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Circular disruption: Digitalisation as a driver of circular economy business models

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Abstract

New circular business models can evolve at all stages of the life cycle of a product. Digitalisation can drive disruptive innovations, new business models and novel ways of collaboration and thus can accelerate the economic transition to more resource-efficient and circular production systems. Yet, there is little empirical research on the enabling role of digitalisation for a circular economy. To address this gap, this paper investigates the role of digitalisation in facilitating circular business models, based on the empirical analysis of a data set of 599 German manufacturing firms and 296 industrial service providers. While relatively few German firms rely on new business models to foster their resource efficiency strategy, we find this share higher for companies with a strong digital focus in the manufacturing sector. This suggests that digitalisation can indeed be a driving force for the implementation of circular business models.

KEYWORDS

business models, circular economy, digitalisation, disruptive innovation, product-service systems, resource efficiency

1 | INTRODUCTION

Moving from the traditional 'take-make-dispose' economic model to a circular economy, that is regenerative by design, will change the way business is done (EMF, 2012; Geissdoerfer et al., 2017). As a new way of looking at the relationships between markets, customers and natural resources, it can disrupt incumbents and even whole industries (BCG, 2018; EMF, 2015; Neligan, 2018b).

At the organisational level, innovations that foster the reuse or more efficient use of resources can contribute to business strategies that make the company less dependent on scarce resources, increase operational efficiency, lower refinancing costs, drive further innovation, and enable new offerings that attract customers and deepen existing relationships (BCG, 2018; Losse & Geissdoerfer, 2021; Neligan, 2018b). This involves a complex transformation process, strengthening relevant innovations, investments and other transition costs to enable business model innovations and new ways of collaboration (BCG, 2018; EMF, 2015; Neligan, 2018b). 'Going circular' does not only require fundamental changes along the entire value chain but can also lead to different products, services and revenue models

(Geissdoerfer et al., 2018; Schöggl, Stumpf, & Baumgartner, 2020; Stahel, 2019).

In this context, digitalisation can be a driving force, enabling new and disruptive business models (for example, Antikainen et al., 2018; CEID, 2020; Chiaroni et al., 2021; Pagoropoulos et al., 2017). The increasing availability of data, automatisation, digital networking and new customer interfaces raises expectations in terms of more resource-efficient and circular production methods and business models (Kristoffersen et al., 2019). To date, only a few examples of successful implementations are reported (Schöggl, Rusch, et al., 2020). For instance, Rolls Royce deploys a service-based business model, where airline manufacturers no longer buy engines but pay a variable fee for their availability. This business model builds on predictive and preventive maintenance enabled by Internet of Things (IoT) technology and Big Data analysis (Bressanelli et al., 2018). Another example comes from Tradelense, founded by the International Business Machines Corporation (IBM) and Maersk who use blockchain technology to digitise container logistics and to make bills of landing attached to maritime containers more accurate and trustworthy (Saberi et al., 2019). Digitalisation has already led to well-documented disruption in a range of other areas, leading to Uber outperforming BMW's market value and Amazon becoming the world's largest retailer (Depter, 2019; Kelly, 2017; Parker et al., 2016), making digitalisation a promising driver for circular disruption.

Despite this intuitive importance of digitalisation as a driver for circular disruption, there is conceptual ambiguity on how both concepts, circular business model (CBM) innovation and digitalisation can be linked in a coherent framework. Different studies address the concept of circular business innovations (see, e.g., Geissdoerfer et al., 2020; Pieroni et al., 2019; Santa-Maria, Vermeulen & Baumgartner, 2021 for an overview). Other studies focus on different digital technologies (DTs) for sustainable and/or CBMs (e.g., CEID, 2020; Gupta et al., 2019; Ingemarsdotter et al., 2020; van Fossen et al., 2019). Lopez et al. (2019) point out that research into business models for resource efficiency and circularity is not yet mature, mostly still conceptual (e.g., Dentchev et al., 2018; Urbinati et al., 2017) and covers only individual or a small number of cases (e.g., Franzò et al., 2021; Stumpf et al., 2021; Urbinati et al., 2021). In addition, empirical evidence on DTs for resource efficiency or for circularity is still largely limited to individual case studies (see, for example, the analysis for German small and medium-sized enterprises [SMEs] in VDI ZRE, 2017, or only limited representative empirical evidence is available [see, for example, for Germany by Neligan, 2018a and Neligan et al., 2021).

To address this gap, this study aims to offer empirical evidence on the facilitating role of digitalisation on circular disruption. First, a literature review is conducted to systemise the link between digitalisation and CBM innovation. In this literature review, we conceptualise CBM innovation as well as circular disruption and show the enabling role of digitalisation in this context. On this basis, we investigate evidence on both the degree of digitalisation and the role of digital business models to facilitate CBMs at firm level, using unique, representative and recent German company data.

The main research questions are:

1. How can businesses integrate CBMs in their product life cycle?
2. Is digitalisation a driving force behind CBMs and, therefore, eventually circular disruption in practice?

The key contributions of this paper are (1) conceptualising the link between DTs and CBM innovations; (2) representative evidence for German firms on the role of digitalisation for resource-efficient and CBMs.

This paper is structured in five sections. After this introduction, Section 2 reviews the concepts of CBM innovation and the role of digitalisation to foster new CBMs. Section 3 explains the data and methodology. Section 4 presents the results. Section 5 presents a conclusion and a discussion of its implications.

2 | LITERATURE REVIEW

This section illustrates the underlying theoretical concepts of this research, by first providing an understanding of the CBM innovation concept and the circular disruption notion and then discussing the enabling role that digitalisation can play in this context.

2.1 | An understanding of CBM innovation and circular disruption

A circular economy aims to keep resources in use for as long as possible by minimising both the required material and energy and the generated waste and emissions of a given economic system (Geissdoerfer et al., 2017, 2020; Neligan, 2018a).

2.1.1 | CBMs

To implement a circular economy, there was an initial focus on technological solutions, like recycling additional materials or automatising disassembly steps; however, as progress in these areas led to little and slow industrial uptake, the research focus shifted to a more systemic view: the business model perspective (Rashid et al., 2013), with its potential for analysis, planning and communication of complex organisational systems (Geissdoerfer et al., 2016; Schöggl, Stumpf, & Baumgartner, 2020). To utilise the business model concept's analytical and communicational potential to integrate circularity on the business level, a modification of the concept is necessary: the CBM (Pieroni et al., 2019).

There is a range of definitions that combine the business model notion with the circular economy concept, often combining Osterwalder and Pigneur's (2010) and Richardson's (2008) notion of business models with circularity elements (e.g., Nußholz, 2017; Oghazi & Mostaghel, 2018) as organisational value proposition, value creation and delivery and value capture elements that aim at a circular economy. To operationalise this definition, Bocken et al. (2016) and Geissdoerfer et al. (2018, 2020) have proposed four generic strategies—cycling, extending, intensifying and dematerialising resource loops—that combine this three-element business model logic with extended use phases, servitisation, digitalisation, sharing solutions, public services, reuse, repair, refurbishment, remanufacturing, recycling, fermentation, composting and combustion.

2.1.2 | CBM innovations

Definitions for CBM innovation are fewer in the literature (Santa-Maria, Vermeulen & Baumgartner, 2021a). These definitions are often rather simple approaches, like a 'shift from a linear to more circular business model' (Bocken et al., 2018, p. 80) or 'a shift from [a linear business model] to a circular business model' (Linder & Williander, 2017, p. 194). A more fruitful approach seems to use the well-established (conventional) business model innovation concept and the often interchangeably used business model transformation notion and discuss potential overlaps with the circular economy notion (e.g., Bocken et al., 2016; Linder & Williander, 2017).

This leads to an understanding of CBM innovation as the 'conceptualisation and/or implementation of circular business models' (Geissdoerfer et al., 2020, p. 8) that can be operationalised through four generic strategies to integrate circular principles into business models: circular start-ups, CBM acquisitions, CBM diversifications and CBM transformations (Geissdoerfer et al., 2020). In addition, it is important to consider antecedents, moderators and characteristics of organisational change processes supporting CBM innovations (Santa-Maria, et al., 2021a).

2.1.3 | Circular disruption

The discussion of CBM innovation, however, does not shed light on an important aspect of business model innovation: disruptive innovation (Christensen, 1997), an innovation that displaces the offerings of incumbents and seizes considerable parts of an existing market. This is particularly relevant in the context of the circular economy, with its often-cited aspiration to accelerate the transition to a more sustainable economic system by replacing the linear economy eventually (EMF, 2012; Webster, 2017). Bauwens et al. (2022)) offer a concept of circular disruption with five key components as 'A transformation in a socio-technical system which causes the systematic, widespread, and fast change from the harmful "take-make-use-dispose" model to a socially and environmentally desirable and sustainable model that reduces resource consumption and address structural waste through the deployment of circular strategies'. In this research, *we define circular disruption as the supersession of a successful linear business model with a circular economy-based approach in considerable parts of the market*.

2.2 | The enabling role of digitalisation for circular disruption

The emergence and diffusion of technological innovations can contribute to circular disruption. Innovation or the ability of companies to innovate is a relevant starting point. Technologies and their applications as well as products and strategies play an important role here. They enable both new types of products, processes as well as services and decisive organisational innovations. There are substitute technologies, which replace already known technologies, and new technologies with unknown functionalities leading to new application possibilities (Rohn et al., 2013), which can also enhance circularity. Great expectations are currently being placed on *digitalisation*, *which we define as the increasing use of DTs in products, services, and processes* (developed from Lenka et al., 2017; Parviainen et al., 2017; Srai & Lorentz, 2019). Digitalisation refers to the conversion of analogue information into digital forms. Products, processes and/or customers can be virtually represented. The increasing integration of sensors and actuators in production processes gives access to larger quantities of digitisable information. Through internal and inter-company, digital networking digital information can be easily transferred and analysed. The resulting knowledge can be shared.

Information and communication technologies as well as automation technologies can reduce the resource consumption of many products during their production, distribution, use and disposal. The use of this potential can not only incrementally ensure greater resource efficiency in existing products but can also support new system solutions as an enabler for resource efficiency, especially if additional paradigms for handling resources emerge which unfold new design options for more efficient resource use (Behrendt & Erdmann, 2010). Hence, digitalisation can be seen as a driving force to enhance circular disruption.

Digitalisation being based on the analysis and utilisation of data is accompanied by new, partly disruptive business models (Neligan, 2018a). DTs can overcome barriers to CBMs and facilitate the operationalisation of circular material, components and product flows. DTs can be seen as a 'glue' between value chain partners and other stakeholders by enabling data sharing and improving transparency along the value chain. Furthermore, DTs offer far-reaching potential for comprehensive networking of 'smart' circular economy strategies from retrospective analysis to artificial intelligence (AI)-supported prediction of data (CEID, 2020).

DTs can be drivers of a circular disruption as their use allows to collect and interpret data more effectively as basis for CBM innovations, for the (re-) design of circular products and for a more objective circularity assessment of products and services (de Sousa Jabbour et al., 2018; Garcia-Muiña et al., 2018; Kristoffersen et al., 2019; Wichmann et al., 2019).

In addition, enabling technologies forming the basis for other technologies are needed such as standards, hardware and interfaces improving the collaboration between people and machines and networks connecting computers and systems. Yet, the use of DTs and their applications to improve resource efficiency often happens step by step. According to the recent representative survey of German firms used for this paper (also see methodology), data and interfaces are particularly important today. In a second step, German companies use platforms, process monitoring via the networking of sensors and actuators and predictive maintenance as important prerequisites for networking in the value chain. DTs, which are important for further networking and collaboration or modelling and simulation, hardly play a role yet. Hence, there is still upward potential for more advanced DTs.

The survey of German firms also shows that digitalisation makes resource efficiency measurable and savings potentials usable. A higher degree of digitalisation in efficiency measures allows German firms to achieve a higher level of resource efficiency which can also enhance circularity. In a previous analysis, Neligan (2018a) also demonstrated clearly that companies that have already embedded digitalisation in their strategy are frontrunners for greater material efficiency and circularity. Highly digitalised companies more frequently use material efficiency measures intensively, are more likely to recognise further potential savings and their efficiency-saving approaches are also clearly more often highly digitalised. Industrial companies with a highly developed digitalisation strategy make considerably more intensive use of new techniques and optimisation approaches in manufacturing processes and also rather avail of new materials or new business models than companies without a digitalisation strategy (Neligan, 2018a). Hence, developing an extensive digitalisation strategy can also enhance circularity in businesses and possibly even CBM innovation.

2.3 | State of research on the use of DTs in new CBMs

To specifically frame the role of DTs in CBMs, we furthermore systematically reviewed the literature, using a search string[1] that combined different DTs with CBMs. The keywords used for DTs were primarily based on the EU's CE action plan (European Commission, 2020), which emphasises the potential of AI, big data, blockchain technology and the IoT for increasing the sustainability and circularity of products and resources. This narrow focus was justified, because we wanted to highlight the state of research on the use of various DTs for CBM, whereas previous literature reviews only focused on the role of DTs for a circular economy more generally. For instance, Rosa et al. (2020), analysed and classified 158 articles according to six Industry 4.0-related and 10 CE-related items, of which 24 focused on CBMs. Most recently, Rusch et al. (2022) reviewed a total 186 articles on the role of DTs for a sustainable and circular economy. They found 15 DT-enabled business model strategies which could be mainly classified (according to the ReSOLVE-framework[2]) as 'virtualize' or 'loop' strategies.

In our review, we found a total of 30 peer-reviewed papers that specifically refer to one or more DTs in a CBM context. The first one of the 30 papers was published only in 2016. The detailed analysis of the 30 papers revealed that eight papers had no CBM or DT focus and were therefore excluded (see Appendix).

On the one hand, there is largely consensus among the authors that DTs can serve as enablers and support for CBMs. For instance, Cezarino et al. (2019) point out that in Industry 4.0 '… new evolving business models are highly driven by the use of smart data so as to offer new services', or Nascimento et al. (2019) state that DTs can support the implementation of new business models on a large scale, provided their maturity. On the other hand, application cases or empirical studies that detail the proclaimed potential are rare. The majority of the reviewed papers are conceptual and review-based in nature (11 of 22 papers). Seven case studies and two empirical studies (one focus group and one survey-based) could be identified. Prescriptive research is similarly rare with only two studies providing a method or a tool.

2.3.1 | Theoretical research

Among the conceptual papers, Alcayaga et al. (2019) provide a framework for IoT-based product service systems (PSS). The authors argue that the application of IoT for the achievement of circular economy strategies most likely affects all components of a business model. The value proposition may be transformed towards performance via a shift to use or result-oriented PSS, the value creation process changes (e.g., further individualisation and higher customer involvement) and new costs and potential new value revenue streams affect the capture of value (Alcayaga et al., 2019). Bressanelli et al. (2018) identify the following eight CE-related functionalities of IoT and big data: improving product design, attracting target customers, monitoring and tracking product activity, providing technical support, providing preventive and predictive maintenance, optimising the product usage, upgrading the product, enhancing renovation and end-of-life activities. Jabbour et al. (2019) provide a relational matrix that links the six different business model strategies of the ReSOLVE framework (EMF, 2015) with respective enabling characteristics of big data.[3] The authors emphasise that new CBMs are required to tackle the complexity involved in utilising big data for a circular economy and that a particular emphasis should also lie on understanding the needs of key stakeholders. Esmaeilian et al. (2020) highlight the general importance of linking blockchain applications to a value-driven business model to avoid sub-optimisation and environmental rebound effects. A sole emphasis on using blockchain technology for eco-efficiency could also promote unsustainable business models.

2.3.2 | Empirical research

Among the case studies, Chiappetta Jabbour et al. (2020) studied circular economy-'first-mover' cases in the Brazilian manufacturing industry and find that emerging Industry 4.0-related technologies seem to play a vital role in unlocking the sharing economy, as applied to product development. Turner et al. (2019) developed business models for re-distributed manufacturing and explore their viability in the context of new manufacturing technologies (i.e., additive manufacturing and 3D printing) printing. A reduction in transportation and an increase in customer involvement were found as main potential benefits. Chauhan et al. (2019)) use the situation, actor, process, learning, action, performance (SAP-LAP) linkages framework (by Sushil) to analyse the applications of Industry 4.0 mechanisms in realising the issues of current circular economy business models. Their results suggest that top managers are the most essential actors for integrating the use of Industry 4.0 achieving a sustainable and circular economy. Ingemarsdotter et al. (2019) find that IoT-enabled monitoring can benefit business models that are based on product access and/or performance, because pricing can be based, for instance, on the actual use of a product. The authors see other benefits for CBMs in the (real-time) monitoring and control capabilities that the implementation of IoT in a company can bring. In the specific case of LED lighting, IoT can support servitised business models (Ingemarsdotter et al., 2020). More specifically, IoT improved the tracking and record keeping of in-use and post-use products, allowed condition monitoring and predictive maintenance as well as the estimation of the remaining lifetime of products. In return the information gained can support design decisions. Challenges have been (1) a lack of structured data management processes to ensure high quality data collection and analysis and (2) the difficulty of designing IoT-enabled products in terms of interoperability, adaptability and upgradeability, especially considering that IoT technologies are evolving rapidly (Ingemarsdotter et al., 2020). Lindström et al. (2018) emphasise the crucial importance of aligning technological with business model development. In their case study with a Swedish micro-SME that developed and operated a multi-usable cloud service platform for big data collection and analytics, they find that the company faced significant challenges regarding organisational and management issues, while technical-related matters were perceived as comparatively easy. In the only survey-based study in the sample, Lähdeaho and Hilmola (2020) find a low interest in blockchain and IoT technologies, mainly because of their perceived low maturity. The survey was conducted among 56 transportation and logistics companies in South Finland.

2.3.3 | Prescriptive research

In one of the first prescriptive studies, Wang et al. (2020) propose an active preventive maintenance approach for complex equipment that allows the collection and analysis of the operational data of equipment in different use cases. In the second, Bianchini et al. (2019) describe a CBM visualisation tool which shall support companies in implementing circular economy practices. Their tool, however, does not utilise DTs.

It summary, while DTs are being considered as essential constituents of new CBMs, they are only rarely utilised to date. If they are, it is mainly in value creation processes. Their role for altering value propositions and value capture processes remains to be explored empirically.

3 | METHODOLOGY

This section describes the data and the underlying survey for the empirical analysis. The analysis of German firms is based on a unique dataset with responses from 599 manufacturing companies and 296 industrial service providers (logistics, business-related services). The data were specifically collected at the beginning of 2020 by the German Economic Institute (IW) for a recent report for the German Federal Ministry for Economic Affairs and Energy. One of the authors not only has preferential unique access but was also responsible for the survey design. The survey concept was developed in different steps: first an extensive literature review was undertaken to formulate first hypotheses and possible survey questions. In a second step the survey concept was discussed with experts, stakeholders, and practitioners in two workshops to ensure that the survey questions were understandable and feasible with little effort for the respondents. This reduces the risk of increased dropout rates which could lead to systematically distorted results.

The survey took place from the end of January to mid-March 2020 as part of the 35th wave of the IW Zukunftspanel. This is a regular and long-established online company survey which has been providing answers from over 1000 companies to questions on structural change several times a year since 2005. Besides more general indicators (e.g., general strategies, innovation, internationalisation and digitalisation), 14 questions were specifically asked to find out more on the relevance of resource efficiency and the role of digital networking and associated business models in this context. The company survey provides original and previously unavailable facts on the situation in German firms. The data deliver answers on the status quo, potentials but also the inherent challenges that German firms still need to overcome to ensure that DTs are used more widely in the future to increase resource efficiency.

Relevant for the empirical analysis in this paper are following two questions: (1) To what extent does your company use the following ways/option to use resource efficiency? (2) To what extent does your company already use the possibilities of digitalisation for the following used ways to use resources efficiently? Both questions were asked for a total of nine ways/options, of which two are at the product level (resource-saving product design and product-service systems) and seven at the process level (strategic resource management, use of new materials, optimisation of production processes, use of new techniques, internal material cycle management, cross-company material cycle management, energy efficiency/saving measures). The second question was only asked if one of the approaches was relevant for the firm. To get answers on the extent, following response categories were used: to a high, medium or low degree. In the first question, two response options were further offered: not yet and not suitable, while in the second question, there was only one relevant option necessary: not at all.

While conceptualising the survey and talking to practitioners, it became clear that the term ‘business model’ is understood differently by both practitioners and academics. There seems a lack of consensus on its definition. Hence, ‘new business models’ were not offered as a possible efficiency-raising approach (way/option) as previously done in Neligan and Schmitz (2017). Instead, the firms were asked in a different question on the objectives of raising resource efficiency, if accessing new markets/business models was a relevant goal. In the relevant question for the following analysis on efficiency-raising ways/options ‘product-service systems’ was used as practitioners seem to understand this better. It is understood as a way to combine product and services (product-service systems) allowing customers to rent or lease the product instead of buying it. The service provider owns the product and is responsible for its maintenance. ‘Product-service systems’ are used as a proxy to gain more insights on how new CBMs can evolve in the following analysis based on the assumption that many CBM frameworks propose putting product-service systems at the core of the business model (Hansen et al., 2020).

The responses are weighed representatively. Large companies are disproportionately represented in the sample compared to the population. For this reason, a weighting based on the German statistical business register (‘Unternehmensregister’) is used to correct for possible size effects. Similarly, the weighting considers that certain industry groups are over-proportionally represented.

For this paper, descriptive statistics is used to explore the large data set in the context of our research question for which there is only very limited other evidence available. Looking at differences in the mean value among different types of firms allows to extract meaningful and valuable information from the data. Different types of firms are developed by combining responses from various survey questions. These were not only asked in the context of resource efficiency but also in the section with more general questions on the firm.

4 | RESULTS

This section gives empirical evidence on the role of digitalisation in enabling CBMs. First, various ways/options to increase resource efficiency in German firms are categorised for the first time into the different stages of a product life cycle. Secondly, a new analysis is undertaken to look the role of product-service systems for new business models facilitating resource efficiency in the German manufacturing sector.

4.1 | Digital strategies for resource efficiency along the product life cycle

CBMs operate in different part of the value chain (OECD, 2018). In addition, the impacts associated with different CBMs often emerge at different parts of the product life cycle (OECD, 2019). This section looks both at how companies improve resource efficiency at the different stages of a product life cycle and at how digitalisation is used for this. From all possible efficiency approaches, new business models can develop, which can lead to more circularity. DTs can play a relevant role here.

For firms, there are several ways to optimise the use of resources at the process and/or product level along the product life cycle. To counter the overconsumption of valuable resources, there are three significant approaches available to businesses: to consume less, to consume multiple times and to substitute resources (Biebeler, 2014; Neligan & Schmitz, 2017).

For many companies, it makes sense to start with the least disruptive change in form of circular process innovations, which involves the development and implementation of new or improved production, logistic or recycling methods. Product innovation is more difficult because it touches more areas of the organisation and might require additional internal but also external know-how and resources. Business model innovation is most challenging as it can change the entire value cycle, including how products are marketed or sold to customers (BCG, 2018; Neligan, 2018b).

The analysis shows that many German firms in the manufacturing and industrial service sector tend to first concentrate on incremental changes before undertaking more disruptive moves. In many companies, the basic course for a modern circular economy is not yet set. These results are in line with previous company surveys by Neligan (2018a) and Biebeler (2014), which both also revealed that is not widespread to save materials on a large scale in product design, via closed-loop recycling or new business models. There is still further potential here for increasing resource efficiency.

The main objectives of German firms for higher resource efficiency are lower manufacturing costs, waste avoidance and environmental protection through resource conservation according to the survey. Only a few companies are aiming for a true circular economy, for example, through looking at the complete life cycle, design optimisation and/or the development of new business models regarding circularity. Developing new markets or business models is solely a clear objective for one in four German firms. Such approaches and targets, however, are central for a strategic readjustment towards a circular economy. Eventually, it can also lead to new more CBMs. However, also in circular economy research, design-related approaches are rarely discussed, and majority of it emphasise on lower-ranking R-strategies like recycling or remanufacturing (Schöggl, Stumpf, & Baumgartner, 2020).

In addition, existing resource saving potentials have not been realised in the German economy yet as the survey data show. At the same time, only a minority of German firms are highly digitalised to increase resource efficiency. Frequently used options for the optimisation of processes and energy consumption as well as the use of new techniques are also the most likely to have a high degree of digitalisation. For other approaches, the rates are significantly lower. To date, at least a quarter of both the German manufacturing and industrial service sector are not digitalised at all for different efficiency measures.

Looking now at the three main stages of a life cycle perspective, the current level of utilisation and digitalisation of approaches increasing resource efficiency in German manufacturing firms and industrial service providers can be described. *At the beginning of life*, product planning and production are relevant stages to enhance circular disruption:

- Product design: Products can be designed in a resource-efficient way (eco-design). If the product functions optimally over its entire life cycle, the use of resources and the generation of pollutants, emissions and waste are minimised. In addition to a lower use of resources, input materials can also be replaced by new materials or secondary raw materials; new technologies can be applied; and aspects of recycling, reparability and closed-loop recycling can be considered in a product design that is suitable for reuse, as well as longevity, already in the planning phase (Neligan, 2018a); 58% of German manufacturing companies use resource-saving options that begin at the product design stage. However, only 15% use this approach to a high degree. While 31% of manufacturing firms consider such a product-related approach as unsuitable, it is even almost every second firm in the industrial services sector. Only 37% of the industrial service providers focus on resource-saving product design to date. However, industrial service providers see fewer opportunities to save resources through a better design in their service offerings. To date, around a third of all companies both in the manufacturing and industrial services sector have their approaches to implement a resource saving product design not digitally networked, or if they are, it is only to a small and medium extent. Only 11% of the manufacturing sector and 9% of the industrial service sector state that they are digitalised to a high extent.
- Production: In the production of goods or the provision of services, care is taken to ensure that energy and materials are used sparingly, and that waste is being avoided. Classical measures for optimisation are the reduction of waste and scrap and the economical use of office materials as well as energy efficiency/saving approaches. Other measures include the better utilisation of machines, material-saving storage, but also the substitution of operating supplies and auxiliary materials and the use of waste heat (energy recovery). At the process level, German firms, in particular in the manufacturing sector, most frequently use measures to optimise energy and processes as well as new techniques and materials. Latter two approaches, however, are not viable for two out of five industrial service providers. DTs are most frequently used to a high degree in the manufacturing sector for the three most popular efficiency measures of process optimisation, increasing energy efficiency, but also for the use of new techniques. Even though only a minority of manufacturing firms (16–19%) have these three options highly digitalised, in almost half of the cases, it is at least to a moderate extent. Among industrial service providers, the share of companies that have the above three ways highly digitalised is somewhat lower, and the use of new techniques is in first place, not only in terms of general but also of strong digitalisation. Only a few companies have a strategic resource management in place. In industry, only a few firms use such an instrument to a great extent, but more than every second company states that it does at least to a limited extent. For industrial service providers, strategic resource management is less relevant.

New business models can help to increase circularity and efficiency *at the middle of life* (distribution, use-phase and support). They can also be useful at other stages of a product life cycle. Industrial service providers can theoretically also play an important role to offer new usage models for customers to improve the return of materials, for example, by offering the use instead of the ownership of a product the analysis. Yet, the data show that more than half of industrial service providers regard product-service systems as unsuitable for their firm, while among manufacturing firms, it is two-fifths. Overall, only a few companies use product-service systems with nearly a quarter of the service providers and almost a fifth of the manufacturing companies to at least a moderate extent. Furthermore, only a few firms have product-service systems digitalised to a high degree, even though three quarters of the manufacturing sectors and two-thirds of the industrial service sector have their product-service systems digitalised to a minimum degree. A similar picture was seen in a previous analysis of the manufacturing sector based on an earlier survey in 2016: Only a third of German manufacturing companies considered new business models as a way of increasing efficiency. Of these, 3 out of 10 had not been digitalised yet, with a further two-fifths having had only a minor level of digitalisation (Neligan, 2018a). A more detailed and new analysis of the role of digitalisation of product-service systems will be given in the following section.

At the end of life, the after-use of the product is being taken care of. Simple take-back/acceptance (new business models), reuse of the company's own residual and waste materials via recycling or energy recovery, cross-company recycling and delivery of residual, waste materials or by-products and proper disposal are examples of how material efficiency can be increased in waste disposal. Only few firms already aim at a genuine circular economy, for example, by looking at the complete life cycle, optimising design and/or developing new business models regarding circularity. The manufacturing sector is most likely to pursue the goals of recycling or reuse, but also the return of products. About a quarter of the manufacturing companies stated that the return of a product is a clear objective, and about 30% each aim at reuse and recycling with their measures for increasing resource efficiency. To date, 60% of the German manufacturing sector use internal material cycle management and around 50% cross-company material cycle management to increase resource efficiency. However, rare materials are being recycled, in particular across companies, to a high degree. Internal and/or cross-company measures for closed-loop recycling are considered inappropriate by broadly a quarter of the manufacturing sector. In the case of industrial service providers, it is even every second company. In the industrial service sector, the utilisation rate amounts to around a third of the firms for each measure. Internal cycle management is the least digitalised measure of the considered approaches in the survey. In the German manufacturing sector, DTs do not play a role for 36% of the firms for internal material cycle management, and in the case of a further 30%, the part they play is minor. Only 12% of the German manufacturing firms are heavily digitalised; 69% have their cross-company material cycles digitalised, but this instrument is only used by 50% of German manufacturing firms. Of the one third of the industrial service providers using either internal or cross-company material cycle management, around three out of five firms have these measures digitalised, rarely to a high extent.

4.2 | The role of product-service systems for new digital CBMs in German industry

Novel forms of products and services and new combinations of them are key for developing CBMs. DTs can be an important enabler. Yet, only a minority of German firms use product-service systems intensively to improve resource efficiency both in the manufacturing and the industrial services sector to date. In addition, product-service systems are rarely highly digitalised (see previous section). This section investigates what role product-service systems for new CBMs in the manufacturing sector have and how digitalisation has an impact on the role of product-service systems.

Firms within a certain sector can act very differently depending on the role of digitalisation in their business model. A new descriptive analysis on the degree of utilisation and of digitalisation of product-service systems for the manufacturing sector shows clearly differences between different types of firms (Figure 1). Large manufacturing firms (250 employees and more) have a far higher utilisation rate and see more often suitability of product-service systems than SMEs (up to 249 employees). While in the manufacturing sector it is only a quarter of the large firms, it is 41% of SMEs that regard product-service systems as unsuitable. Only 9% of large manufacturing firms state that they have not implemented product-service systems yet—in the case of SMEs it is 21%. Large firms have their product-service systems not only more often digitalised than SMEs but also more frequently to at least a medium degree.

By looking at different types of firms combining answers from various questions in the survey, interesting differences can be identified (also see methodology). Since the focus in this paper lies on the role of digitalisation for new CBMs, following types of firms are regarded as important: type of business model (classic, computerised, data-driven) and the general degree of digitalisation of the firm (computerised, digitalised). It is expected that with a rising degree of digitalisation, product-service systems become more common in firms since additional services to a product very often require data and digital networking and/or interoperability.

The type of business models is defined as follows. The range of products and services offered by companies is diverse and can range from classic products/services without data-based processes (classic business models) to those with data-based processes (computerised business models) to data-driven products/services. Data can also be sold as a product (data-driven business models). While classic business models still dominate with almost two-thirds in the German manufacturing sector, almost a fifth each have already expanded their classic products/services to a computerised business model that include data-based processes or have data-driven business models with central functions being conditioned by digital data-based applications.

Looking at the role of product-service systems for these three types of business models, it shows that product-service systems become more relevant and suitable the more digitalised the business model is (Figure 1). This indicates that introducing additional services to a product becomes easier the more data and digital networking are available. Nonetheless, regardless of the business model in place, it is still not very common to use efficiency-oriented product-service systems to a high degree yet. It is solely an avantgarde in the German industrial sector that combines products and services intensively to foster resource efficiency. Just 3 out of 10 producing firms with a classic business model have a product-service system in place—16% use it only to a minor degree, 10% to a medium degree and only 4% to a high degree. At the same time, more than half of the firms with a

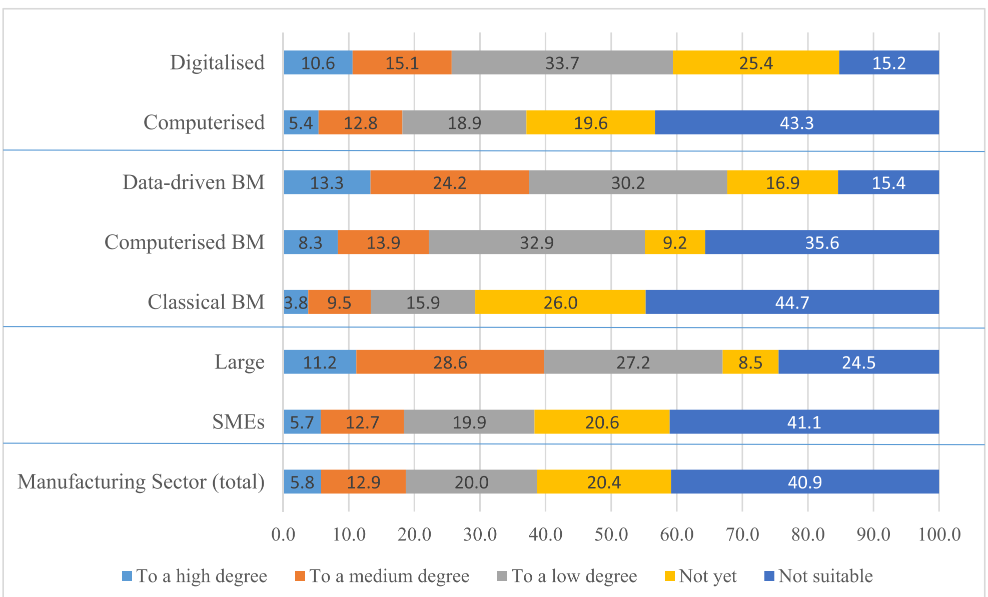

FIGURE 1 Degree of use of product-service systems for resource efficiency. Shares as a percentage of firms in the relevant group in the manufacturing sector. Question: To what extent does your company use the following ways/options to use resources efficiently? (Product-service systems was one of nine options with five response categories: to a high degree, to a medium degree, to a low degree, not yet, not suitable). *Source*: IW-Zukunftspanel, 2020, own calculations, $N = 583$, BM, business model

computerised business model and even more than two-thirds with a data-driven model have product-service systems implemented to enhance resource efficiency. Despite the higher level of digitalisation in both types of business models, it is also only a minority with 8% of firms with computerised business models and 13% with data-driven business models that use product-service systems to a high degree. For both types of business models, 3 out of 10 state that they use them merely to a minor extent. Yet, another interesting finding is that the suitability of product-service systems increases with a higher level of digitalisation in the business model. While 45% of firms with classic business models and 36% of the firms with computerised business models do not see a combination of product and services as suitable, it is only 15% of firms with data-driven business models. Latter also more often state with 17% that they do not have established them in their product portfolio yet. At the same time this is only for 9% of firms with computerised business models the case, meanwhile it is still for one out of four with classic business models.

In addition, the results are shown for the general degree of digitalisation of manufacturing firms. Nine of ten manufacturing companies are computerised, and almost one of ten is truly digitalised. There are hardly any firms left that are not at least computerised. Latter is defined by several conditions: Firms attach considerable importance to an internet presence, to digitalisation in their business strategy and/or to networked Information and Communications Technologies/Electronic Data Processing (ICT/EDP) systems for processing. Alternatively, firms are seen as computerised if they make relevant process data available centrally or ICT/EDP systems are networked with suppliers and customers and can interact. Truly digitalised means that products, processes and/or tools are virtualised. In addition, companies work with these virtual models, or business models are based on data models, data analyses and/or specific algorithms. At best, companies have networked and automated operational processes based on virtual images. Suppliers and customers are also included in these digital, self-controlling processes.

A comparison according to the level of digitalisation shows in this new analysis that three out of five of truly digitalised firms have product-service systems in place, while it is only 37% with computerised firms, which form the majority of the manufacturing sector. Yet, looking at the earlier typification, truly digitalised firms have not implemented product-service systems as often as firms with data-driven business models, and the degree of intensity is also lower.

The degree of digitalisation of product-service systems varies depending both on the level of digitalisation in general and of the business model (Figure 2). Noteworthy is that a high level of digitalisation for both types of digital firms does not automatically imply a full digitalisation of their product-service systems as the digital networking and data use can be taking place elsewhere within the firm and not for the purpose of a product-service system. Yet, while only 60% of the firms with classic business models have product-service systems digitalised—mainly to a low degree—firms with computerised business models (91%) and data-driven business models (85%) have much higher rates of digitalisation, with more than half of

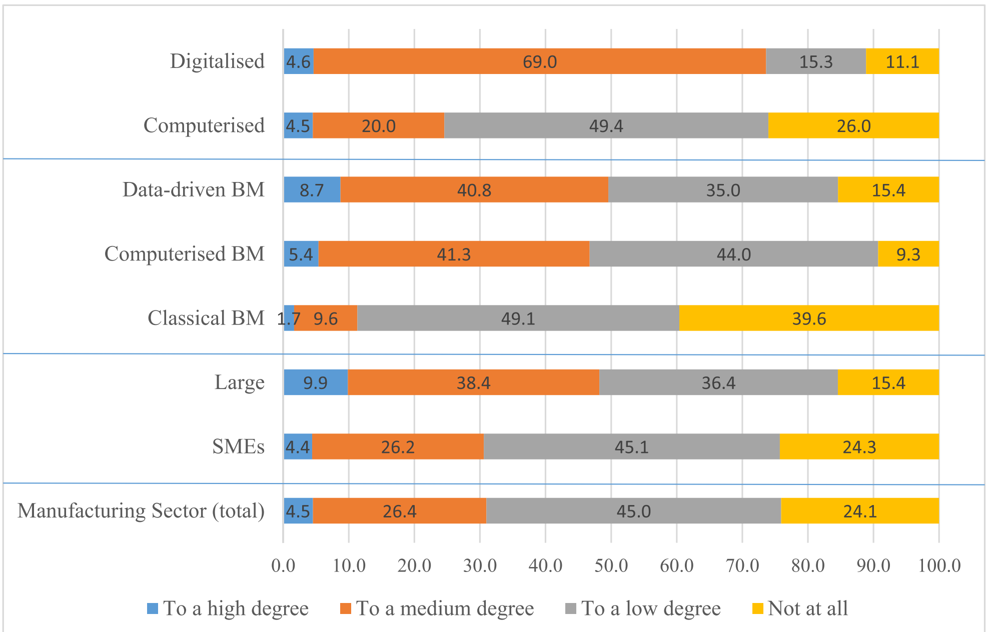

FIGURE 2 Degree of digitalisation of product-service systems for resource efficiency. Shares as a percentage of firms applying product-service systems to enhance resource efficiency in the relevant group of the manufacturing sector. Question: To what extent does your company already use the possibilities of digitalisation for the following used ways to use resources efficiently? Question on digitalisation was only asked if option was used (Product-service systems was one of nine options with four response categories: to a high degree, to a medium degree, to a low degree, not at all). *Source*: IW-Zukunftspanel, 2020, own calculations, $N = 277$, BM, business model

them being digitalised to at least a medium degree. Looking at the general level of digitalisation, it shows that three quarters of this avantgarde of truly digitalised firms with product-service systems state that these are at least digitalised to a medium extent, while half of the computerised firms have their product-service systems only digitalised to a low degree, a quarter to a least to a medium degree and another quarter not at all; 11% of truly digitalised firms state that they have not digitalised their product-service systems yet.

While relatively few German firms rely on new business models, for example, for a part of the business or a new part of the business, to foster their resource efficiency strategy, we find that the share is higher for those with a strong digital focus. This suggests that digitalisation can be a driving force behind the implementation of CBMs.

5 | CONCLUSIONS

Integrating circularity into business models is a key lever for moving towards a circular economy. Even though digitalisation is widely acknowledged to cause disruption in a broad range of areas, literature is scarce on linking the concept to the circular economy and CBMs as an enabler for circular disruption. This paper is addressing this gap by conceptualising circular disruption, which can be a key driver for accelerating the transition towards a circular economy. There is a wide range of DTs that can nurture circular disruption and innovative ways of doing circular business discussed in this paper.

The main *theoretical contributions and implications* of this paper are as follows:

1. We have observed CBMs based on cycling different steps of their value chain and correspondent impacts at different parts of their product life cycles. Especially, new business models can help to increase circularity and efficiency at the middle of the life cycle, that is, distribution, use-phase and support services. From different resource efficiency measures, ranging from resource-saving product design to optimising internal and external material cycles, new efficient and CBMs can develop. Yet, the empirical results for German firms show that the basic course for a modern circular economy is not yet set in many companies looking at their objectives and approaches in the context of resource efficiency. Traditional measures for the optimisation of processes and energy consumption are still predominant. Only a minority of firms aim at developing new markets or business models.
   The findings regarding the link between DTs and CBM innovations have implications for both business model innovation and circular economy theory. The results suggest that digitalisation is a driving force behind CBMs. Our literature review revealed a growing number of related concepts but a lack of empirical studies and utilisation cases. DTs are mainly used in value creation processes, while their role in altering value propositions and value capture processes remains to be explored in detail. However, our sample shows that only a minority of German firms have highly digitalised resource efficiency measures and if so mainly in the case of frequently used optimisation measures. The paper also shows that only a minority of German manufacturing firms use product-service systems to enhance resource efficiency to move towards new CBMs. If they do, they are only rarely digitalised to a high degree. Our analysis also showed that there is still considerable upward potential to enhance circular disruption via CBMs.
2. Business model theory suggests digitalisation as an important driver for business model innovation activities (Chesbrough, 2010; Massa et al., 2017; Zott et al., 2011), and our findings are broadly aligned with this, showing digital business models as a driving force in the investigated firms. However, circular economy literature usually puts quite a strong emphasis on business model innovation as one—or even the key—lever for 'going circular' (Geissdoerfer et al., 2017; Lovins et al., 2014; Rashid et al., 2013). This is only partially substantiated by our data—we feel that theory would predict more than only two-fifths of firms using business model innovation to improve their circularity, as in our sample. Yet, introducing additional services to a product becomes easier the more data and digital networking are available as the data clearly indicates. Nonetheless, regardless of the business model in place, it is still not very common to use efficiency-oriented product-service systems to a high degree yet. Furthermore, a high level of digitalisation does not automatically imply a full digitalisation of their product-service systems as the digital networking and data use can be taking place elsewhere within the firm and not for the purpose of a product-service system.
   This also has *implications for managerial practice*. First, the incremental approach to CBM innovation observed within the sample hints at a potential for circular disruption by bold players, which can relatively easily surpass the efforts observed. However, it might also hint at current actors not perceiving the right yet, which might hint at increased risks for this kind of investment at the current stage. Secondly, the research underlines the role of DT in CBM innovation efforts. From the observed, we would derive that looking into integrated approaches combining digital and circular strategy are promising for companies interested in engaging the circular economy. Finally, we would encourage to use the business model innovation lens, we used in this study, to think about diversification into circular. As postulated by Rashid et al. (2013), we find it a useful lens for business strategy, although we would encourage to also take a broad business model or ecosystem perspective beyond the immediate organisational unit for most circular economy-related strategic decisions (see, e.g., Geissdoerfer et al., 2020; Kanda et al., 2021).

Our research also points to a range of *future research avenues*. First and foremost, the concept introduced in this paper—circular disruption—provides a meaningful new lens through which the transition towards a circular economy can be investigated. This lens can be useful both in descriptive research, since it provides access to disruptive phenomena that might otherwise be overlooked in the data, and in prescriptive or design work, since it can provide a lever to accelerate implementation of the circular economy. Another important path is to gain a deeper understanding of different digitalisation strategies also in relation to relevant non-digital alternatives to provide further orientation for industrial decision makers concerned with CBMs. Finally, we would recommend looking into the cost–benefit relation of the different strategies and investigate whether there are strategic trade-offs, like compromised sustainability performance.

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ENDNOTES

[1] Search string: TITLE-ABS-KEY ('circular') AND TITLE-ABS-KEY ('business model*') AND TITLE-ABS-KEY ('internet of things') OR TITLE-ABS-KEY ('artificial intelligence') OR TITLE-ABS-KEY ('industry 4.0') OR TITLE-ABS-KEY ('blockchain') OR TITLE-ABS-KEY ('big data') AND (LIMIT-TO (DOCTYPE, 'ar') OR LIMIT-TO (DOCTYPE, 're')); used in Scopus on 1 October 2020.

[2] ReSOLVE = Regenerate, Share, Optimize, Loop, Virtualize, Exchange (EMF, 2015).

[3] Grouped according to the four Vs (1) volume, (2) variety, (3) velocity and (4) veracity.

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APPENDIX A

TABLE A1 Classification of the 30 papers analysed

Type	Source
Conceptual	Alcayaga et al., 2019; Bressanelli et al., 2018; Cezarino et al., 2019; Chauhan et al., 2019; Esmaeilian et al., 2020; Lechner & Reimann, 2019; Lopes de Sousa Jabbour et al., 2018; Miaoudakis et al., 2020; Narayan & Tidström, 2020
Case study	Chiappetta Jabbour et al., 2020; Ingemarsdotter et al., 2019; Ingemarsdotter et al., 2020; Jabbour et al, 2019; Lindström et al., 2018; Rossi et al., 2020; Turner et al., 2019
Empirical	Lähdeaho & Hilmola, 2020; Nascimento et al., 2019
Review	Kerin & Pham, 2019; Zhou et al., 2020
Tool	Bianchini et al., 2019; Wang et al., 2020
No specific CBM focus	Cioffi et al., 2020; Czikkely et al., 2019; Garcia-Muiña et al., 2018, 2019; Gorissen et al., 2016; Ramakrishna et al., 2020; Rejikumar et al., 2019; Sarc et al., 2019