In any case, this could lead to product and service innovation, in such forms as product–service systems and performance services wherein companies retain ownership of the products while the relevant data are used to optimise performance and expand service offerings (e.g., Alcayaga *et al.*, 2019; Frishammar and Parida, 2019). Integration of data into the systems and implementation of data-driven services might enable richer and longer customer relationships (Spring and Araujo, 2017), personalisation of the customer experience, and greater user involvement (e.g., Bressanelli *et al.*, 2018; Khan *et al.*, 2018).

In addition, data can be used for improving operational performance and optimising assets' utilisation, maintenance, and the end-of-life activities. Smart systems and embedded intelligence produce data on condition, operation, status, location, use, history, and surrounding systems, which enable any necessary real-time monitoring and control of systems and material flows (Lopes de Sousa Jabbour *et al.*, 2018; Rajala *et al.*, 2018). These data can be used for optimising processes and supply chains (Zhang *et al.*, 2017), reducing waste in production systems between supply chains (Lopes de Sousa Jabbour *et al.*, 2018), finding hidden patterns and correlations that could inform systems' optimisation (Gupta *et al.*, 2018), and conducting fault diagnostics (Zhang *et al.*, 2017). Data use can assist in identifying failures; monitoring, controlling, and intervening in the operations; planning the maintenance; and optimising delivery routes (Jabbour *et al.*, 2019). It can also enable sophisticated maintenance activities, including preventive, predictive, and prescriptive maintenance and the automation of these activities (Alcayaga *et al.*, 2019; Bressanelli *et al.*, 2018), alongside optimisation of end-of-life activities – reuse, remanufacturing, recycling, etc. (Bressanelli *et al.*, 2018). Data can be of use in judging the environment-related performance of circular business models too (e.g., Jensen *et al.*, 2019; Manninen *et al.*, 2018), though assessing the impact of large integrated systems may be difficult (Aid *et al.*, 2017). In addition, some significant differences exist between branches of industry in data's use and interpretation (Tseng *et al.*, 2018).

Approaches to Obtaining Value from Data in Circular Business Models

Proceeding from the literature review, we identified two approaches to gaining value from data under circular business models: an outward-oriented one and an inwardly focused one. Examining the outward-focused approach, we found reference to utilisation of data as enhancing the customer experience in respect of circular-economy objectives through good product and service design, extension of product life, stronger user involvement, and building of product–service systems. Taking this approach necessitates possessing data-based information and knowledge pertaining to not only products' and services' performance over their entire life cycle but also customers' behaviour and preferences. When used in support of circular design principles such as reliability and durability, trust in products and attachment to them, extended product life, and non-material products (these circular design principles are based on the work of Moreno *et al.*, 2016), data can play a significant part in encouraging longer use lives for products and slowering resource flows.

Among the relevant business activities in the context of enhancement to customer experience are improving product and service design, attracting the target customers, monitoring and tracking product-related activity, providing technical support (including preventive and predictive maintenance), optimising use, upgrading the products, and enhancing renovation and end-of-service-life activities (e.g., Bressanelli *et al.*, 2018; Rajala *et al.*, 2018; Zheng *et al.*, 2018). For example, giving customers access to data from products' real-world use can enable them to tune their usage patterns better, dissuade from careless use behaviour, and guide them toward suitable preventive and predictive maintenance; such data also can be utilised for provision of personalised advice and of mutually beneficial sharing-based business models (Bressanelli *et al.*, 2018).

In work representing the second approach, the inward-focused approach, one finds data serving as input to optimising the economic and environmental performance of circular systems and supply chains at a more technical and operations-oriented level. In this approach, the value is seen as lying in real-time and historical data on system or process performance and on related flows (of materials, energy, etc.). For this approach, use of data possesses vast potential to aid in narrowing the streams of resource flows by 'tightening up' various production steps or links in the value chain, 'lightweighting' the products, optimising yield and eliminating losses, and reducing material use (again, principles rooted in work by Moreno *et al.*, 2016).

Relevant business activities in the context of managing circular systems, supply chains, and value networks encompass managing the supply chains, optimising operation performance, improving assets' utilisation, managing waste, monitoring and tracking activity, and gauging environment-related performance (Gupta *et al.*, 2018; Hopkinson *et al.*, 2018; Lopes de Sousa Jabbour *et al.*, 2018; Rajala *et al.*, 2018; Zhang *et al.*, 2017).

These two approaches to value from data are not entirely separate. Rather, they overlap. They can be mutually supportive in slowing cycles, closing loops, and narrowing resource flows. For both approaches, the literature identifies potential for circular business models' application in which significant customer, business, and societal value is created and captured by means of data.

The idea of these two approaches is close to what Urbinati *et al.* (2017) pinpoints as so significant in creating new circular business models: a customer value proposition that involves extensive co-operation with the customers and a value network that encompasses reverse supply-chain activities and collaboration with the supply chain's other actors. This is in line with what Zolnowski *et al.* (2016) describe as the source of data-driven business innovations – customer-centred or co-operative value innovation and company-centred or co-operative productivity improvements.

Types of Data with Specific Value for Circular Business Models

With regard to circular business models, the literature review points to awareness of potential value in the following data categories especially: customer behaviour, use throughout the life cycle, system performance, and material flows. These are detailed in Table 2, below. The first category, consisting of data on the customers' behaviour, habits, and preferences, offers insight into, for example, how customers use products. Secondly, data covering the full life cycle of goods or services help us understand such factors as how usage has affected the reuse value of the materials. The performance category refers to data on the operation of larger technical or organisational systems, and its use can aid in, for example, optimising supply chains. Finally, data on flows of materials through various production, consumption, and end-of-life-management systems can stimulate insight into, for instance, waste streams that could be avoided. These four classes of potentially valuable data are highly interlinked, and these too can support closing the resource loops, slowing their cycle, and narrowing their flows.

To be valuable for circular business models, the above-mentioned data on customer behaviour, products' and services' full life, performance of systems, and material flows must be exploited in efforts to direct customer experience, supply chains, and value networks toward circular economy (e.g., Alcayaga *et al.*, 2019; Khan *et al.*, 2018; Zheng *et al.*, 2018). Thus, data must be transformed into information and knowledge that guides decision-making toward closing resource loops through

Data category	Definition	Description of a specific use of data in circular business models	References
Customer behaviour	Data on the customers' behaviour, habits, and preferences	The data can yield insight into how customers use various products and services and into how their needs can be met resource-efficiently. This insight enables companies to provide a service rather than a mere product and may help them extend their ownership of the products to the full service life. That, in turn, can encourage optimisation of products' design, maintenance, and lifetime management to support a long service life, ease of reuse, recyclability, and meeting of other circular-economy objectives.	Bressanelli *et al.*, (2018); Khan *et al.*, (2018)
Product and service lifetime	Data on the full service life of a product – raw materials to post-use life	This data type can inform insight into how product life could be extended or how use has affected the reuse value of the component materials. With such insight, companies can extend their products' service life through such means as long-life products, maintenance, and product upgrades. In addition, the most suitable design, operation, and disposal strategies can be chosen in light of the full life cycle, and these choices contribute to reducing consumption of resources.	Khan *et al.*, (2018); Spring and Araujo, (2017); Zheng *et al.*, (2018)
System performance	Data on the operation and performance of systems and value networks – devices, processes, activities, and value chains	This type of data can afford insight into how to improve operations' performance and optimise asset-utilisation, maintenance, and end-of-life activities throughout the systems and the supply chains. Such insight enables optimising systems' resource use by such means as finding and exploiting hidden patterns and correlations or applying data-driven initiation of predictive maintenance actions, thereby averting the risk of subsequent failure and large waste volumes.	Gupta *et al.*, (2018); Lopes de Sousa Jabbour *et al.*, (2018); Tseng *et al.*, (2018); Zhang *et al.*, (2017)
Material flows	Data on flows of materials through various production, consumption, and end-of-life systems	The data can yield insight into the volume, characteristics, and geographical location of various material flows, waste streams among them. This insight can inform efforts to reduce the use of resources and to avoid unnecessary waste streams or build business activities that exploit the relevant streams.	Aid *et al.*, (2017); Mishra *et al.*, (2018); Nascimento *et al.*, (2019); Rajput and Singh, (2019)

Table 2: Examples of the specific use of particular data types in circular business models

reuse and recycling of materials, slowing the looping by such means as designing long-life goods and extending the service life, and narrowing resource streams via resource-efficiency. Circular-economy objectives might be well in line with the general potential identified in data – for better utilisation of assets, higher-efficiency operations, a fuller and longer customer experience, and transparency of information (Chen *et al.*, 2015; Günther *et al.*, 2017).

However, data might not always reveal an accurate picture of circular phenomena, irrespective of the potential for novel data-analysis tools and models (artificial-intelligence applications among them) to unveil patterns and correlations that may advance understanding of circular phenomena further (e.g., Jabbour *et al.*, 2019). The detectability, measurability, and interpretability of the event determine whether the associated data supplied can be of value for decision-making (Pigni, 2016). Lack of access to relevant data that could inform understanding of often complex circular phenomena could lead to underutilised value for decision-making. In summary, companies moving from linear business models to circular ones must simultaneously develop their capabilities, processes, and activities throughout the value's creation, delivery, and capture (Frishammar and Parida, 2019). Companies have to possess the ability to identify data streams that can generate value, the capacity to use appropriate tools and technologies to tap these streams, ability to orchestrate the skills and resources required, and the necessary mindset (Pigni, 2016). For reaping the full sustainability potential of circular strategies, systems thinking is needed (Bocken *et al.*, 2016; Brown, 2019; Lewandowski, 2016). To this end, data could be of great help in solving unstructured, exploratory, and wicked problems (Surbakti *et al.*, 2019) connected with circular economy or with sustainability-related challenges more broadly.

Discussion and Conclusions

Our review, aimed at creating new insight into the nexus of circular business models and data, is one of the first comprehensive surveys addressing the value of data in a networked circular-economy context. We sought greater understanding of the use and perceived utility of data in realisation of circular business models, and we identified which circular business models and strategies typically appear to benefit from data. In addition, the two distinct approaches to value from data were clarified, as were the types of data found to be valuable in the context of circular business models. Awareness of these directions can aid in further improving both practical and scientific expertise in the field. Our primary goal with regard to informing practice was to provide business-relevant decision-supporting insight into how data may be conceptualised as a source of value under circular business models.

The corpus reviewed indicates that current understanding of the role and value of data in circular business models is fragmented but also that improved access to data is commonly seen as a driver and enabler of circular economy. Diverse business models and strategies identified in the literature can take advantage of data at the core of the value creation.

In the outward-focused approach to value from data that we pinpointed, data sources are utilised for directing the customer experience toward circular-economy objectives via more suitable product design, longer service life, greater user involvement, and product–service systems. At the same time, there was attention to an inward-focused approach, wherein real-time and historical performance and material-flow data etc. are used to optimise the economic and environmental performance of circular systems and supply chains. While the literature points to benefits from both approaches, understanding of the route from data to circular business models and onward to circular impacts (or the other way around) remains weak.

Another question considered is whether the role and value of data as conceptualised in relation to circular business models differs from data's role and value under other business models. In general, joint use of circular business models and data gets justified in terms of potential environmental benefits. However, environment-linked benefits may be gained also when, for example, one seeks supply-chain cost savings without having specific circular-economy objectives. While such data-driven optimisation of business activities might dovetail with environmental sustainability objectives, more comprehensive circular-economy value-creation rationales are likely to demand comprehensive understanding of circular-economy phenomena and objectives.

Business models and also data's potential role and value can be highly context-specific and dependent on the business and its ecosystem's conditions for exploiting data in pursuit of circular benefits. The material reviewed discusses neither the possibly quite substantial investments in capabilities and technology that exploiting data may demand nor other obstacles and constraints to realising data-focused circular business models. Also, the vast increase in the volume of potentially valuable but unstructured and non-quantifiable data should be kept in mind, as should the possible non-existence of relevant data. In addition, discussion of whether data-driven circular business models capture the full scale of sustainability was beyond the scope of our study. Nonetheless, it is clear that many of the conceptual mechanisms identified can be expected to display delayed, non-linear, and feedback-related effects, bound up with risks of adverse consequences connected with sustainability.

Our approach has its limitations, most prominently that this stage of evaluation was confined to examining the understanding displayed in the articles reviewed and the research designs reported. Clearly, not all research that could assist in understanding the role and value of data could be identified through our review method, and the literature examined might be unevenly distributed. Another factor is that both the concept of circular business models and that of data-driven approaches are showing strong development over time. The concepts and definitions are still evolving as studies accumulate from a host of disciplines (e.g., the fields of strategy, business models, management studies, information systems, operations management, engineering, and sustainability research). Hence, this review should be taken in its temporal context and as offering a starting point for scholarship of this nature. It represents a perspective gained via a systematic approach to describing the current state of understanding of data's role and value in circular business models.

Opportunities for Further Research

We will now discuss the key opportunities for further research that were revealed through examination of the literature. These fall into three areas: data as a driver of innovation in development of circular business models, the role of collaboration in capturing value from data, and ways of creating value jointly with customers. As we discuss each of these in turn, we refer to both the state of the art, as evidenced by our review, and the research gaps indicated.

Proposition 1: Data Can Inform Circular Business Models' Development

Our review of the 44 articles showed that data and related information technologies, services, and platforms are commonly seen as drivers and enablers of circular economy and as possessing potential to act as key inputs to a variety of circular business models (the state of the art). While the literature highlights potential opportunities for using data in circular business models, there is less systematic assessment or empirical evidence of data's role and value in these models, showing a gap. Data may clearly exhibit potential to enable and accelerate the development of innovative, even transformative, circular business models, but systemic understanding of circular phenomena and the context in which innovative business models are to be introduced remains necessary (another gap). The path from data to circular business models and, in turn, to circular impacts or, *vice versa*, from circular impacts and business models to valuable data is still little understood (a gap). In a final gap, fuller insight into strategies for designing data-driven circular business-model innovation and how to facilitate the emergence of such business-model innovations in a networked circular-economy context is needed.

Contributions from specialists in data-driven value creation and business models would, therefore, be beneficial for filling gaps by taking research on the impacts and benefits of data in circular-economy context further. Further empirical and conceptual research is needed if we are to understand the role and value of data in circular business models and specify the understanding more fully. Our finding of a need for further research is in line with conclusions from previous studies (e.g., Alcayaga *et al.*, 2019; Rajala *et al.*, 2018), which have identified, for example, a need to increase understanding of closed-loop business models based on platforms with multiple actors (Rajala *et al.*, 2018) and of technologies' impact on product design and circular strategies (Alcayaga *et al.*, 2019).

Proposition 2: Collaboration Is Needed for Capturing Data's Value in Circular Business Models

In the articles reviewed, collaboration in collecting and sharing data and simultaneous efficient flow of information in the value networks are portrayed as crucial for capturing data's value in a networked circular-economy context. However, there remains a need to better understand how inter-organisation collaboration can contribute to data-driven circular business-model innovation and how such collaboration could be enhanced. Interesting matters include companies' strategic decisions on openness levels in creating and sharing data and the business models used to capture value from collaborative value propositions.

Circular economy is seen as inherently collaborative, and inter-organisation innovation is needed for sustainability impacts (e.g., Lewandowski, 2016; Lüdeke-Freund *et al.*, 2019). Circular value creation takes place throughout the supply chain and the network formed of suppliers, manufacturers, retailers, customers, and other potential partners (Lewandowski, 2016; Manninen *et al.*, 2018). There is growing interest in how companies can collaboratively create circular value propositions and system-level business models (Brown, 2019). The need for collaboration in exploiting the value of data is consistent with what is visible for more general data-driven business models and the related notion that value of data is produced in activities involving other stakeholders in the data ecosystem (Bharadwaj *et al.*, 2013; Thomas and Leiponen, 2016).

In circular business models, the impetus for collaboration can arise from such angles as a need to understand complex crosscutting systems, such as global supply chains, along with shared risks, critical leverage points, and technical barriers (Brown, 2019). Company reluctance to share data for reason of privacy, security, or competitiveness concerns is not specific to circular business. Digital trust is necessary between any collaboration partners (Rajala *et al.*, 2018), and data access may be controlled via formal contracts or selling of data alongside explicit specification of data ownership and rights (Günther *et al.*, 2017).

Proposition 3: Data Can Yield Insight on How to Co-create Value with Customers

The literature shows that several types of circular business model are aimed at changing the role of the customer in the value creation. This may occur, for example, when one provides the customer with service, access, or performance instead of product ownership. As evidenced by the literature, the middle stretch of a product's life (i.e., the use of products and services) is receiving growing interest. There is awareness also that data on customers' behaviour and preferences and lifelong data on products and services can be of great value for understanding how to design circular products, services, and business models that all extend service life or how to provide a personalised offering that reduces users' consumption of resources. However, a gap is visible with regard to research into the customer's changing role in circular business models and how data can be used in response.

Circular business models, when extending a company's responsibility for the ownership of products over their entire life, increase interaction with customers (Lewandowski, 2016). The interactions are a possible source for additional valuable data, of use for enhancing customers' experience and customer relations. Getting more involved in the product-use phase can lead companies to rethink their relationship with customers and consumers (Hofmann, 2019) and to make customers a significant part of the value co-creation. Such developments represent new opportunities for circular business models.

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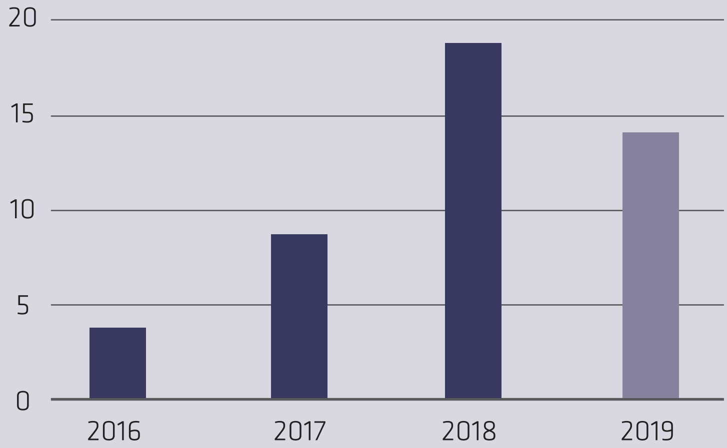
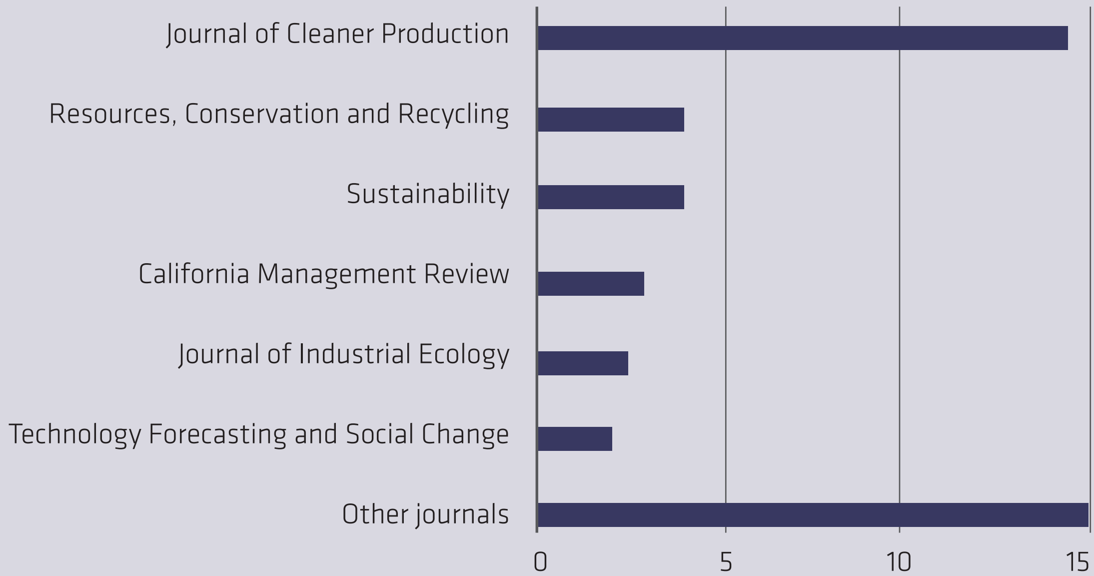
<table>
<tr><th></th><th>Summary of the articles reviewed</th></tr>
<tr><td>Years of publication</td><td>Number of articles

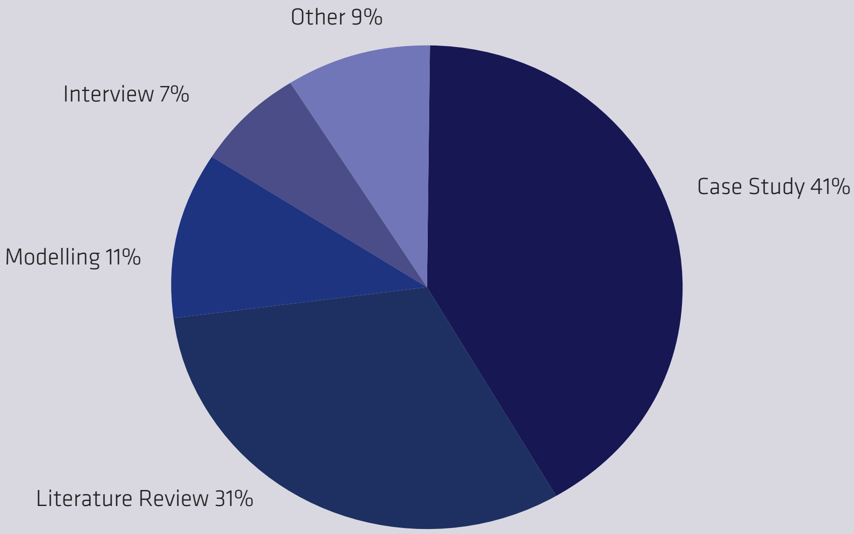


No relevant articles were published before 2016. The bar for 2019 covers the months from January to August.</td></tr>
<tr><td>Journals</td><td>Number of articles



The ‘other journals’ category covers *Advanced Engineering Informatics*, *Annals of Operations Research*, *Annual Review of Materials Research*, *Applied Sciences*, *Autonomous Agents and Multi-Agent Systems*, *Industrial Marketing Management*, *International Journal of Information Management*, *International Journal of Management Cases*, *International Journal of Precision Engineering and Manufacturing – Green Technology*, *Journal of Manufacturing Systems*, *Journal of Manufacturing Technology Management*, *Management Decision*, *Marine Policy*, *Production Planning & Control*, and *Social Sciences*, with one article each.</td></tr>
</table>

Annex 1: Summary of the literature reviewed

	Summary of the articles reviewed
Research methods	 The other research methods were action research, questionnaire-based surveys, preparation of perspective papers, and multi-method approaches.

Annex 1: Summary of the literature reviewed *(Continued)*

Authors	Title	Journal	Year	Method	Context	Perspective on the data	Business models and strategies discussed
Aid, G., Eklund, M., Anderberg, S., & Baas, L.	'Expanding roles for the Swedish waste management sector in inter-organizational resource management'	Resources, Conservation and Recycling	2017	Interviews	Waste management	Material flow and environmental impact data	Industrial symbiosis
Alcayaga, A., Wiener, M., & Hansen, E.	'Towards a framework of smart-circular systems: An integrative literature review'	Journal of Cleaner Production	2019	Literature review	Smart circular systems	Products' lifetime data	Product–service systems; maintenance; reuse; remanufacturing; recycling
Asif, F., Lieder, M., & Rashid, A.	'Multi-method simulation based tool to evaluate economic and environmental performance of circular product systems'	Journal of Cleaner Production	2016	Modelling	Circular product systems	Data as input to a software tool	Circular product systems
Bressanelli, G., Adrodegari, F., Perona, M., & Saccani, N.	'Exploring how usage-focused business models enable circular economy through digital technologies'	Sustainability	2018	Case study	Circular economy; digital technologies	Digital technologies	Servitized business models
Camacho-Otero, J., Boks, C., & Pettersen, I.	'Consumption in the circular economy: A literature review'	Sustainability	2018	Literature review	Circular economy; consumption	Customer data	No specific model or strategy

Annex 2: Articles included in the literature review

Authors	Title	Journal	Year	Method	Context	Perspective on the data	Business models and strategies discussed
Cezarino, L., Liboni, L., Oliveira Stefanelli, N., Oliveira, B., & Stocco, L.	'Diving into emerging economies bottleneck: Industry 4.0 and implications for circular economy'	Management Decision	2019	Literature review	Circular economy; industry 4.0	Opportunities and limitations connected with industry 4.0	No specific model or strategy
de Mattos, C., & de Albuquerque, T.	'Enabling factors and strategies for the transition toward a circular economy (CE)'	Sustainability	2018	Case study	Circular economy	Data as a key aspect of circular business models	Industrial symbiosis; extending resource value; reverse supply chain
Favi, C., Marconi, M., Germani, M., & Mandolini, M.	'A design for [a] disassembly tool oriented to mechatronic product de-manufacturing and recycling'	Advanced Engineering Informatics	2019	Modelling	Disassemblability and recyclability	Data as input to a software tool	Disassemblability; recyclability
Fisher, O., Watson, N., Porcu, L., Bacon, D., Rigley, M., & Gomes, R. L.	'Cloud manufacturing as a sustainable process manufacturing route'	Journal of Manufacturing Systems	2018	Literature review	Cloud manufacturing	Cloud manufacturing as a mechanism to share and exploit data	Automation, process resilience, waste reduction, reuse, and recovery
Frishammar, J., & Parida, V.	'Circular business model transformation: A roadmap for incumbent firms'	California Management Review	2019	Case study	Circular business transformation	The potential role of software and data-analytics specialists	Product–service systems
Garcia-Muiña, F., González-Sánchez, R., Ferrari, A., & Settembre-Blundo, D.	'The paradigms of Industry 4.0 and circular economy as enabling drivers for the competitiveness of businesses and territories: The case of an Italian ceramic tiles manufacturing company'	Social Sciences	2018	Case study	Circular economy; industry 4.0	Industry 4.0 in support of collecting, storing, and processing of data	No specific model or strategy
Gilbert, P., Wilson, P., Walsh, C., & Hodgson, P.	'The role of material efficiency to reduce CO_2 emissions during ship manufacture: A life cycle approach'	Marine Policy	2017	Modelling	Life-cycle analysis	Data as input to life-cycle analysis	Material-efficiency
Gupta, S., Chen, H., Hazen, B., Kaur, S., & Santibañez Gonzalez, E.	'Circular economy and big data analytics: A stakeholder perspective'	Technology Forecasting and Social Change	2018	Interviews	Circular economy; Big Data analytics	Big Data as a facilitator of circular economy	No specific model or strategy
Heyes, G., Sharmina, M., Mendoza, J., Gallego-Schmid, A., & Azapagic, A.	'Developing and implementing circular economy business models in service-oriented technology companies'	Journal of Cleaner Production	2019	Case study	Circular business models	Data's monitoring and analysis as an attractive business model for IT companies	Data's monitoring and analysis
Hofmann, F.	'Circular business models: Business approach as driver or obstructer of sustainability transitions?'	Journal of Cleaner Production	2019	Literature review	Circular business models	Digital technologies supporting circular business models	No specific model or strategy
Hopkinson, P., Zils, M., Hawkins, P., & Roper, S.	'Managing a complex global circular economy business model: Opportunities and challenges'	California Management Review	2018	Case study	Circular business models	Asset-tracking tools; real-time visibility	No specific model or strategy

Annex 2: Articles included in the literature review *(Continued)*

Authors	Title	Journal	Year	Method	Context	Perspective on the data	Business models and strategies discussed
Jabbour, C., Lopes De Sousa Jabbour, A., Sarkis, J., & Filho, M.	'Unlocking the circular economy through new business models based on large-scale data: An integrative framework and research agenda'	Technology Forecasting and Social Change	2019	Literature review	Circular economy; Big Data	Big Data in unlocking the potential of circular economy	'Regenerate, share, optimize, loop, virtualize, exchange'
Jensen, J., Prendeville, S., Bocken, N., & Peck, D.	'Creating sustainable value through remanufacturing: Three industry cases'	Journal of Cleaner Production	2019	Case study	Sustainable remanufacturing	Data in assessment of environmental and economic performance	Remanufacturing
Khan, M., Mittal, S., West, S., & Wuest, T.	'Review on upgradability – a product lifetime extension strategy in the context of product service systems'	Journal of Cleaner Production	2018	Literature review	Upgrading; extending products' service life	Data to support designing of upgradable services	Product–service systems
Leising, E., Quist, J., & Bocken, N.	'Circular Economy in the building sector: Three cases and a collaboration tool'	Journal of Cleaner Production	2018	Case study	Circular economy	Information flow in the supply chain	No specific model or strategy
Lieder, M., Asif, F., & Rashid, A.	'Towards Circular Economy implementation: An agent-based simulation approach for business model changes'	Autonomous Agents and Multi-Agent Systems	2017	Modelling	Circular business models	Data as input to understanding customers' behaviour and preferences	No specific model or strategy
Lindström, J., Hermanson, A., Blomstedt, F., & Kyösti, P.	'A multi-usable cloud service platform: A case study on improved development pace and efficiency'	Applied Sciences	2018	Case study	Cloud service platforms	Data collection and analytics in Big Data operations	No specific model or strategy
Lopes De Sousa Jabbour, A., Jabbour, C., Godinho, F., & Roubaud, D.	'Industry 4.0 and the circular economy: A proposed research agenda and original roadmap for sustainable operations'	Annals of Operations Research	2018	Literature review	Circular economy; industry 4.0	Industry 4.0's technologies to collect, analyse, and act on data	'Regenerate, share, optimize, loop, virtualize, exchange'
Lüdeke-Freund, F., Gold, S., & Bocken, N.	'A review and typology of circular economy business model patterns'	Journal of Industrial Ecology	2019	Literature review	Circular business models' design	Identifying equipment databases as an example of auxiliary services	No specific model or strategy
Manninen, K., Koskela, S., Antikainen, R., Bocken, N., Dahlbo, H., & Aminoff, A.	'Do circular economy business models capture intended environmental value propositions?'	Journal of Cleaner Production	2018	Case study	Circular business models	Lack of data for verifying the environmental benefits of circular business models	No specific model or strategy
Matsumoto, M., Yang, S., Martinsen, K., & Kainuma, Y.	'Trends and research challenges in remanufacturing'	International Journal of Precision Engineering and Manufacturing – Green Technology	2016	Literature review	Remanufacturing	Design tools as requiring significant quantities of product data	Remanufacturing
Merli, R., Preziosi, M., & Acampora, A.	'How do scholars approach the circular economy? A systematic literature review'	Journal of Cleaner Production	2018	Literature review	Circular economy	Linking of Big Data and the Internet of Things to circular economy	No specific model or strategy

Annex 2: Articles included in the literature review *(Continued)*

Authors	Title	Journal	Year	Method	Context	Perspective on the data	Business models and strategies discussed
Mishra, J., Hopkinson, P., & Tidridge, G.	'Value creation from circular economy-led closed loop supply chains: A case study of fast-moving consumer goods'	Production Planning & Control	2018	Case study	Closed-loop supply chains	Integration of material data with supply-chain databases and systems	Closed-loop supply chains, reverse material flows, and reverse logistics
Nascimento, D., Alencastro, V., Quelhas, O., Caiado, R., Garza-Reyes, J., Lona, L., & Tortorella, G.	'Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context'	Journal of Manufacturing Technology Management	2019	Interviews	Circular economy; industry 4.0	The value of data in collection and sorting of waste	Selective waste collection; sorting of waste
Niero, M., & Olsen, S.	'Circular economy: To be or not to be in a closed product loop? A Life Cycle Assessment of aluminium cans with inclusion of alloying elements'	Resources, Conservation and Recycling	2016	Modelling	Life-cycle assessment	Life-cycle data	A closed product loop
Niero, M., Hauschild, M., Hoffmeyer, S., & Olsen, S.	'Combining eco-efficiency and eco-effectiveness for continuous loop beverage packaging systems: Lessons from the Carlsberg circular community'	Journal of Industrial Ecology	2017	Case study	Life-cycle assessment	Life-cycle data	Circular industrial systems
Oghazi, P., & Mostaghel, R.	'Circular business model challenges and lessons learned – an industrial perspective'	Sustainability	2018	Case study	Circular business models	Lack of tools to handle products' lifetime data	No specific model or strategy
Pialot, O., Millet, D., & Bisiaux, J.	'"Upgradable PSS": Clarifying a new concept of sustainable consumption/production based on upgradablility'	Journal of Cleaner Production	2017	Action research	Product-service systems; upgradability	Using data to achieve upgradability	Product-service systems
Planing, P.	'Will digital boost circular? Evaluating the impact of the digital transformation on the shift towards a circular economy'	International Journal of Management Cases	2017	Literature review	Digital transformation	Focus on digital transformation	No specific model or strategy
Rajala, R., Hakanen, E., Mattila, J., Seppälä, T., & Westerlund, M.	'How do intelligent goods shape closed-loop systems?'	California Management Review	2018	Case study	Intelligence of goods in closed-loop ecosystems	Intelligent goods; traceability; digital identity	Closed-loop business models; digital platforms
Rajput, S., & Singh, S.	'Connecting circular economy and industry 4.0'	International Journal of Information Management	2019	Survey	Circular economy; industry 4.0	Enabling and challenging factors within industry 4.0	No specific model or strategy
Reuter, M., van Schaik, A., Gutzmer, J., Bartie, N., & Abadías-Llamas, A.	'Challenges of the circular economy: A material, metallurgical, and product design perspective'	Annual Review of Materials Research	2019	Literature review	Circular economy	Data needed for assessing the circular benefits	No specific model or strategy
Saidani, M., Yannou, B., Leroy, Y., & Cluzel, F.	'Heavy vehicles on the road towards the circular economy: Analysis and comparison with the automotive industry'	Resources, Conservation and Recycling	2018	Multi-method approach	End of life	Insufficiency of data for understanding the end-of-life options	End-of-life perspective

Annex 2: Articles included in the literature review *(Continued)*

Authors	Title	Journal	Year	Method	Context	Perspective on the data	Business models and strategies discussed
Spring, M., & Araujo, L.	'Product biographies in servitization and the circular economy'	Industrial Marketing Management	2017	Literature review	Circular economy; servitization	Potential of Internet of Things solutions and smart connected products, along with product biographies	Servitization
Tseng, M., Tan, R., Chiu, A., Chien, C., & Kuo, T.	'Circular economy meets industry 4.0: Can big data drive industrial symbiosis?'	Resources, Conservation and Recycling	2018	Perspective paper	Industry 4.0; Big Data; industrial symbiosis	The nexus of industry 4.0 and circular economy	No specific model or strategy
Tura, N., Hanski, J., Ahola, T., Ståhle, M., Piiparinen, S., & Valkokari, P.	'Unlocking circular business: A framework of barriers and drivers'	Journal of Cleaner Production	2019	Case study	Circular economy	Enhanced information management technologies, services, and platforms as drivers for circular economy	No specific model or strategy
Veleva, V., & Bodkin, G.	'Corporate–entrepreneur collaborations to advance a circular economy'	Journal of Cleaner Production	2018	Case study	Circular economy; collaboration	Lack of data for assessing circular economy's performance	No specific model or strategy
Vermunt, D., Negro, S., Verweij, P., Kuppens, D., & Hekkert, M.	'Exploring barriers to implementing different circular business models'	Journal of Cleaner Production	2019	Case study	Circular business models	Lack of information and data, as a barrier to circular business models	No specific model or strategy
Zhang, Y., Ren, S., Liu, Y., Sakao, T., & Huisingh, D.	'A framework for Big Data driven product lifecycle management'	Journal of Cleaner Production	2017	Case study	Big Data; product life-cycle management	Big-Data-driven product life-cycle management	Product life-cycle management

Annex 2: Articles included in the literature review *(Continued)*

About the Authors

Päivi Luoma is an experienced professional in strategy and business development, new business concepts, and innovation strategies. She has 20 years of experience on working with impact-driven companies and their innovations globally. She has a background in environmental economics and corporate responsibility. Lately she has focused on sustainable business models, co-creation and clean technologies, as well as commercialising circular innovations. Currently she is working on her PhD on the role and value of data in circular economy business and ecosystems.

Anne Toppinen is Professor of forest economics and marketing at University of Helsinki and the leader of Helsinki Institute of Sustainability Science (HELSUS). Toppinen's expertise is on sustainability transformations and business economics and markets in the context of circular bioeconomy. She has also studied policy coherence and diffusion of sustainability practices in the natural resource context, as well as related sustainable business models. She has published over 130 scientific peer review journal articles and supervised 14 doctoral theses. For more information of her projects and publications, see https://www.helsinki.fi/en/researchgroups/forest-bioeconomy-business-and-sustainability

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